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GA-C19570(7/90)
(7/24/90)

PROGRAM STATUS

3rd QUARTER – FY 1990

CONFINEMENT SYSTEMS PROGRAMS

- DIII-D RESEARCH OPERATIONS
- INTERNATIONAL COOPERATION
- CIT PHYSICS
- DIGNITOR STUDIES

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Contract No. DE-AC03-89ER51114
General Atomics Projects 3466/3467/3470/3473

This Quarterly Report Under
DOE Contract DE-AC03-89ER51114
is Submitted in Compliance with Sections A and B
of the REPORTING REQUIREMENTS CHECK LIST

JULY 24, 1990

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Contract Management Summary Report

TITLE: OPERATION OF DIII-D FACILITIES & RELATED RESEARCH		CONTRACT NO.: DE-AC03-89ER51114
CONTRACTOR: GENERAL ATOMICS P.O. BOX 85608 SAN DIEGO, CA. 92138	COST & LABOR PLAN DATE: JUNE 29, 1990	START DATE: SEPTEMBER 30, 1989 COMPLETION DATE: SEPTEMBER 28, 1990

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
PLANNED	\$3,479	\$2,660	\$3,601	\$2,931	\$2,636	\$3,296	\$2,821	\$2,447	\$2,786	\$2,192	\$2,467	\$2,008	\$33,324
ACTUAL	\$3,938	\$2,732	\$3,732	\$2,461	\$2,723	\$3,417	\$2,477	\$2,551	\$2,684				\$26,715
VARIANCE	(\$459)	(\$72)	(\$131)	\$470	(\$87)	(\$121)	\$344	(\$104)	\$102				
CUM VAR	(\$459)	(\$531)	(\$662)	(\$192)	(\$279)	(\$400)	(\$56)	(\$160)	(\$58)				(IN THOUSANDS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
PLANNED	183.4	183.2	174.5	165.0	159.3	161.9	165.0	159.2	159.3	146.6	142.7	141.9	1942.0
ACTUAL	207.1	190.8	179.0	151.3	167.2	160.4	156.0	152.9	148.8				1513.5
VARIANCE	-23.7	-7.6	-4.5	13.7	-7.9	1.5	9.0	6.3	10.5				
CUM VAR	-23.7	-31.3	-35.8	-22.1	-30.0	-28.5	-19.5	-13.2	-2.7				

SIGNATURE OF PARTICIPANT'S PROJECT MANAGER & DATE: _____

PROGRAM STATUS
3RD QUARTER – FY 1990
DIII-D RESEARCH OPERATIONS

DIII-D PROGRAM
COMING ATTRACTIONS
3RD QUARTER – FY 1990

- Installation of ORNL, FWCD, ICH antenna.
 - Installation of 110 GHz ECH antenna.
 - Installation of Advanced Divertor ring, baffle and diagnostics.
 - Completion of vent, pumpdown and checkout.
 - Two weeks tokamak operations
 - Ship the second 110 GHz magnet to Varian, continue gyrotron testing, and complete mode converter development (GA IR&D).
-

PROGRAM STATUS

3RD QUARTER – FY 1990

TASK: DIII-D RESEARCH OPERATIONS

OPERATING

B/R NOs: AT101014D (Operating)
35AT10020 (Capital)

FY90 FUNDING: \$30,443 K
FY90 PLAN: \$30,443 K⁺

CONTRACT NO: DE-AC03-89ER51114

CAPITAL

GA PRINCIPAL INVESTIGATOR: T. SIMONEN

FY90 FUNDING: \$ 1649 K

SAN PROJECT MANAGER: C. BEIGHLEY

FY90 PLAN: \$ 1649 K*

OFE PROGRAM MANAGER: E. OKTAY

MILESTONE	LEVEL	APPROVED DATE	TARGET DATE	COMPLETION DATE
62. Report on ITER status	I	10/89	10/89	10/89
63. Report on fluctuation measurements	I	12/89	12/89	12/89
59. Report ECH current drive	I	1/90	1/91 ^(1,2)	
60. Evaluate IBW	I	7/90	7/90	7/90 ⁽⁵⁾
64. Report on local transport	I	3/90	3/90	3/90
67. Report on ITER status R&D tools	I	4/90	4/90	4/90
61. Evaluate role of profile control in modifying β limits	I	7/90	7/90	7/90 ⁽⁵⁾
68. Operate first 110 GHz gyrotron	I	(3)	TBD ⁽⁴⁾	
65. Install Advanced Divertor	I	8/90	8/90	
66. Install Fast Wave Current Drive Antenna	I	8/90	8/90	7/90 ⁽⁵⁾
69. Evaluate edge electric field	I	8/90	8/90	

REMARKS:

- (1) Milestone delayed due to program redirection caused by funding constraints.
- (2) Milestone date reschedule awaiting OFE approval.
- (3) New milestones awaiting OFE approval.
- (4) Milestone data pending delivery of first gyrotron from Varian.
- (5) Milestone awaiting OFE approval of completion.

*Total \$2125 K available to cost in FY90 including \$476 K unpaid commitments at FY89 year end.

⁺\$300 K additional funding received to resume September '90 operations after vent.

PROGRAM STATUS
3RD QUARTER – FY 1990
DIII-D RESEARCH OPERATIONS

HIGHLIGHTS:

- Completed five weeks tokamak operations.
 - Initiated summer vent.
 - Achievement of 10.7% beta.
 - Carried out first dimensionless transport scaling experiment.
 - Completed IBW program.
 - Demonstrated divertor heat reduction with gas puffing.
 - Field Task Proposals presented to OFE.
 - Presentation of DIII-D program to FPAC.
 - Made presentation to Admiral Watkins.
 - SAN Safety Review (July 16–18).
-

INTRODUCTION AND SUMMARY

This quarter began with an extremely productive period of plasma operations which was followed by a vent of the vessel to install the Advanced Divertor, FWCD antenna, and launcher for the 110 GHz ECH system. Research program results include important results on transport, plasma boundary physics, stability and high beta, and completion of the IBW program. The transport of dimensionally similar plasmas was seen to scale with gyro-Bohm like characteristics. Detailed studies of the edge region identified discrepancies between theories and the observed poloidal rotation behavior. The use of gas puffing into the x-point region of the divertor plasmas appeared remarkably effective in reducing the heat flux into the divertor target. The edge tile current array has identified currents flowing in the boundary region just outside the last closed flux surface under a wide variety of conditions. The current is apparently driven in part by thermoelectric effects and decreases at the L-H transition. Lastly, a new record high toroidal beta value of 10.7% was achieved in a discharge with elongation of 2.35.

The vessel was vented in late May for new hardware installation. The work is proceeding well although considerable attention is being paid to the scheduling of work to accommodate unexpected late delivery of the advanced divertor ring. This component is now in house (July 18). The Thomson scattering system is also undergoing a major upgrade to a multipulse system, and this work is proceeding toward its anticipated first use in mid September and completion by the end of the calendar year. The ultimate goal of the present effort is to complete the vent and return to plasma operations in mid September with the new Advanced Divertor and FWCD hardware available. This goal appears to be attainable with the tasks presently identified and the available resources. The required activities to complete this include close and recondition the vessel, testing and recommissioning the power supplies, commission the new hardware including testing with plasma, and recommissioning the neutral beam systems including restarting the cryo system.

First testing of the 110 GHz has occurred at Varian with 240 kW of power delivered to the load (July 20). The magnet has undergone a through design review to minimize the possibilities of further fabrication difficulties.

A review of the safety related aspects of the DIII-D program was carried out by a team of specialists from DOE/SAN in July with the result that the program was found to remarkably strong and effective.

Three presentations of the DIII-D program were given to OFE (FTP's), FPAC, and Admiral Watkins.

A summary of the DIII-D field task proposal is given at the end of this quarterly report.

RESEARCH PROGRAM

Although the run time was short this quarter (five weeks), important new results were obtained. A careful confinement scaling experiment showed that gyro-Bohm scaling is the correct way to scale present day results to reactors. Data from the new edge CER systems found some discrepancies with theories connecting poloidal rotation with turbulence suppression across the L-H transition. Operation with deuterium puffing in the divertor region to increase radiation reduced the heat flux to the divertor plates by a factor of three. The prototype tile current array data showed an unexpected decrease, and sometimes a sign reversal, of the scrape-off layer current density near the separatrix. In a high elongation discharge ($\kappa = 2.35$), volume average toroidal beta of 10.7% was achieved, the highest ever achieved in a large tokamak. Detailed studies of ELMs show that ELMs consist of three phases. Detailed measurements of the non-axisymmetry of the PF and TF fields were completed. MHD oscillations which have some features of the theoretically postulated Toroidal Alfvén Eigenmodes (TAE) were identified. Vertically unstable plasmas were found to disrupt when the edge q reached the extremely low value of 1.3. Very little effect of ECH on $n = 2$ modes was seen. The Ion Bernstein Wave Heating program was ended. The edge ion heating was found to be correlated with parametric decay instabilities.

Much of the work accomplished this year was reported in several conferences and workshops this quarter. A total of ten papers were presented at the EPS conference recently held in Amsterdam including an invited overview of DIII-D results. Six papers were presented at the 8th Topical Conference on High-Temperature Plasma Diagnostics and will be published in the Review of Scientific Instruments. Two papers were given at

the Plasma Surface Interactions Conference at Bournemouth, U.K. Presentations were also made at the ITER H-mode database meeting at JET and the ITER workshop on statistics and confinement at Garching.

Confinement

Once the variation of confinement with normalized gyro-radius ρ/a is clearly established, existing experiments can be scaled to dimensionally similar experiments of larger size and/or toroidal field rather than relying on empirical scaling expressions to predict future device parameters required for ignition. An L-mode confinement study was carried out with dimensionless variables q , beta, and normalized collisionality held fixed while ρ/a was varied a factor of two by changing the toroidal field. A discharge at 2 T was compared to a dimensionally similar discharge at 1 T. The thermal diffusivity over most of the plasma changed in a manner consistent with a short scale length turbulence (gyro-reduced Bohm) model. The global confinement was similar in the two cases indicating the variation of confinement with ρ/a was more consistent with a long scale length (Bohm) model. The apparent discrepancy in these results is believed to be due to a difference in neutral beam power deposition profiles caused by a somewhat broader density profile and more importantly a higher density in the 2 T case.

Improved reflectometer measurements of the density fluctuations at the plasma edge indicate that the zone over which the fluctuations are suppressed during the L- to H-mode transition is 4.5 ± 1 cm for a 1 MA discharge. A theory by Shaing predicts that the width of the suppression zone should scale with the ion poloidal gyro-radius however no variation was observed during experiments designed to test this theory. Because the fluctuation suppression zone was measured to be somewhat narrower than anticipated, several of the CER chords will be rearranged to make more ion temperature and rotation measurements in this edge plasma region.

More detailed analysis has confirmed that in some cases H-mode discharges with the vessel walls carbonized have more peaked density and pressure profiles than in discharges without carbonized walls. The peak to average density ratio is near 2. These discharges are of interest because of their potentially higher fusion reactivity in the plasma core.

Boundary Physics

Additional radiative divertor experiments were run. Both deuterium and nitrogen were injected directly under the x-point of a single null diverted plasma. The maximum heat flux on divertor tiles was reduced by about a factor of 3. In these experiments the neutral beam injected power ranged from 10 MW to 19 MW. The deuterium puffing also reduced the low- and medium-Z impurities in the core plasma: central nickel was reduced by about a factor of 5, oxygen by 50% and carbon by 30%. Injected nitrogen initially increases radiation from the divertor plasma region. Later, the divertor radiation subsides somewhat, but radiation increases around the edge of the confined plasma. Nitrogen was indeed measured to cross the separatrix, but it did not build up in the central plasma, in agreement with the first radiative divertor experiments reported last quarter. Heavy divertor gas puffing damps the measured scrape-off layer current and decreases the measured divertor plasma T_e .

The prototype tile current array data shows an unexpected decrease, and sometimes a sign reversal, of the scrape-off layer current density at or near the separatrix. No one explanation of this phenomenon has yet gained acceptance. The tile array was also used to study wall currents driven by plasma disruptions and thereby to understand and predict the electromagnetic forces acting on the vacuum vessel.

The new divertor Langmuir probes were placed in operation. Although the limited number of installed power supply and data channels made it impossible to operate all probes simultaneously, much useful data was taken. Probe data confirms the presence of a low or reversed current layer near the separatrix and further shows a dip there in the floating potential.

The probes show approximately equal inner and outer divertor plasma pressures during quiescent H-mode. However, during rapid ELMing, the inner pressure between ELMs falls to a low level. The data seems to be consistent with detachment of the plasma from the inner divertor as a consequence of the local rise in neutral pressure occasioned by the ELM.

In the past there has often been a significant difference between the separatrix location as calculated from the magnetic data by the EFIT code and that deduced from the boundary Thomson scattering profiles. This discrepancy is crucial, because the gradients of n_e and T_e are large at the separatrix. Better correspondence between the magnetic and Thomson data is found when EFIT is run in a mode that allows the presence of finite J at the separatrix.

Rigorous and useful definitions of magnetic helicity and its transport were obtained. The key idea is to keep only physical magnetic flux interlinkage and to eliminate spurious gauge and "reference" helicity terms that enter with conventional approaches. External linkage is obtained in a natural way. While the new result does not contain any new terms, it affords a rigorous formulation that includes and extends various earlier partial, *ad hoc* expressions. The identified helicity flux terms do not transport helicity across toroidal magnetic surfaces any faster than the classical diffusion rate, unless the surfaces are at least slightly broken. The boundary physics application is to DC helicity injection via electrically biased divertor plates.

Beta and Stability

In a high elongation discharge ($\kappa = 2.35$), volume average toroidal beta of 10.7% was achieved. This is the highest beta achieved to date in a large tokamak. In this discharge, $I/aB = 3.1$ and $\beta_N = \beta_T/(I/aB) = 3.5$. This is the highest normalized current at which $\beta_N = 3.5$ has been achieved. The computed central β_T is about 40% with half of the contribution from the fast ions. The region near the magnetic axis has closed $|B|$ contours and a very steep pressure gradient which results primarily from the fast ions. In this region, the shear is negative because of the high κ . Ideal ballooning stability analysis shows that to be Mercier stable $q(0)$ must be greater than 1.08. The results also show that pressure gradients in the central region far exceed the optimum first stability limit and approaching the second stability region. Stability calculations also show the discharge to be stable to the $n = 0$ axisymmetric mode with a conducting wall at the vacuum vessel and unstable if the wall is 11% further away. The plasma is unstable to a 1/1 internal mode.

Studies of fluctuations preceeding and during edge localized modes (ELMs) show that an ELM may consist of three phases: 1) a precursor which may be a coherent single mode, a mixture of coherent modes, or broad band fluctuations, which in the case of the coherent modes has ballooning character and high n , 2) a burst of fluctuations extending to MHz frequencies which may begin slightly before, overlapping the precursor, and extend through the rapid rise phase of the H_α signal; these fluctuations are observed on the magnetics, reflectometer, and FIR scattering and do not have ballooning character; these fluctuations are similar to what has been identified as a precursor on the PBX-M magnetics, and 3) an L-mode like phase in which the frequency spectra is narrowed to a few hundred KHz corresponding to the flattop phase of the H_α signal. When a coherent precursor is present its frequency is observed to decrease just before the ELM; this is consistent with a preliminary observation on edge CER that suggested some decrease in edge rotation speed just before an ELM.

Detailed measurements of the non-axisymmetric error fields of the individual poloidal field coils have been made. These measurements will allow a quantitative determination of the position and shape errors which may cause the "locked mode" phenomenon and may have effects on confinement. A set of well matched and positioned pickup coils was assembled inside the vessel and aligned magnetically to be on a toroidal field line. The shaping coils (F-coils) and the ohmic heating coil (E-coil) were then energized individually and the $n = 1$ and $n = 2$ asymmetric fields measured. In addition, the $n = 0$ axisymmetric field of the E-coil was measured. In general, the preliminary analysis of the results shows that the field errors are dominated by the outer F-coils (numbers 6 and 7). From the fields measured, one can calculate the shift and/or tilt of individual F-coils which produces the $n = 1$ field and the ellipticity and "bowing" which produces the $n = 2$ field. The analysis has identified at least one coil that may be as much as 18 mm shifted with respect to the toroidal field and shows that some coils are somewhat out of round or bowed.

The MHD oscillations with high toroidal mode numbers that have been observed in high β_N discharges are characterized in the magnetic data by a group of spectral peaks in the range 50–150 kHz. These modes are observed only at $\beta_N \gtrsim 3.3$. The peaks are equally spaced in frequency and have consecutive values of n (toroidal mode number) usually in the range 4 to 10. The mode is strongly peaked at the outboard midplane, with a typical amplitude ratio of 50 to 100 between the outboard and inboard sides. The

poloidal variation of amplitude and phase for each n number can be fit well by a mixture of 3-4 adjacent m numbers, centered about $m = n + 1$ or $m = n + 2$. Soft X-ray data shows that these modes are localized radially. The radial localization, peaking in the bad curvature region, and correlation with high β_N suggest a form of ballooning mode. Another possibility is the Toroidicity-induced Alfvén Eigenmode (TAE mode, or "gap" mode), driven by beam ions. The observed frequency agrees with the predicted value for TAE modes of $\omega = v_A/2qR$. The discrete TAE eigenmodes are predicted to form by coupling of modes with neighboring m numbers, as observed. The high- n oscillations are observed in shots having a large beam ion population (high power and low density) and a low Alfvén speed (low toroidal field). With a sufficiently short scale length for the fast ion pressure and sufficiently high mode number, the fast ion diamagnetic drift frequency can exceed the Alfvén frequency, as required to drive the instability. However, the Alfvén speed is still greater than the parallel velocity of an untrapped beam ion, which may not be consistent with predictions for the TAE mode.

Detailed equilibrium fits on a number of discharges undergoing loss of vertical control show that the plasma moves vertically monotonically and does not reverse its direction as has been suggested as a possible fix to the problem of vertical disruption forces. Good disruption equilibria have been obtained into the current decay phase ($I_p/I_{max} \sim 0.5$) with the plasma more than 110 cm off axis. Equilibrium calculations performed at intervals of one millisecond during the current decay confirm that the actual disruption does not occur until the edge safety factor is well below two. In two cases that were examined, the disruption occurred between an edge q of 1.1 and 1.3. The value is significant in the modeling of disruption forces because the plasma current does not start its rapid decay until the disruption occurs.

Electron Cyclotron Heating

During the third quarter, ECH experiments on the suppression of low n modes which arise at high normalized beta were performed. High beta conditions were obtained through high power neutral beam heating. ECH was added near the $q = 2$ surface as a means of stabilizing the MHD activity. These experiments were an extension of experiments performed last quarter, in which $n = 2$ activity was apparently suppressed during short pulses of ECH; in the present experiments, long pulses of ECH power were available.

However, very little effect of the ECH on mode growth was found, and the limits on normalized beta and the confinement at high normalized beta were not improved. Analysis is continuing regarding the effect of the ECH on the pressure profile.

Electron cyclotron heating was also used to support the Ion Bernstein Wave heating experiments.

The prototype 110 GHz ECH launcher was prepared for installation on DIII-D. It will initially be installed with the beam rotated to about 20 degrees from radial so that current drive experiments can be performed.

Ion Cyclotron Heating Using Ion Bernstein Waves (IBW)

Three days of dedicated IBW experiments were performed this quarter. The main thrust of the experiments was to explore the previous results, in which an improvement of the confinement of ions was observed during the IBW heating, under the conditions of carbonized walls, since carbonization has been shown to greatly reduce the influx of metallic impurities during IBW. At the same time, ECH was to be added in order to increase the ratio of electron to ion temperature, so that any improvement in ion energy confinement would be reflected in an increase in ion temperature. However, perhaps because of the carbonization, the improvement in ion confinement was not reproduced.

A detailed analysis of experimental results has revealed important correlations between edge ion heating and ion cyclotron quasi-mode (ICQ) amplitudes. Both the deuterium edge heating and the ICQ are strongest at the magnetic field for which efficient coupling to the IBW is expected. The edge ion heating has a power threshold of several hundred kilowatts, comparable to the power threshold for parametric decay instability. The density of the energetic tail of the ion distribution function is found to increase linearly with the ICQ amplitude. This is the first convincing evidence of a correlation between edge ion heating and parametric decay instability in the ion cyclotron range of frequencies.

Analysis of IBW antenna loading data was carried out with a refined antenna model which takes into account the mutual coupling between the two halves of the antenna, the distributed nature of the antenna loading (both resistive and reactive) along each current strap, and the correct impedance transformations in each antenna feed. Initial results for high-edge-density data indicates that much of the variation in resistive and reactive loading

seen previously using a simple lumped antenna model for the analysis is due to the effect of the mutual coupling rather than a dependence of loading on the antenna $k_{||}$ spectrum. Analysis of low-edge-density data has yet to be done.

The IBW antenna was examined and removed from DIII-D. One Faraday shield rod was found to be damaged, presumably when the antenna was pushed in past the limiter radius. The single molybdenum rod was protruding about an inch past the plane of the shield, and clearly acted as the main outside limiter on some shots. This probably accounts for the relatively low edge density observed in limited discharges with the antenna pushed in.

Current Drive

Two experimental days were devoted to collection of additional data to complete a description of the neutral beam current drive (NBCD), high β_p regime of DIII-D plasmas. Scans of plasma current and injected power were obtained, as well as a scan of Thomson scattering time for analyzing profile evolution in these discharges. The work on electron cyclotron current drive (ECCD) over the past year was summarized in a paper presented at the European Physical Society meeting on controlled fusion in Amsterdam (by R. James, et al.) . In addition to the observation of 50–100 kA of ECCD with strong single-pass absorption, of particular note is the recognition of the synergistic interaction between the ECCD and the residual inductive toroidal electric field. A quantitative analysis of this effect is now under way. Finally, as one of the tasks of the summer vent of DIII-D, the fast wave current drive (FWCD) antenna was received from ORNL and successfully installed in the vessel. Much credit is due to the staff from ORNL who brought the hardware and assisted in the installation.

OPERATIONS

Tokamak Operations

During the third quarter of FY90, five weeks of operation were scheduled and the obtained availability was 79.1%. The operations schedule and the vent periods are shown in Fig. 1. Details of the availability are shown in Fig. 2. A one day vent occurred shortly

DIII-D FY90 Third Quarter Operations

● Vent to repair cracked window

● Vent to install advanced divertor hardware

● Record Beta = 10.7%

□ = Maintenance
▨ = Operations
▤ = Vent

PERCENTAGES OF MACHINE TIME
4-90 thru 6-90

PERCENTAGES OF TOTAL DOWN-TIME
4-90 thru 6-90

after the March vent, where the source of the bromine contamination was removed. The unscheduled vent was made necessary by a broken window, which was replaced with a blank flange. The second vent is the major summer vent, that is scheduled to last two months. During this vent the advanced divertor ring is being installed among other things.

The two week operation period in April was plagued by an elusive leak, that developed between the 165° magnetic probe secondary vacuum and the vessel. The secondary vacuum had earlier developed a leak to air, which had not been discovered, since it did not cause any increased leak rate into the primary vacuum. It took three days to find the leak, because of its unusual nature. For the repair the secondary vacuum was first pinched off, which left the machine pumping on the magnetic probe array, but before the operation started in May the secondary was connected to a turbo pump. Simultaneously the global leak rate in the vessel dropped to 1.1×10^{-5} torr liter/sec. This is about 30-50% lower than the value routine obtained in the past. This shows that the acceptable global leak rate for the machine should be lowered to this new value. The major leak in the magnetic probe will be repaired during the summer vent, but a turbo pump will still be used to pump on the secondary vacuum to compensate for the residual small leaks in the system.

The machine worked extremely reliable during the three weeks of operation in May with an availability of 94% and a very good vacuum. The vessel was carbonized the weekend between the first and the second operation week in May. The good vacuum condition and a better understanding of the vertical instability for highly elongated plasmas made it possible to obtain a new world record beta value of 10.7%.

An electron gun was installed temporarily on the machine the day before the start of the June vent. This was done to investigate the possibility of lowering the initiation pressure for the glow discharge. Experiments in a test chamber had shown earlier that it is possible to lower both the initiation and sustaining pressure for glow using an electron gun. The test in the machine showed that it is possible to initiate the discharge glow at 3.7 mtorr with the gun compared to greater than 100 mtorr without the gun. The lowest possible sustaining pressure was independent of whether the gun was on or not. This is in contradiction with the results from the test chamber, where the electron gun also helped lowering the minimum sustaining pressure. It might be due to limited current capability of the power supply used. The required current is dependent on the size of the vacuum

chamber, and the current capability was therefore sufficient for test in the test chamber. The data from this test are important for the design of the advanced divertor cryo pumping system. The electron gun will be installed on the machine vessel during the summer vent, but a new power supply is needed to get the full benefit of the electron gun.

The first week of the summer vent was used to measure the magnetic error field in the plasma region from the different coils. Error fields are believed to play an important role in the plasma transport through their effect on magnetic islands. Thus an understanding of the error fields and their origin is very important.

The advanced divertor ring, the Fast Wave Current Drive antenna, the fast Langmuir probe, the divertor irradiation materials experimental system DIMES diagnostic, and one 110 GHz ECH waveguide will be installed during the vent. The charge exchange recombination (CER) diagnostic for measuring ion temperatures will be modified, and most of the diagnostics are calibrated while the vessel is open. Several floor tiles in the vessel will be leveled in an attempt to reduce flow of carbon into the plasma.

Major maintenance tasks are undertaken also during the vent periods. They cover the power systems, the neutral beam lines, cryo system, water system, diagnostics, computers, and the data acquisition system. The resistance of the electrical connections on the buswork will be checked. A new 6000 l/sec turbo pump will be installed, but will not operational until after the vent period.

Two weeks of ohmic plasma operation are scheduled for August to test the new items installed during the vent. Two weeks of full plasma operation have been made possible in September due to extra funding.

Radiation Management

Radiation Health Physics. The total neutron radiation at the site boundary in the 3rd quarter was 1.67 millirem, the total gamma radiation was 0.47 millirem, giving a total for the quarter of 2.14 millirem (below our quarterly allocation of 20 millirem per year).

Estimates were made of the radiation dose to be received by each person scheduled to enter the vessel during the summer vent to ensure that no ones work plan exceeded their allowed dose. The highest dose estimate was 166 millirem in June and 176 millirem in July and these were conservatively overestimated for safety. (The maximum dose an individual actually received during June was 46 millirem and the second highest dose was 25 millirem.) The estimates for June and July are both within the allowable limits of our DIII-D procedures of a total of 300 millirem per quarter for DIII-D personnel. Based on our site boundary dose total of 2.2 millirem for the 3rd quarter a maximum exposure of 110 millirem could have been received while on site leaving a limit of 190 millirem that can be used for the vessel entries during June. Similarly, if a limit of 190 millirem is allotted for vessel entries in July a site boundary dose limit of 2.2 millirem is available for possible September operations.

The DIII-D vessel was vented and radiation measurements were made prior to entry. The dose rate in the vessel ranged from 2.5 to 3.5 millirem per hour, which was slightly less than the dose rate at the time of entry during the Dec. 89 vent.

We completed a radiation survey of the southeast hillside and found that the radiation on the hillside is 2.3 times higher than at the public site boundary monitoring station. This steep hillside area is uninhabited and fenced. Although it is not GA property its access is controlled through GA and does not have unrestricted public access where the DOE radiation guidelines apply. Therefore this does not result in any additional restriction of DIII-D operation.

The DIII-D Work Authorization was updated, reviewed, and approved by Health Physics. Also approved was an increase in the hours visitors may be present without requiring a film badge from 12 to 18 hours a quarter.

Work started on creating a database system for the radiation exposures of personnel that would also be able to make use of the automatic magnetic card key system logging of pit entries. The goal being elimination of all the paper work now generated and to have the easy access and summary capabilities inherent in a database.

Plasma Neutron and Hot Ion Physics. Analysis and charge exchange measurements of the hot ion energy distribution were advanced this quarter. The TEXAS charge exchange code was successfully modified to calculate the beam attenuation in DIII-D. The appearance of edge heating during IBW correlated well with the parametric decay spectra. Improvements in fusion product diagnostics were made. The 14 MeV neutron detector signal was improved with the elimination of noise from the signal. Future work is needed to evaluate if the signal is contaminated by pile up of gammas. The neutron analysis code NCTR was modified to include a test for high count rate and possible saturation of a channel. This fixed a problem found to occur in some low neutron rate shots with saturated channels being included in error. The 15 MeV proton detector fabrication continues.

A calculation of Q_{DD} and Q_{DT} in a high neutron rate shot and in a high confinement shot were made. The highest Q_{DD} and Q_{DT} were in the high neutron rate shot (2.8×10^{15} n/s) with a Q_{DD} of 2.2×10^{-4} and a Q_{DT} of 0.1. The Q_{DT} calculation uses the results of the ONETWO code to obtain the fraction of neutrons from beam-target reactions and the fraction from thermal reactions. The lower density, higher neutron rate shot has 82% of its neutrons from beam-target reactions versus 58% in the higher density, high confinement shot. The code, however, does not include beam-beam reactions which should also be a major contributor to the neutron rate and would affect the Q_{DT} calculation. The possibility of adding beam-beam neutron results to the code is being investigated.

Neutral Beam Operations

Operational Summary. Neutral Beam heating has been available with all eight sources on a routine basis for plasma experiments during the past quarter. The major source of down-time has been a vacuum leak on the lifting bellows of the 210° right source calorimeter. Experiments with argon fueling of 5 of the sources were also performed to see if an electron rich environment at the plasma edge could influence the onset of the L-H transition.

System Availability. Overall availability was approximately 90% during the quarter. Injection experiments were scheduled for 68.1% of the operating time. The downtime (9.8%) was primarily due to vacuum problems associated with the calorimeter bellows on

the 210° beamline and with various small power supply problems. Beam power delivery in the range of 18-20 MW has been routine.

Recent Activities. Argon beam operation of the long pulse sources was performed and beam injected into a plasma to study the L-H transition by argon neutral beam injection. The sources had to operate in the gas starvation mode, since the argon is so easily ionized that breakdown in the accelerator region occurs if gas flow is higher than 7 torr liters/sec. Unfortunately, the experiment was unsuccessful in triggering the H-mode. It was found that the impurity influx caused by the argon beam overwhelmed any effect of the fast ion loss on the edge electric field produced by the electron excess left at the plasma edge by the prompt loss of the argon ions.

Drift duct cleaning after torus carbonization turns out to be time consuming and requires many beam shots. The beam loss is extremely large in the early stage of duct cleaning, and beam pulse length limitation becomes crucial to protect the drift duct. For this protection, a fast beam interlock system employing the duct photodiode signal has been installed. Beam injection into the torus through the drift duct will be terminated if the photodiode signal reaches a preset value.

To investigate the line melt marks observed on the drift duct walls during the last vent, an IR camera system was set up to view the 330° duct outer surface. Preliminary data was gathered during the final run week of this quarter. A hot spot was observed following a beam pulse and its location was indeed determined by the strength of the toroidal magnet field. A controlled experiment is still needed to complete investigation of the magnetic field effects on re-ionized particles within the drift duct region. A mini proposal is being written to perform this experiment.

Three Rogowski coils have been installed, two inside the 330° beamline and one around its drift duct. These will be used to measure directly the neutralization efficiency. Examination of the preliminary results shows that the charged beam current can be measured, but signal baseline drift of the integrator signals needs to be eliminated before reliable results can be produced. Development of a rugged integrator system that is drift-free needs to be a high priority in the fusion community. We are indebted to Dr. Ioshiaki Doi for the extensive work that he has put in on this Rogowski system during his stay at GA. He will return to Brazil at the end of July.

Average Beamline Availability
For DIII Shots: 68945 to 68952
March 24, 1990 through July 12, 1990

A major leak developed in the bellows on the 210° right source calorimeter lifting assembly and put this beamline out of commission for a two week period in April. In May, the 30° right source calorimeter bellows also developed a leak. However, a temporary solution (torr-seal applied to stop the leak) was feasible in this case and the 30° sources were available for plasma heating experiments. Investigation of the failure has shown a design problem in the original assembly in which the bellows convolutions squirmed against the stainless steel lifting shaft. It is likely that all eight units will fail in the same way. A re-design of the affected components has been made to eliminate the squirm and parts have now been ordered to replace all assemblies during the summer.

All eight sources have now been inspected as part of the vent activities. The 330° left source was found to have electrical shorts between the arc chamber bucket and probe plate. This source has been remounted on the beamline after it was removed to fix these shorts. MOV's on the filament plates and insulation plate were found to have been damaged. These MOV's will be upgraded to more substantial units (parts on order) during the vent.

Inspection of the beamline internals has revealed some additional melting of the copper duck bills, lower edges of the ion dump, and magnet louvers. These items are all sacrificial beam absorbers and periodic replacement has been anticipated. All components with significant melt zones have been replaced as part of the vent activity. We have, however, detected some melting of a baffle collimator for the 210° left source and this appears to indicate a shift in the steering of the beam from this source. A similar steering problem exists with the 30° left source. When operations resumes in September, steering experiments for these two sources will be scheduled to better optimize their optic axes.

The NB Logbook system in the new Neutral Beam Database (4th Dimension) has been in use during this quarter. Suggestions and comments were collected and are being implemented to make the system more user friendly.

NB Personnel have now installed the new Macintosh computer in the tokamak control console. It will function in a very similar way to the Macs in the beam console and use the identical software. All of this software has now been configured using object oriented coding and this will significantly simplify future maintenance upgrades of the systems.

The NB central control console project is progressing very well and is scheduled to be tested in early September when beam operation resumes.

Work on the revision of the Modcomp control computer software and operating system is proceeding well and has been estimated to be more than 40% complete. It is hoped that we will be able to resume operations with the new Infinity database, the intertask communications and the screen display tasks fully implemented.

The flammable gas-flow monitors (hydrogen and deuterium) for the ion source and neutralizer fueling measurements have proven to be too unreliable to use in their present configuration. It is very important to implement accurate gas flow control to the sources to ensure that the pressure in the accelerator grids is maintained at the optimum during high

power operation. Excessive re-ionization in this region can lead to premature grid failure. In addition, inventory control of the hydrogen on the cryopanel was to be automated through this system to ensure that the condensed gas always remained below the 13 torr explosive partial pressure. We have talked extensively with the equipment manufacturer about the high failure rate of the flowmeter probes but, because of the recent extensive reductions in staffing at GA, are now limited by the lack of knowledgeable manpower to deal with the problem at this time.

Plans for 4th Quarter Operations Period.

- Replace calorimeter bellows
- Bring central console to fully operational status
- Start operational testing with new Modcomp software

ECH Operations

There were 14 days of ECH operations this quarter. There were 9 gyrotron systems available due to high vac-ion current on system #5 making it inoperable. There were 237 rf/plasma shots with a best day figure of merit (based on pulse length requested to pulse length received) of 70%. One run day was dedicated to ECH modulation at various frequencies up to 30 Hz with a figure of merit greater than 90% on some of the shots.

ICH Operations

There were 14 days of plasma operations this quarter. Of the 212 requested rf shots, 210 were achieved for a system availability of 99%. Average power for the reporting period was 600 kW with consistent peak power of 960 kW. Two days were dedicated to combined ECH/IBW operations with no indicated problems associated with the simultaneous operation and injection. It was noted that at low fields and high rf power that the toroidal field coil current interlock would pick up the rf and cause the shot to terminate.

Computer Data Systems

DIII-D operated during April and May of this quarter. Large amounts of data were collected during the period, usually over one gigabyte per day. The largest shot collected to date was 45.7 megabytes. The VAX computers at DIII-D are very busy during the data acquisition and analysis phases between shots, using an average of 90% of memory and over 95% of the available CPU cycles. The physicists have found that delays in running analysis programs are now having an effect on how quickly they can make decisions about how to set up the next shot and actually fire the next shot.

The new serial highway on the Q2 MODCOMP acquisition system was set up with many CAMAC crates switched from Q1. This balances out the load of data going through each MODCOMP Q1 and Q2. This means that for power supply shots, the actual time to do all acquisition will be shortened by about a minute and a half. The regular data acquisition is faster by half a minute.

Software checks were installed on the control computer and the master MODCOMP acquisition computer so that the control computer can tell when data acquisition is complete and another shot can be started. This speeds up shot duty cycle for shots which do not heat up the vessel.

Some problems with neutral beam systems receiving erroneous timing requests were investigated. A hardware check will be built in to prevent any damage to hardware. Software changes were made to alert operators to potential problems in receiving timing information on the beam systems. Some additional changes should be made during the next quarter. Also, the latest version of the link software which connects the various systems was installed. This should eliminate the problems which arose from the link occasionally going up and down.

The neutral beam software upgrade/rewrite of the Berkeley message service programs has proceeded well during this quarter. Data base utility and interface routines have been written and major portions of the screen manager and dispatcher are done. During the vent, all software has been moved from the Spare MODCOMP to the neutral beam systems where testing is more realistic.

Plans were made for decommissioning the Thomson laser experiment VAX 11/750. A new computer system will be in place during next quarter. Laser disks were copied to 8 mm tape and a RA81 data disk was moved to the USC cluster. The remaining RA81 on the 750 will be installed on the DIII cluster after the 750 is turned off.

It was decided that the DEC-10 format DIII data tapes stored in an offsite vault are not worth keeping. They are very old, have never been used since 1984, are in a format which none of our existing computers can read, and the data is stored on other tapes in a usable format. All users were contacted to discuss any concerns. Those tapes will be released/ destroyed during August.

During this quarter, five microVAXes received upgraded ethernet communications boards. This was necessary since DEC will not support the old boards, and the latest software is optimized for the new boards. A trade-in program made the swap reasonable. During June all but two VAX and micro-VAX systems were upgraded to VMS 5.3-1. Of the two micro- VAXes not done, one has been constantly in use, and the other is down and waiting for a disk to be repaired and returned. A new microVAX 3400 was received from UCLA for a Fast Langmuir probe experiment. It has been installed and is being configured to look like other DIII-D systems.

A problem has existed for some time relating to the accuracy of the timing information associated with the data base. With the newer digitizer equipment, clock rates of $1.e-7$ seconds (0.1 microsecond) for a megabyte of samples has been used. A 32-bit real number does not have enough bits to accurately represent these times through the span of the data. Plans were made and coding has been started to store all timing information as 64-bit reals. Codes on the MODCOMP acquisition system which gather clock data and incorporated it into the data base all will be modified. The actual data base format has been changed to accommodate the new 64-bit fields. All VAX codes which handle the data base need to be altered to receive the 64-bit fields. And the user data interface code (PTDATA) has to be altered to return and use the 64-bit fields. PTDATA will be changed such that existing codes which ask for data, but expect the old format will continue to execute correctly. Application codes will need to be modified if they wish to access the new 64-bit data. This work should be finished before the end of the quarter.

There was a successful conclusion of the escrow account with Multiflow, Inc. which held the source code for the TRACE computer. All software appears to be intact as promised. Bell Atlantic Business System Services, Inc. purchased the maintenance portion of Multiflow, Inc. A maintenance agreement with them is pending. The TRACE has been very stable and has experienced some increase in general usage. It is expected that usage will rise sharply when the EFITD code is in production. This has been delayed because the graphics output package vendor (DISSPLA from Computer Associates) has been very slow in responding. EFITD should be available for use after the current DIII-D vent. In the meantime, we are looking at a public domain graphics package from NASA that reportedly mimics DISSPLA.

Several printers have been examined. One (NewGen Turbo PS400) has been brought on-site for evaluation. Although its speed was disappointing for Tektronix formatted output, it has performed well with general VAX output, such as TeX, and with postscript formatted files from the MACs. Two other printers are scheduled to be evaluated early this next quarter, with a decision made before the end of the quarter.

Both the MODCOMP and Digital Equipment maintenance contracts were renewed during this quarter.

A DOE meeting to discuss the needs of the various groups (experiment, theory, USC, engineering) for computers for the next five years was held. A draft report for the experiment section was written and submitted for inclusion in the overall report.

The USC VAX Cluster was available to the users 97% of the period. The decrease in the USC system availability is attributed to failed Dilog disk drives. These drives have had problems since their initial installation in the first quarter of FY90. They did perform near flawlessly for almost 3 months, but started to fail the first of June. We are working with the vendor to reach an equitable solution to this situation. The USC VAX/VMS upgrade was postponed because of the Dilog disk problems. The upgrade to version 5.3-1 was completed early in July.

PROGRAM DEVELOPMENT

Experimental Planning

The anticipated five weeks of plasma operations were completed in the first part of the quarter and then the vessel was vented for new hardware installations. The vent will be approximately two months long, finishing at the end of July. The major components to be installed are complete now and it is anticipated the machine will be closed near the anticipated closing date.

Following the vent there will be a period occupied with making the final connections to the advanced divertor and FWCD antenna, vacuum vessel preparation and discharge cleaning, and testing of electrical power systems. This will be followed by a two week period of systems testing of the new components with ohmic plasmas. This is considered extremely important because of the uniqueness of particularly the advanced divertor hardware. The neutral beams will then be conditioned prior to two weeks of normal plasma operation in September. Although resources and manpower continue to be constraining, we are giving considerable attention to the return to plasma operations in September. This plan is summarized in the attached schedule.

The work scheduled for the vent is being completed. The IBW antenna was removed and the FWCD antenna constructed at ORNL has been installed. The antenna was received in excellent condition and ORNL provided technical support for the installation. Measurement of the error fields in the vessel from the coil systems were measured with the result that they were found to be consistent with the anticipated fields due to known coil locations. A number of the high spots (~ 1 mm) in the tile array on the vessel floor were leveled by shimming. The advanced divertor tile current measurement array and a number of specialized divertor diagnostics have been installed.

The fabrication of the advanced divertor ring assembly has been delayed at the manufacturer by several weeks, but other vent tasks have been reordered so that impact has been minimized. The ring is now in-house (19 July) and leak tight. The baffle plates between the ring and the vessel wall remain to be completed, but they are the last component to be installed.

The Thomson scattering diagnostic is presently being converted to multipulse operation, and it is anticipated to be ready for first operation in time for the September operations period. The work remaining to complete this conversion will be done in the first three months of the next fiscal year.

The conceptual design of the Advanced Divertor Pumping system is progressing well. The characteristic parameters are being established and an in-vessel design is being developed. It is anticipated that this hardware can be installed next summer assuming suitable funding is developed. This design is being done with the help of a scientist from ORNL. JET has agreed to collaboration on design, engineering, and experimentation on advanced divertors in conjunction with their anticipated installation of an enhanced divertor in late 92 or early 93 in JET.

Safety

A review of the safety practices and implementation at DIII-D was carried out July 16 thru 18 by a team of specialists from DOE/SAN office. The conclusions (informal oral report) of the committee were that DIII-D had an excellent program in place, that it was well implemented, and that there was a good attitude toward safety. They also noted that our safety officer had developed into a well qualified professional. They suggested that there be more periodic oversight of the program in terms of periodic audits of implementation and record keeping (although the present status of either didn't appear to be a problem). A number of helpful specific suggestions were also made and will be transmitted in their final report. Overall, this review was a positive experience for all.

Milestone Schedule

Task Description		Issue	Approved Date	Target Date	Completed Date
59.	Report results of outside launch ECH current drive experiments	B	1-90 ⁽¹⁾	1-91	
60.	Evaluate the potential of IBW heating for tokamaks	B	7-90	7-90	7-90 ⁽²⁾
61.	Evaluate the role of profile control in modifying β limits	A	7-90	7-90	7-90 ⁽²⁾
62.	Complete interim report on DIII-D ITER R&D tasks	B	10-89	10-89	10-89
63.	Submit initial report on fluctuation measurement studies (with UCLA)	B	12-89	12-89	12-89
64.	Submit report on results of local transport studies	B	3-90	3-90	3-90
65.	Complete installation of the advanced divertor baffle/electrode ring (with ORNL, SNLA, SNLL, & UCLA)	A	8-90 ⁽³⁾	8-90	
66.	Complete installation of the fast wave current drive antenna (with ORNL)	B	8-90 ⁽³⁾	7-90	8-90 ⁽²⁾
67.	Complete interim report on DIII-D ITER R&D tasks	B	4-90	4-90	4-90
68.	Operate prototype 110 GHz gyrotron	A		TBD ⁽⁴⁾	
69.	Evaluate the role of edge plasma rotation in the L to H transition	A	8-90	8-90	
70.	Inject pellets into DIII-D H-mode plasmas	A		TBD ⁽⁵⁾	

Task Description	Issue	Approved Date	Target Date	Completed Date
71. Complete interim report on DIII-D ITER R&D tasks	A	10-90	10-90	
72. Obtain first data from multipulse Thomson scattering radial profile	A	1-91	1-91	
73. Correlate turbulence measurements with ITG mode theory	A	12-90	12-90	
74. Test particle control with the advanced divertor	A	3-91	3-91	
75. Evaluate FWCD efficiency	A	6-91	6-91	
76. Begin DIII-D 110 GHz ECH experiments with 4 gyrotron system	B	9-91	TBD ⁽⁴⁾	
77. Transport measurements with pulse modulated ECH	A	7-91	7-91	
78. Report on DIII-D 110 GHz ECH Current drive	A		11-92 ⁽²⁾	
79. Evaluate divertor pumping	A		TBD ⁽⁵⁾	
80. Divertor biasing report	A	5-92	5-92	
81. Report on results of 110 GHz ECH experiments	A	6-92	6-92	
82. Turbulence studies report	A	12-92	12-92	

⁽¹⁾Delayed due to program redirection caused by funding constraints.

⁽²⁾Milestone awaiting OFE approval.

⁽³⁾Milestone date moved from 5/90 to 8/90 due to funding constraints.

⁽⁴⁾Milestone date pending delivery of gyrotron from Varian.

⁽⁵⁾Milestone date pending FY91 budget.

HARDWARE DEVELOPMENT

Advanced Divertor Program

ADP Diagnostic Development

The prototype Tile Current Array (TCA) performance was evaluated and some design changes were made for the elements of the full array. The changes will improve stray pickup rejection during large transient events and make the resistor unit more compact. The full array consists of 28 elements. It will provide poloidal coverage (floor, ceiling and middle of the center post) at one toroidal location and $n = 1$ toroidal coverage in the floor. The new elements have been made and will be installed in the June-July vent.

Ten power supplies and data acquisition channels were installed by SNL for the upgraded 19 Langmuir probe divertor floor array. The array operated during the Spring experiments and collected large amounts of data, much of which still needs to be analyzed. Eleven new Langmuir probes on the ADP bias ring will be added to the array this summer. Because the present array already collects enough data to significantly increase the main DIII-D data system load, the highest priority now is to buy a dedicated computer.

Other ADP collaborators are preparing diagnostics for installation during the June-July vent. The SNL-UCLA fast stroke probe system is under construction. The LLNL tangential viewing divertor H_{α} TV was redesigned for compatibility with the new ADP ring and baffle, and it is being rebuilt. The ORNL divertor spectroscopy system is under construction.

ADP Pumping System

Many ADP cryopump system concepts were analyzed by ORNL collaborators using the DEGAS code. Pumping of at least 50% of the entering particles is predicted for the better configurations. This analytical work has been closely coupled with cryogenic and mechanical design engineering at GA, to establish a well integrated conceptual design. The design uses two phase helium flow, which is consistent with connection to the existing neutral beam liquid helium system. No fluid instabilities are expected from the two phase operation in the parameter range chosen. The design hides liquid nitrogen surfaces, which condense water and volatile hydrocarbons, from direct impact by fast neutrals born at the baffle entrance. o compare our conceptual designs with those of JET to determine the

concept to be built for DIII-D. This collaboration will also include benchmarking codes from JET and the U.S. with DIII-D data.

The JET tokamak program has agreed to a cooperation on divertor pumping. We will send people to JET to compare our conceptual designs with those of JET to be built for DIII-D. This collaboration will also include benchmarking codes from JET and the U.S. with DIII-D data.

ADP Engineering/Physics

Most design work for the ADP divertor bias ring electrode and baffle system was completed. Advanced divertor installation work began in early June and will continue into early August. Most hardware deliveries are on schedule. The major exception is the Inconel ring for the electrode. Fusion engineering is working with the vendor to expedite the ring fabrication, and the sequence of vent tasks is being rescheduled to accommodate the late ring delivery.

Inspection during the present vent revealed that irregularly raised divertor floor tile edges are beginning to erode. Although DIII-D has so far not experienced any "carbon bloom" problems. However continued operation at the 15 to 20 MW heating level is anticipated in the future so erosion is a matter of some concern. Therefore, the feasibility of improved tile leveling is being studied.

The first phase of the DIMES divertor sample exposure system was designed and will be installed during the vent. The sample will not be removable under vacuum in this phase.

2 MW, 110 GHz ECH Project

The prototype gyrotron has started testing and has produced 30-50 kW of RF power. Three different operating regimes have been identified with at least one showing indications of being appropriate for high power RF production. Further testing of the prototype has been stopped because the 400 kW, 140 GHz gyrotron is using the Varian test stand. Completion of testing of the tube and delivery to GA is now projected to be mid November. Discussions with Varian to accelerate the testing is in progress.

The first magnet was delivered to Varian on May 2, 1990, however measurements of the magnetic field indicated that the magnetic axis was off of center by as much as 0.300 inches and in order for the magnet to be usable the gyrotron had to be tilted to match. This was accomplished by the use of premachined spacers, which have been supplied by GA.

The coils for the number 2 magnet have been wound and placed on the cold bore. The stack has undergone its "open dewar" test and all coils have passed. This magnet is about one month behind schedule owing to the decision to review the assembly procedure and support system, so as to avoid the problems of the first magnet.

Owing to concerns over meeting this years budgetary guidelines, and a better understanding of the test measurements of GA's prototype mode converter, the plan to build a Vlasov mode converter has been stopped.

The #5 60 GHz gyrotron tank has been removed from the gyrotron vault area as part of the effort to install the 110 GHz equipment. The first 110 GHz tank has been placed in the vault, however it can not be completed until a high voltage bushing is available. The vendor will not commit to a delivery date.

The waveguide machining tool has been received at GA and is undergoing changes to allow it to machine tubes of different length and diameters. It's first task will be to make two short waveguide sections that are to be placed in the ECH launcher assembly. These parts were to be made out of copper, but the vendor could not cut the grooves. GA will now make the parts out of aluminum.

The first launcher has been installed in the DIII-D vacuum vessel during the present vent period.

General Atomics has provided company IRD funding to complete the development of the mode converter. A low power converter is scheduled to be available by September 30th for testing. The design of the vacuum tank, which houses the converter has been assigned to Fusion Engineering. The results of low power tests on the prototype, will be incorporated into the design for a high power version.

The vendor fabricating the directional coupler could not gun drill the part to the required tolerances. The job has been pulled and is being redesigned for easier fabrication. GA will be the prime and will find individual vendors to perform subtasks as needed. This part is expected to be available for the October high power testing program. A backup slotted miter bend is being pursued should the fabrication of the coupler exceed schedule.

A reassignment of responsibilities for the 110 GHz project is under way owing to the large change in project personnel within the last month. Along with the changes in responsibilities the overall project is being reviewed with emphasis on what is needed to be accomplished in the next three months, and what is it going to cost. Emphasis was placed on the construction of the second magnet, to insure that it will meet specification. The second highest priority was to review the overall schedule and to evaluate the impact that the delayed testing of the prototype gyrotrons was having.

Fast Wave Current Drive (FWCD)

The fast wave current drive antenna was installed on schedule in place of the IBW antenna. The radial position of the Faraday shield face was fixed at 0.4 cm outboard of the tile surface, in an attempt to compromise between maximum loading (minimum antenna/separatrix distance) and conservative heat loading.

OPERATIONS SUPPORT

Services including storekeeping, materials handling, quality assurance, plant engineering, inspection, safety monitoring and control, scheduling, cost control, procurement control, status reporting, and engineering services such as document control, design integration, space allocation and CAD support were provided to DIII-D under "Operations Support." Status of the DIII-D Possessory Interest (PI) and Sales Tax issue is contained in a separate section of this report.

TRANSPORT INITIATIVE DIAGNOSTICS

The upgraded CER system and the correlation reflectometer (UCLA project) enabled a comparison of the radial extent of the rotational shear layer and the turbulence stabilization layer. The phase contrast imaging diagnostic did not detect IBW waves in

the plasma interior (we believe there were none!). Test data from a prototype channel of the multi-pulse Thomson showed good agreement with the ruby laser system.

COLLABORATIVE EFFORTS

LLNL — During the third quarter of FY90, Livermore personnel remained active in several areas of the DIII-D program: divertor physics, non-inductive current drive, and transport studies.

Our staff made presentations of the collaboration results at two international meetings; the results of our ECCD experiments at the EPS meeting in Amsterdam, and the results of radiative divertor experiments at the PSI conference in England. In addition, we discussed the design of the Motional Stark Effect diagnostic with the diagnostic team at JET.

We have continued to upgrade the BASIS version of the ONETWO code. We added the ability to store a time history of any of the calculated variables in the code. This will enable us to plot the evolution of transport parameters in a time-dependent analysis mode such as studies of the L- to H-mode studies. We also upgraded the bootstrap current model to be consistent with the model of Hirshman. This upgrade was based on work done by C. Challis during the winter.

We have examined the data to better understand an apparent discrepancy between the divertor strike points as determined with EFIT, and that determined from the IRTV data. We find that the agreement is significantly improved by running EFIT in a manner which allows finite plasma current at the separatrix. In addition, we find some of the IRTV data is suspect because the field lines viewed by the camera strike the tiles at a very shallow angle, producing a distorted heating profile due to tile edge effects.

JAERI — Hiroshi Matsumoto presented "Physics of L-H Transition" at the 17th European Conference on Controlled Fusion and Plasma Physics. Takeshi Fukuda has worked on analysis of sawtooth density pulse propagation. Yutaka Kamada has analyzed soft X-ray data to study the effect of sawtooth on confinement.

UCLA — Operation of the broadband sweep reflectometer continued. The narrowband sweep reflectometer and the FIR scattering system were used to obtain fluctuation data in support of a number of transport experiments. The correlation reflectometer obtained important new data.

MARYLAND — Analysis of superthermal electron effects in ECCD experiments continued.

ORNL — Ed Lazarus gave an EPS paper on the stability of highly elongated plasmas. ORNL staff relocated to GA for installation of ADP diagnostics and cryo-pump design.

U. Illinois — Glen Sager continued work on fast ion physics toward his Ph.D.

MIT — Stefano Coda operated his phase contrast imaging system on DIII-D.

UC Berkeley — Taina Kurko-Suonio worked at GA on analysis of transport transients across the L-H transition. Three UCB students took up residence at GA for summer projects.

UCSD — The DIII-D transport research program continued to collaborate closely with Pat Diamond and Hamid Biglari.

UC Irvine — Bill Heidbrink and a student worked on new diagnostics for DIII-D and the search for TAE modes.

UNICAMP, Brazil — Dr. Ioshiaki Doi continued to work with the DIII-D Neutral Injection Group.

SANDIA — The new Langmuir probes produced much data.

DIII-D POSSESSORY INTEREST AND SALES TAX ACTIVITY - 3rd Quarter FY90

Possessory Interest Tax

The U.S. District Court responded to motions for summary judgment by the U.S. Department of Justice and San Diego County by denying the Department of Justice's motion and granting the substance of San Diego County's motion. The question of *valuation* (which will determine the amount of possessory interest tax to be paid) was left open with both parties invited to respond to the issue by August 10 after which a *final judgment* will be issued in September.

We understand that the Department of Justice will appeal the District Court decision. If the appeal does not eliminate the requirement to pay possessory interest taxes, the appeal process will delay payment for at least a year.

At present valuation, the amount of possessory interest tax due as of October 31, 1990 will be ~~\$5000~~,000 plus \$127,000 in interest and \$163,000 in penalties for a total of \$790,000.

Sales Tax

GA has requested a sales tax hearing date in mid-October, 1990. However, GA's tax attorney, Mike Faber, and Dennis Loper, the lobbyist, both recommend GA withdraw its request sometime before the hearing date. In view of the court decision regarding possessory interest taxes, there appears to be some risk of the Board overturning the prior hearing officer's recommendations which limiting valuation if we appear at a full Board hearing. The dollar amount at risk is so large that the DOE/DOJ attorneys have agreed to let GA withdraw from the hearing sometime in late August. By waiting a while to withdraw, billing is delayed and payment will not have to be made until after the new government fiscal year begins.

The amount of DIII-D sales tax due for all audited periods (1981 - September 30, 1988) is \$325,000. With interest and penalty estimated through October 31, 1990, the total is around \$565,000. GA could have to pay some or all of this amount in October/November, 1990.

Funding/Staffing

DIII–D authorized tasks and budgets for FY90 were restructured in the 3rd quarter to reflect the final distribution of operating and capital funds plus the additional \$300 K received to start up operations in September following the vent (\$30,443 K operating & \$1649 capital).

Staffing levels have been reduced on DIII–D since the beginning of FY90 from 200 FTE's in October, to 142 FTE's in June. Further reductions were initiated in May/June which will be effective in July. This involved layoffs, resignations and transfers to other divisions within GA.

DIII-D RESEARCH OPERATIONS

- OPERATING -

	FY90 BUDGET		FY90 ACTUALS	
	FTE's	TOTAL \$000	FTE's	TOTAL \$000
BASE OPERATIONS	59.3	11,345	60.5	8,745
DATA SYSTEMS	9.2	1,663	8.8	1,204
DIAGNOSTICS	5.4	1,226	7.1	1,106
HEATING	25.7	4,692	24.8	3,580
OPERATIONS SUPPORT	23.5	4,279	24.0	3,383
SPECIAL TASKS				
TRANSPORT DIAGNOSTICS	10.9	2,537	13.7	2,368
ADVANCED DIVERTOR	7.8	1,482	6.3	1,058
110 GHz (2 MW)	6.0	3,165	12.8	2,936
TAXES	0.0	54	0.0	0
Total	147.8	30,443*	158.0	24,380

*\$300 K additional funding received to resume September 1990 operations after vent.

DIII-D RESEARCH OPERATIONS

- CAPITAL -

	FY90 BUDGET		FY90 ACTUALS	
	FTE's	TOTAL \$000	FTE's	TOTAL \$000
BASE OPERATIONS	-	223	-	158
DATA SYSTEMS	-	111	-	161
DIAGNOSTICS	-	231	-	130
HEATING	-	23	-	54
OPERATIONS SUPPORT	-	-	-	-
SPECIAL TASKS				
TRANSPORT DIAGNOSTICS	-	205	-	308
ADVANCED DIVERTOR RING	-	20	-	-
110 GHz (2 MW)	3.9	836	3.4	619
Total	3.9	1,649*	3.4	1,430

*Total \$2125 K available to cost in FY90 including \$476 K unpaid commitments at FY89 year end.

Contract Management Summary Report

TITLE:	DIII-D RESEARCH OPERATIONS	B/R NO: AT101014D	CONTRACT NO.:	DE-AC03-89ER51114
CONTRACTOR:	GENERAL ATOMICS P.O. BOX 85608 SAN DIEGO, CA. 92138	COST & LABOR PLAN DATE:	START DATE:	SEPTEMBER 30, 1989
		JUNE 29, 1990	COMPLETION DATE:	SEPTEMBER 28, 1990

PLANNED	\$3,392	\$2,426	\$3,466	\$2,688	\$2,519	\$3,142	\$2,169	\$2,196	\$2,447	\$1,897	\$2,260	\$1,841	TOTAL	\$30,443
ACTUAL	\$3,625	\$2,513	\$3,496	\$2,370	\$2,617	\$3,215	\$1,844	\$2,332	\$2,368					\$24,380
VARIANCE	(\$233)	(\$87)	(\$30)	\$318	(\$98)	(\$73)	\$325	(\$136)	\$79					
CUM VAR	(\$233)	(\$320)	(\$350)	(\$32)	(\$130)	(\$203)	\$122	(\$14)	\$65					(IN THOUSANDS)

PLANNED	178.8	180.5	169.3	158.0	152.0	154.4	138.6	146.6	146.2	133.1	131.5	130.1	TOTAL	1819.1
ACTUAL	200.2	184.1	172.5	147.2	162.3	153.2	131.4	143.8	135.7					1430.4
VARIANCE	-21.4	-3.6	-3.2	10.8	-10.3	1.2	7.2	2.8	10.5					
CUM VAR	-21.4	-25.0	-28.2	-17.4	-27.7	-26.5	-19.3	-16.5	-6.0					

SIGNATURE OF PARTICIPANT'S PROJECT MANAGER & DATE: _____

Contract Management Summary Report

TITLE:	DIII-D CAPITAL EQUIPMENT	B/R NO: 35AT10020	CONTRACT NO.:	DE-AC03-89ER51114
CONTRACTOR:	GENERAL ATOMICS P.O. BOX 85608 SAN DIEGO, CA. 92138	COST & LABOR PLAN DATE:	START DATE:	SEPTEMBER 30, 1989
		JUNE 29, 1990	COMPLETION DATE:	SEPTEMBER 28, 1990

PLANNED	\$10	\$200	\$67	\$121	\$6	\$10	\$555	\$127	\$210	\$174	\$100	\$69	TOTAL	\$1,649
ACTUAL	\$190	\$116	\$97	\$39	\$38	\$56	\$547	\$135	\$212					\$1,430
VARIANCE	(\$180)	\$84	(\$30)	\$82	(\$32)	(\$46)	\$8	(\$8)	(\$2)					
CUM VAR	(\$180)	(\$96)	(\$126)	(\$44)	(\$76)	(\$122)	(\$114)	(\$122)	(\$124)					(in thousands)

PLANNED	0.0	0.0	0.0	0.0	0.0	0.0	20.0	5.0	6.0	5.0	5.0	5.0	TOTAL	46.0
ACTUAL	0.0	0.0	0.0	0.0	0.0	0.5	19.8	3.5	6.5					30.3
VARIANCE	0.0	0.0	0.0	0.0	0.0	-0.5	0.2	1.5	-0.5					
CUM VAR	0.0	0.0	0.0	0.0	0.0	-0.5	-0.3	1.2	0.7					

SIGNATURE OF PARTICIPANT'S PROJECT MANAGER & DATE: _____

7

RDN BROWN X-3266
 RELEASED 10/27/89
 ISSUE # 6, REVISED 7/20/90
 STATUS DATE 7/20/90
 32M BUDGET

DIII-D FY 1990 MASTER SCHEDULE

1350E V-10, REVISED 7/20/90 STATUS DATE 7/20/90 32M BUDGET				FY 1990 OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 16 23 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 6 13 20 27 3 10 17 24 31 7 14 21 28																																																																			
ITEM	DESCRIPTION	CHARGE NO.	T. LEADER																																																																				
1	OPERATION PLAN			OPS XXXXXXXXXX														OPS XXXXXX														OPS XXXXXX										OPS XXXXXXXXXX										HWR C/O I-----I										OPS I-----I									
2	VESSEL VENTS AND SHUTDOWNS			DIRTY VENT XXXXXXXXXXXXXXXXXXXXXXXXXXXX														CLOSE/BAKE XXXXXXXXXXXXXXXXXXXXXXXXXXXX														DIRTY VENT XXXXXXXXXXXXXXXXXXXXXXXXXXXX										CLOSE/BAKE/PS TST I-----I																													
3	CONFERENCES			FUSION ENG SYMP XXXX														APS XXXX														TIF XXXX										EPS XXXX										A I										IAEA I--I									
4	MILESTONES			2-6)														(11-14)														(19-23)										(25-29)										(OCT 1-5)																			
55	ASSESS MAXIMUM BETA TAU		TAYLOR	9/89 COMPLETE																																																																			
62	REPORT ON ITER STATUS		LUXON	10/89 COMPLETE																																																																			
63	REPORT ON FLUCTUATION MEASUREMENTS		MATSUMOTO	12/89 COMPLETE																																																																			
64	REPORT ON LOCAL TRANSPORT		BURRELL	3/90 COMPLETE																																																																			
67	REPORT ON ITER STATUS		LUXON	4/90 COMPLETE																																																																			
60	EVALUATE IDN		PRATER	7/90 COMPLETE																																																																			
2	I-V MONITORS	3466.810.204	SCHAFER	DESIGN & FAB HDW XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
7	DIAGNOSTIC MOVES (GA) (OSVH)	3466.810.204	HILL	MOVE XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
8	NEW DIAGNOSTICS (COLLABORATORS) (OSVH)	3466.810.206	HILL	DESIGN, PROCURE, ASBL & TEST XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
9	DIAGNOSTIC MODS (COLLABORATORS) (OSVH)	3466.810.206	HILL	DESIGN, PROCURE, ASBL & TEST XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
10	EROSION STUDIES	3466.902.500	WONG	REPLACE TILE XXXXXXXXXXXXXXXXXXXX																																																																			
1	PHASE I (INTERGRATED EXPOSURE) (ISVH)	3466.902.500	WONG	DESIGN, FAB, ASBL & TEST XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
2	PHASE II (REAL TIME MEASUREMENTS) (ISVH)	3466.902.500	GALLIX	INSTL XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
11	CONNECT & C/D SYSTEM			CONNECT C/D I-----I																																																																			
11	FAST WAVE CURRENT DRIVE SYSTEM	3466.812.XXX	MAYBERRY	DESIGN XXXXXXXXXXXX																																																																			
1	TRANSMISSION LINES	3466.812.130	HENSEN	PROCURE XXXXXXXXXXXX																																																																			
2	INSTRUMENTATION	3466.812.130	PINSKER	DESIGN, FAB, INSTALL & TEST XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
3	ANTENNA FAB, ASSY & INSTALLATION (ISVH)	3466.812.150	PHELPS	FAB AT ORNL XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
4	C/D SYSTEM	3466.812.XXX/ CARY 3466.360.210		ASBL AT ORNL XXXXXXXXXXXXXXXXXXXXXXXXXXXX																																																																			
				RHW/INSTL XXXXXXXXXXXX																																																																			
				COMP I-----I																																																																			
				V C/O I-----I																																																																			
				FY 1990 OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 16 23 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 6 13 20 27 3 10 17 24 31 7 14 21 28																																																																			

LEGEND
 PRIMARY CRITICAL PATH = =====
 SECONDARY CRITICAL PATH = ++++++
 COMPLETED MILESTONE = ▲
 PROGRESS OF EVENT = IXX---I
 INSIDE VESSEL HWR = ISVH
 OUTSIDE VACUUM HDW = OSVH
 ALL DATES SHOWN REFLECT FRIDAYS

PROGRAM STATUS

3RD QUARTER - FY 1990

TASK: INTERNATIONAL COOPERATION

FY90 FUNDING: \$ 1007 K

B/R NO: AT101014Z

FY90 PLAN: \$ 1007 K

CONTRACT NO: DE-AC03-89ER51114

GA PRINCIPAL INVESTIGATOR: T. SIMONEN/J. LUXON/R. FISHER

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: E. OKTAY

TORE SUPRA

Additional experiments on the enhanced particle confinement previously observed with resonant helical perturbations applied to plasmas limited on the inner graphite wall were successful. Surprisingly a larger improvement in confinement was observed at higher toroidal magnetic field. At 3.1 Telsa, we observed a 25% increase in electron density with approximately 25% decrease in particle recycling light. Further analysis and experiments are planned. During these runs, we set a new record for Tore Supra plasma shot duration, 14.2 seconds.

ASDEX

In April, Al Hyatt and Dan Thomas completed a successful trip to ASDEX. They were successful at demonstrating a 3-4 mA neutral lithium beam of 20-25 mm diameter over the entire 2 m length of the beamline. This represents an improvement of a factor of 5 over the old ASDEX source. The new high current source is being installed on ASDEX and Dan Thomas is at Garching during July for the data runs.

Bob Harvey is also at ASDEX for the LHCD experiments.

JFT-2M

Tony Leonard and Al Hyatt have been at JFT-2M since May. Preliminary results from the initial biased divertor experiments are very interesting. Using commonly biased inner and outer divertor plates, and using co-injection neutral beam heating to reach H-mode, we found that the application of negative bias to the plates lower the H-mode threshold from about 270-300 kW down to under 130 kW.

We will report on results on the effect of error fields on H-mode at a CIT workshop on error field effects at PPPL on July 19-20.

JET

Jim DeBoo and Dave Schissel continued work on the international H-mode database. DeBoo has responsibility for performing the regression fits for the empirical scaling. A first look at the data identified some collinearities and inter-machine conflicts. Tony Taylor concluded his stay at JET and was replaced by Gary Jackson. Taylor was involved in the re-analysis of JET equilibrium data which showed that their carbon blooms were probably caused by the separatrix x-point being behind the divertor tiles. A letter was received from Dr. Rebut agreeing to terms of an advanced divertor collaboration.

INTERNATIONAL COOPERATION — FY90 —

PROJECT 3467

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
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TORE SUPRA
(3467.100)

ASDEX
(3467.300)

JET
(3467.400)

CHS
(3467.700)

PERANICH
ERROR FIELDS/
TRANSPORT

JFT-2M
(3467.800)

Legend

WORK AT GA

WORK AT INT'L SITE

INTERNATIONAL COOPERATION

	FY90 BUDGET		FY90 ACTUALS		Current Plan
	FTE's	TOTAL \$000	FTE's	TOTAL \$000	
TORE SUPRA	1.1	202	1.1	167	211
ASDEX	1.4	263	1.8	268	297
JET	1.2	235	1.2	222	278
CHS	0.1	18	0.0	4	11
JFT-2M	1.5	289	1.3	164	210
Total	5.3	1,007	5.4	825	1007

Contract Management Summary Report

TITLE:	INTERNATIONAL COOPERATION	B/R NO: AT101014Z	CONTRACT NO.:	DE-AC03-89ER51114
CONTRACTOR:	GENERAL ATOMICS P.O. BOX 85608 SAN DIEGO, CA. 92138	COST & LABOR PLAN DATE: APRIL 19, 1990	START DATE:	SEPTEMBER 30, 1989
			COMPLETION DATE:	SEPTEMBER 28, 1990

PLANNED	\$77	\$34	\$68	\$120	\$107	\$139	\$69	\$97	\$94	\$84	\$58	\$60	TOTAL	\$1,007
ACTUAL	\$123	\$103	\$139	\$52	\$65	\$136	\$76	\$55	\$76					\$825
VARIANCE	(\$46)	(\$69)	(\$71)	\$68	\$42	\$3	(\$7)	\$42	\$18					
CUM VAR	(\$46)	(\$115)	(\$186)	(\$118)	(\$76)	(\$73)	(\$80)	(\$38)	(\$20)					(IN THOUSANDS)

PLANNED	4.6	2.7	5.2	6.9	7.1	7.2	4.7	5.9	5.3	6.0	3.7	4.3	TOTAL	63.6
ACTUAL	6.9	6.7	6.5	4.1	4.7	6.4	4.2	3.9	5.2					48.6
VARIANCE	-2.3	-4.0	-1.3	2.8	2.4	0.8	0.5	2.0	0.1					
CUM VAR	-2.3	-6.3	-7.6	-4.8	-2.4	-1.6	-1.1	0.9	1.0					

SIGNATURE OF PARTICIPANT'S PROJECT MANAGER & DATE: _____

PROGRAM STATUS
3RD QUARTER – FY 1990

TASK: CIT PHYSICS

FY90 FUNDING: 200 K*

B/R NO: AT101018B

FY90 PLAN: 200 K

CONTRACT NO: DE-AC03-89ER51114

GA PRINCIPAL INVESTIGATOR: R. STAMBAUGH/ J. LUXON

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: T. JAMES

MILESTONE	LEVEL	APPROVED DATE	TARGET DATE	COMPLETION DATE
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Funding for work on CIT physics was received this quarter. Several physics R&D planning tasks were initiated. These tasks included maximum elongation versus aspect ratio, vertical disruptions, error fields, confinement scaling, H-mode, and ECH launchers.

REMARKS:

* \$200 K funding received 3rd Quarter FY90.

Contract Management Summary Report

TITLE:	CIT PHYSICS	B/R NO: AT101018C	CONTRACT NO.:	DE-AC03-89ER51114
CONTRACTOR:	GENERAL ATOMICS	COST & LABOR PLAN DATE:	START DATE:	SEPTEMBER 30, 1989
	P.O. BOX 85608	JUNE 29, 1990	COMPLETION DATE:	SEPTEMBER 28, 1990
	SAN DIEGO, CA. 92138

SIGNATURE OF PARTICIPANT'S PROJECT MANAGER & DATE: _____

PROGRAM STATUS
3RD QUARTER – FY 1990

TASK: DIGNITOR STUDIES

FY90 FUNDING: \$ 25K

B/R NO: AT101018B

FY90 PLAN: \$ 25K

CONTRACT NO: DE-AC03-89ER51114

GA PRINCIPAL INVESTIGATOR: J. HELTON/F. PUHN

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: C. BOLTON

MILESTONE	LEVEL	APPROVED DATE	TARGET DATE	COMPLETION DATE
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DIGNITOR STUDIES

See attached.

REMARKS:

DIGNITOR

Plasma Equilibrium and Stability Analysis

Ideal MHD equilibrium studies are being done in support of the proposed ignition tokamak DIGNITOR. These studies are being done in order to design an optimal poloidal field coil shaping (PFC) system for DIGNITOR.

Earlier in FY90, a PFC system was found for DIGNITOR which met the plasma objectives of DIGNITOR and had the properties necessary for the design of an acceptable feedback control system.

More detailed analysis has been done in the third quarter to optimize the design of the PFC system for DIGNITOR. In particular, the PFC properties which make possible the design of an acceptable feedback control system have been studied in detail. These properties were previously studied for the DIII-D PFC system and their direct connection to obtaining and maintaining DIII-D plasmas was established. Using this earlier DIII-D work and the detailed study of the DIGNITOR PFC system properties, further refinements have been made to the DIGNITOR PFC system. The results, so far have been very positive and lead us to believe that the PFC system for DIGNITOR is close to the optimal ignition tokamak PFC. Of course, the optimal PFC system for an ignition tokamak cannot be as versatile as that of DIII-D due to the necessary PFC system constraints imposed on an ignition tokamak.

This work has yet to be done for plasmas with complex plasma cross-section and/or complex current profiles. However, from the results obtained so far it is predicted that these future results will also be very positive.

Contract Management Summary Report

TITLE: DIGNITOR DESIGN STUDIES B&R NO. AT101018B

CONTRACT NO.: DE-AC03-89ER51114

CONTRACTOR: GENERAL ATOMICS
P.O. BOX 85608
SAN DIEGO, CA. 92138

COST & LABOR PLAN DATE:
APRIL 19, 1990

START DATE: SEPTEMBER 30, 1989
COMPLETION DATE: SEPTEMBER 28, 1990

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
PLANNED	\$0	\$0	\$0	\$2	\$4	\$5	\$4	\$3	\$7	\$0	\$0	\$0	\$25
ACTUAL	\$0	\$0	\$0	\$0	\$3	\$5	\$1	\$0	\$2				\$11
VARIANCE	\$0	\$0	\$0	\$2	\$1	\$0	\$3	\$3	\$5				
CUM VAR	\$0	\$0	\$0	\$2	\$3	\$3	\$6	\$9	\$14				(IN THOUSANDS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
PLANNED	0.0	0.0	0.0	0.1	0.2	0.3	0.2	0.2	0.3	0.0	0.0	0.0	1.3
ACTUAL	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.1				0.6
VARIANCE	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.2	0.2				
CUM VAR	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.5	0.7				

SIGNATURE OF PARTICIPANT'S PROJECT MANAGER & DATE: _____

DIII-D RESEARCH PROGRAM STATUS, ISSUES, AND PRIORITIES

April 12, 1990

DIII-D RESEARCH PROGRAM STATUS, ISSUES, AND PRIORITIES

I. INTRODUCTION

The DIII-D program integrates across the OFE CS, APP and D&T divisions, across many laboratories and universities (national and international), and integrates the physics of transport in high beta H-mode plasmas with the divertor geometry and heating systems of next generation devices such as CIT and ITER. We are attempting to bring the best skills and knowledge to the DIII-D program through a combination of General Atomics staff and collaborations to make the most rapid and cost-effective progress possible.

DIII-D progress in the past year has been remarkable, see Tables I and II. Beta's have exceeded CIT and ITER needs and temperatures and confinement products are within a step of the largest tokamaks. New transport diagnostics are beginning operation for in depth high beta H-mode transport investigations. H-mode discharges have been sustained for 10 seconds with ohmic current drive. H-mode collaborations have been increased. The next step is to extend our high beta transport research to plasmas with non-inductive current drive and pressure profile control. Details of this program are described in the DIII-D FY92 Field Task Proposal and in the DIII-D Long Range Experimental Plan. This plan is outlined in Fig. 1. Here we highlight recent program progress, indicate program issues, and priorities for increased and reduced funding levels.

General Issues and Priorities

The DIII-D 5-year program plan was reviewed in August 1987. We have followed the recommendations of the panel (see Table III) modified according to the national program emphasis on: Transport, CIT and ITER. The DIII-D program leads to CIT, ITER and STE (a Steady State tokamak experiment being proposed by LLNL and GA). Since DIII-D is a leading contributor to the national program, it is appropriate to have a mid-term senior review of the DIII-D program priorities as soon as the FPAC review is completed this summer.

Fig. 1. Integrated Long Range DIII-D Program Plan.

Table I
Highlights of DIII-D's Past Years Accomplishments

-
- Completed radiation shield roof and wall extensions
 - allows deuterium neutral beam operation with improved confinement.
 - increased plasma stored energy from 1.3 to 3.6 MJ (using carbonization).
 - Doubled energy confinement time to 0.34 seconds.
 - increased fusion ignition parameter $n\tau T$ to $10^{20} \text{ m}^{-3} \cdot \text{s} \cdot \text{keV}$.
 - increased H-mode duration to 10 seconds with no impurity accumulation.
 - Tripled ion temperature of H-mode plasmas to 17 keV.
 - reaching levels required for ignition.
 - providing a regime with $T_i \gg T_e$ for transport studies.
 - Increased electron temperature to 5 keV.
 - generating 1.7 MW, highest power ECH microwave heating in U.S.
 - attained parameters of target plasma for FWCD experiments.
 - Increased plasma beta to 9.3% (from 6.8%).
 - well beyond that needed for CIT or ITER.
 - 5% beta at full field (2.1 T).
 - high poloidal beta, $\beta_p = 5.1$ ($\epsilon\beta_p = 1.8$ at $\beta_N = 3.7$).
 - Verified that the Troyon beta limit describes the limiting value of beta that can be routinely achieved over a wide range of plasma parameters.
 - understanding the physics governing the limit has allowed extension of the Troyon limit by 40% to $\beta_N = 5$.
 - Obtained first measurement of edge electric field and plasma fluctuations.
 - will lead to increased understanding of transport in H-mode plasmas.
 - Developed a comprehensive understanding of vessel force mechanisms resulting from a disruption.
 - accounts for high vertical forces.
 - Increased neutral beam injection power to 20 MW.
 - more than 35% above original design level.
 - Increased plasma current with divertor to 3 MA.
 - 20% above design limit.
 - Double null Divertor demonstrated.
 - heat loads can be balanced.
 - confinement similar to single null.
 - Carried out 1 MW ion Bernstein wave ICH experiments.
 - coupling limited to edge without central heating.
 - Launched DIII-D/JET size scaling experiment.
 - important for understanding H-mode confinement and ITER data base.
 - Initiated the advanced divertor program to further develop the divertor for high confinement and impurity and particle control.
 - Collaborative program uses DOE resources at LLNL, ORNL, SNL, and UCLA.
 - Obtained critical engineering R&D data for CIT and ITER.
 - includes transport, startup, divertor and disruption data.
 - increased maximum elongation to 2.5 and extended understanding of vertical stability control.
 - Accelerated confinement research in response to transport initiative.
 - includes new diagnostics, particle and energy control tools and additional experimental operations.
-

Table II
Maximum DIII-D Parameters Achieved to Date 3-19-20, Not Simultaneous

R	Nominal	1.67 m
a	Nominal	0.67 m
κ	Maximum	2.5
B_T	Range	0.5-2.2 T
I	Divertor and limiter	3.0 MA
q_{95}	Lowest	1.75
I/aB	Maximum	3.3
$\beta_T(0)$		16%
$\langle\beta_T\rangle$		9.3%
β_p		5.1
$\epsilon\beta_p$		1.8
$\bar{n}_e$		$1.4 \times 10^{20} \text{ m}^{-3}$
$T_e(0)$		5 keV
$T_i(0)$		17 keV
W		3.6 MJ
τ_E	$P_{\text{HEAT}} = 2.8 \text{ MW}$	0.34 seconds
$n_e\tau_E$		$0.39 \times 10^{20} \text{ m}^{-3} \text{ seconds}$
$n_eT_i\tau_E$		$1 \times 10^{20} \text{ m}^{-3} \text{ keV seconds}$
H-mode duration		10.3 seconds
Z_{eff}	Lowest	1.3
P_{NBI}		20 MW
P_{ECH}		1.7 MW
P_{ICH}		1.0 MW

Table III
Panel Recommendations on DIII-D 5-Year Fusion Research Program Plan
Sheffield, Parker, Rutherford, and Weitzner
August 6 - 7, 1987
✓ = accomplished or underway

Pursue Vigorously

- ✓ • 6 MW 120 GHz (FY89-93)
- ✓ • 2 MW ICH (FY90)
- ✓ • Improved Vessel Armor (FY88)
- Upgrade Diagnostics
- ✓ — mode identification (UCLA FY89-90)
- ✓ — multipulse Thomson Scattering (FY89-90)
- ✓ — edge plasma beam probes (APP FY90-91)
- ✓ — fusion products measurements (Irvine FY89-90)

Pursue

- ✓ • Neutron Shielding (FY88-89)
- Pellet Injection (FY92)
- ✓ • Divertor Biasing (FY90-91)

Delay until optimum strategy clarifies based on results

- Increase ECH from 6 to 10 MW
- Increase ICH from 2 to 9 MW
- Increase pulse capability to 10 sec
- Add ergodic limiter (until positive results from other devices)

II. HIGH BETA CONFINEMENT

With the achievement of 9.3% beta, the DIII-D high-beta program emphasis has shifted to transport studies at high beta, extending the first stability regime beyond the Troyon limit, (see Fig. 2) and entering the second stability regime. DIII-D has now operated at 5% beta at its full magnetic field ($B = 2.1\text{T}$). Hot-ion H-mode transport studies have been carried out at normalized beta up to 3.0, equal to those projected for CIT and ITER, with a maximum ion temperature of $T_i = 17\text{ keV}$.

Experiments on plasma shaping and profile control are underway. Plasmas with elongation up to $\kappa = 2.5$ have been produced as have plasmas with normalized betas up to $\beta/(I/aB) = 5.0$ (see Fig. 3). These high normalized betas are obtained by creating broad pressure profile and narrow current profiles consistent with theory. These results point the direction to enhance first stability regime tokamak performance.

Poloidal betas as high as $\beta_p = 5.2$ ($\epsilon\beta_p = 1.8$) have also been produced in neutral beam current drive discharges. These plasmas are calculated to be entering the second stability regime. These high normalized beta and high poloidal beta results demonstrate that tokamak operating regimes can be successfully extended with current and pressure profile control and form the basis for our high priority on pursuing an rf current drive program.

Issues and Priorities

Reliable avoidance of high beta disruption or collapse, axisymmetric stability at high elongation, and the influence of current and pressure profiles on these, continue to be identified as important issues for ITER and CIT. The DIII-D tokamak is the best facility to extend high beta and high elongation research. However, increasing priorities in support of TTF and other CIT and ITER topics, limits the amount of experimental operating time devoted to this research.

Fig. 2. β_T vs I/aB for DIII-D neutral beam heated discharges. The increased current capacity of the double null divertor (DND) over the single null divertor (SND) is shown.

Fig. 3. Calculated stability boundaries in β_N and l_i for a DIII-D single-null divertor configuration with $q_{95} = 3.2$ and a conducting wall at $r = 1.5 a$. Inset shows the three pressure profiles used.

III. TRANSPORT STUDIES

DIII-D H-mode studies have been extended to 17 keV ion temperatures with new profile and fluctuation diagnostics. These capabilities are now being exploited and will be further extended in FY91 and FY92. Our research include steady state and ECH modulated transport coefficient measurements.

H-mode transition physics is under intense study with our new electric field measurements (from CER rotation data) and localized fluctuation measurements (UCLA-reflectometry). Coordinated H-mode scaling experiments have been carried out on DIII-D and JET. Results are shown in Fig. 4. The DIII-D/JET collaboration has been extended into the ITER H-mode data base. We propose similar coordinated experiments with JT-60U in FY92. A series of size and/or magnetic field scaling experiments with controlled dimensionless parameters have been planned to provide a physics-based scaling for projecting CIT performance. Recent DIII-D experiments have also demonstrated that divertor plasmas with aspect ratio up to 5.3 can be produced for aspect ratio studies, as shown in Fig. 5. Future work will include evaluating the role of magnetic field irregularities.

Issues and Priorities

Fully diagnosed and analyzed transport experiments are extremely manpower-intensive. Visitors are helpful. However a strong DIII-D base program is essential. Our major transport diagnostic upgrade will be completed in FY90, however several important diagnostics remain to be added in FY91 (see Transport Diagnostics). When high power ECH is available we will be able to optimize confinement with current and pressure profile control. Transport studies would benefit from additional onsite manpower.

Fig. 4. Results of coordinated DIII-D/JET H-mode scaling experiments.

Fig. 5. Demonstration of DIII-D capability to vary aspect ratio with divertor configuration.

IV. DIVERTOR/EDGE PHYSICS

The DIII-D divertor design is similar to that proposed for CIT and ITER. The availability of 20 MW of neutral beam power for 5 seconds allows DIII-D to simulate CIT divertor loading conditions (10 MW/m^2 average and 50 MW/m^2 during ELMs). Already erosion is observed in the divertor tiles. H-modes of 10 second duration have been produced at 0.7 MA (see Fig. 6). To operate 10 second plasmas at higher current will require additional power supplies. New diagnostics (divertor and edge plasma parameters as well as edge currents) together with modeling are being developed as part of the collaborative advanced divertor program (ADP). First results of edge current flow (shown in Fig. 7) are as predicted by Staebler and Hinton.

The advanced divertor ring will be installed in July 1990 and neutral pressure measurements will be made in the fall to determine the feasibility of cryogenic pumping of recycling neutrals to control the density of H-mode discharges. The H-mode density is presently proportional to plasma current, so confinement experiments cannot differentiate between current or density scaling. Density control will also allow us to carry out higher temperature transport experiments as well as to improve the efficiency of current drive experiments.

Issues and Priorities

Funding for the ADP cryopump needs to be identified. The cryopump construction is delayed until FY92 but is desired to advance to FY91 with incremental funding by applying JET funding to the cryopump construction. The JET project would like to see a FY91 test on DIII-D as a prototype to the JET divertor upgrade.

Fig. 6. World's longest duration H-mode plasma (10.3 sec) Steady state density, energy confinement time, and impurity concentrations are achieved.

Fig. 7. Measurements of divertor edge current magnitude and polarity as predicted by Staebler-Hinton theory.

V. ECH HEATING AND CURRENT DRIVE

ECH current drive was demonstrated at the level of 100 kA this year. This result is consistent with theoretical predictions and is the largest ever demonstrated (see Fig. 8). Based on theory we expect a rapid increase in the driven current with higher ECH power (due to higher electron temperature and nonlinear enhancements). Recent DIII-D experiments have produced H-modes in the CIT configuration and have achieved the ITER startup objectives (see lower Fig. 9). Modulated ECH transport experiments are planned in FY90. In FY91 experiments with 60 GHz ECH and ICH fast wave current drive will be carried out with the ORNL ICH antenna which is being installed this summer.

In late FY90 a 0.5 MW 110 GHz gyrotron will begin operation. The 2 MW system will be operational in late FY92. The total ECH system power will then be 3.6 MW to allow extensive ECH transport as well as pressure and current profile control and modification experiments to be carried out. Fully sustained ECH current drive operation should also be possible.

Issues and Priorities

Strong support is needed for completion of the 110 GHz system in FY91. Critical items include: mode converter, gyrotron magnet, gyrotron, and waveguide construction. Funding for this project, as well as for power and water systems for the JAERI 5 MW system, are included in the base budget. Incremental funding would allow more ECH operation and acceleration of the JAERI support systems. If budgets are reduced we would reduce 60 GHz operations and complete the 110 GHz construction since it will provide us with new capabilities which are critical to the future tokamak beta and confinement optimization program.

Fig. 8. ECH current drive demonstration. In the upper figure the ECCD is in the same direction as ohmic current so the loop voltage is lower than predicted by only ECH heating. In the lower figure the ECCD opposes the ohmic current so the measured loop voltage is higher.

Fig. 9. An important consideration for future devices is the effect of error fields on discharge initiation. In DIII-D, startup is possible with $B_v \sim 60$ G by using ECH assist.

VI. ICH PROGRAM

The ICH program will switch antennas from IBW to fast wave current drive (FWCD) this summer. So far, our IBW heating results have been consistent with those from smaller tokamaks. The antenna loading behavior is not explained by existing linear coupling theories, suggesting that direct coupling to the IBW may not be occurring. Particle confinement improvement during IBW has been observed on DIII-D just as in previous experiments, and there are indications of some direct ion heating and/or improvement in ion confinement. However, the increases in T_i observed to date on DIII-D have been relatively small compared with those from the previous experiments. These results may indicate that confinement improvement, rather than direct ion heating may be the dominant effect of IBW injection. In this case, the limiting condition for the ion temperature is $T_i \leq T_e$ since the power to heat the ions must flow from the electrons. In previous experiments on small tokamaks, $T_i \ll T_e$ in the target plasmas, so that large increases in T_i due to IBW confinement improvement were possible. In DIII-D the initial difference between T_e and T_i is much smaller due to the better confinement of the larger device. Hence, only small ion temperature increases are possible due to confinement improvement alone. The DIII-D results quantify the difficulty of coupling to the IBW with toroidal loop antenna structures; this problem is the main obstacle to the application of Bernstein wave ion heating in large tokamak devices.

This summer we will install a 4-element ICH antenna which was built at ORNL. The four elements can be phased to launch a unidirectional fast wave to drive current. DIII-D is an ideal test bed for FWCD because of its high beta and ECH capability, (both enhance the FWCD efficiency). The antenna will be checked out in the end of FY90 and experiments will be performed in FY91. The current drive program is shown below.

Although the objective of our ICH program is FWCD, the antenna can be viewed as a pair of double strap antennas. The double strap antenna is the configuration proposed for CIT. DIII-D is thus uniquely equipped to examine fast wave ICH heating questions for CIT in the divertor H-mode configuration.

Issues and Priorities

If additional operating funds are available we would increase ICH operations and add an ICH diagnostic. Since the ICH operating costs are modest and the FWCD antenna is a new capability we would continue FWCD even if the budget is reduced 10% because of its high leverage in the tokamak program.

If the FWCD results are positive and we can couple 2 MW into one half of the antenna we propose adding a second FMIT unit to raise the power level to 4 MW [FY91(I)]. The base FY92 budget would allow this FMIT to be completed, (or started), or to improve the antenna.

Assuming the 4 MW FWCD results are encouraging, we propose in FY92(I) to increase the power to 8 MW. This would either be a 60 or 200 MHz system depending on experimental results (on DIII-D and elsewhere), theoretical analysis and available technology.

Fig. 10. DIII-D Current Drive Plan

VII. TRANSPORT DIAGNOSTICS

The DIII-D diagnostic capability is comprehensive and similar to that of TFTR (Table IV) although the costs are lower (Table V). New diagnostics are being added in FY90.

The charge exchange recombination diagnostic is now operational with 16 new edge channels to provide high resolution ion temperature and rotation profiles from which the radial electric field, and its shear, can be deduced and compared with H-mode transition theories. Results from the old system are shown in Fig. 11. The UCLA reflectometer and scattering diagnostics are providing new and improved fluctuation measurements. The long wavelength MIT phase contrast imaging diagnostic is installed and is being commissioned. The multi-pulse multi-laser Thomson scattering system is ready for plasma checkout. These new diagnostics will all be operational in FY91.

Issues and Priorities

Although diagnostic fabrication will be reduced in FY91 because of budget limitations, several key instruments are needed. Current profile measurements are a critical need for high beta and confinement studies as well as noninductive current drive experiments. Recently a single channel LLNL polarimeter began operation with 2 cm spatial and 10 ms temporal resolution (see Fig. 12). We plan to expand this system to six channels in FY91. Our standard bolometer system needs improvement since it cannot respond during H-mode plasmas with ELMs. Since H-mode is the anticipated operating mode of CIT and ITER it is crucial to improve this transport diagnostic. The APP division of OFE is funding a lithium beam fluctuation diagnostic; DIII-D funding is needed to install that diagnostic. We plan to add a multichannel superheterodyne ECE diagnostic with 2 cm spatial resolution for temperature gradient measurements (a LLNL postdoc already is onsite for this task).

Fig. 11. Differences in rotation between two emission lines ('warm' and 'cold' lines) at plasma edge show that the radial gradients of v_θ and E_r are large. With the two lines being emitted from regions separated by about 2 cm, (a) shows that dv_θ/dr is about $0.5 \times 10^6 \text{ s}^{-1}$ in L-mode and about $1.5 \times 10^6 \text{ s}^{-1}$ in H-mode and (b) shows that dE_r/dr is about 750 kV/m^2 in L-mode and 2000 kV/m^2 in H-mode. D_α waveform is shown in (c), with time of L-H transition indicated by dashed line.

Fig. 12. Preliminary data from motional Stark effect polarimeter. The measured tilt angle (gamma) tracks the plasma current and shows changes with sawteeth.

Table IV
Comparison of TFTR and DIII-D Diagnostic Capabilities
(From September 1989 Cost Review Report)

Quality	TFTR		DIII-D	
	Inst.	Chan.	Inst.	Chan.
Ion Temp	5	64	3	26
Electron Temp	6	103	4	61
Electron Density	4	89	4	54
Energetic Ions	6	42	3	5
Impurity Concentration	6	44	3	18
Radiated Power	3	62	1	21
Fusion Products	8	41	3	26
Magnetic Properties	5	102	4	131
Shape & Position Control	4	92	3	169
Plasma Edge/Wall	5	14	4	53
Divertor Diagnostics	0	0	6	11
Fluctuations/Wave	7	165	9	221
<u>Plasma Current</u>				
Safety Footer Profiles	1	10	1	1
Miscellaneous	6	15	6	15
TOTAL	66	843	55	812
<u>Mbytes Physics Data Shot</u>		30		27

Table V
Comparison of TFTR and DIII-D Diagnostic Costs
(From September 1989 Cost Review Report)

	TFTR			DIII-D		
	Base Operation	Diagnostics Operation	Data Handling	Base Operation	Diagnostics Operation	Data Handling
FY89 Costs K\$	23,343	8,268	2,327	13,361	2,688	2,909
Physics FTE	27.3	24.1	-	27.9	9.7	0.5
Eng. FTE	37.2	11.2	7.5	10.8	1.0	0.2
Other FTE	<u>192.8</u>	<u>68.0</u>	<u>15.3</u>	<u>70.1</u>	<u>14.3</u>	<u>20.1</u>
TOTAL FTE	257.3	103.3	22.8	108.3	25.0	20.9

VIII. TOKAMAK OPERATIONS

The completion of neutron shielding allowed full deuterium plasma operations. The neutral beam power with deuterium reached 20 MW (exceeding the 14 MW design) and the plasma current in a double null divertor configuration reached 3 MA (exceeding the 2.5 MA design). Carbonization was employed to reduce radiation loss of high current discharges so that transport studies could be extended to 3 MA.

Following the FY89 DIII-D 3 M\$ reprogramming, we stepped up work on new transport diagnostics and tools and increased operations. In October 1989 the staff level reached 200 FTE in anticipation of the advised 35 M\$ FY90 program level. The 31.8 M\$ budget, with inflation and the increased costs resulted in an abrupt reduction in staff to 155 FTE (145 FTE late in the year). As shown (Fig. 13), these manpower levels are below previous years. Nevertheless, as Fig. 14 shows, we are increasing diagnostic instruments, data output and heating systems capabilities. The increased emphasis on transport places severe demands on physics manpower due to the sophistication of the diagnostics and analysis of the experiments.

Issues and Priorities

Tokamak operations in FY90 will be constrained to 14 weeks by the 31.8 M\$ budget. The FY90 DIII-D experiments are listed in Table VI. The 14 weeks of operation will be completed by June after which transport diagnostics, advanced divertor, FWCD ICH antenna, and one channel of 110 GHz ECH will be installed while IAEA papers are written. Limited checkout of this equipment will occur in August and September. The severe restrictions on material purchases and spare parts will place mortgages on FY91 and FY92 operations costs. We are concerned that replacement parts will not be adequate to support the projected operating levels. No contingency is included for unexpected equipment failures. The budget assumes that the government will prevail in the possessory interest lawsuit against San Diego County, so no funding for taxes is included.

FY91 operations will increase to 16 weeks. With the added diagnostics, the data output will exceed the FY89 output. Computer upgrades (included in incremental funding requests) would allow us to analyze more data. Additional manpower and budget would allow more operation to be included (250 K\$/week). If funding is reduced by 10% we would mothball one neutral beam line to reduce operating costs and to provide spare parts. In addition physics operations would be reduced by 8 weeks. After completing the transport initiative upgrade fabrication work in FY92, the base operations will increase to 20 weeks.

Upgrades to the power systems could be very cost effective, but are not included in the base budget. The 3 MA discharges were obtained with full power supply capability with no margin nor flexibility in plasma shape. Additional power supplies (500K\$) would allow us to utilize 3 MA discharges in the research program as well as to separately power divertor ring bias and the locked mode perturbation coil. These upgrades are proposed in FY91 and FY92 incremental funding. Two other power upgrades are candidates for FY93 funding. The neutral beam power could be increased from 20 to 30 MW by upgrading 7 transformers (at 100 K\$ each). Simultaneous full operation of neutral beams and rf systems could occur with a new substation (950 K\$).

Fig. 13. DIII-D manpower reduction from FY89 to FY90.

Systems Capabilities

Fig. 14. Comparison of DIII-D capability and output with resources.

Table VI. DIII-D EXPERIMENTS - FY90

Topic	Time (days)
1. Operating Regime Extension	9
1.1. 10 second pulse length	
1.2. Carbonization	
1.3. 3 MA plasma	
1.4. Startup by I and B ramping	
2. Current Drive	4
2.1. ECCD	
2.2. NBCD	
3. Stability Studies	15
3.1. Ideal kink and ballooning limits	
3.2. High β_p and high β_N (second stability)	
3.3. Stability limits and profile control	
3.4. κ and δ dependence of stability limits	
3.5. β limit scaling vs. I/aB	
3.6. Locked modes	
4. RF	9
4.1. Nonthermal electrons with ECH	
4.2. IBW and ion confinement	
4.3. Phase contrast imaging	
4.4. ECH assisted initiation	
4.5. High T_e	
5. Transport Physics	8
5.1. Momentum transport	
5.2. Field errors and confinement	
5.3. Confinement at low q	
5.4. Confinement at high κ	
5.5. Parallel transport	
6. Edge and Boundary	7
6.1. Divertor studies	
6.2. ELMs, gas, and impurities	
6.3. Density limit	
7. H-mode Studies	18
7.1. ELMs	
7.2. L-H transition	
7.3. Confinement in hot ion H-mode	
7.4. ECH H-mode	
7.5. Self-similar scaling	
7.6. Limiter H-mode	
7.7. Modulated ECH	
7.8. Fluctuations	
Totals	70

IX. THEORY AND MODELING

The DIII-D program is strongly coupled to APP supported theory and modeling activities. The predictive understanding developed in this way significantly advances our ability to design an economical fusion reactor. Three areas of our focus are:

1. MAGNETOHYDRODYNAMIC (MHD) EQUILIBRIUM AND STABILITY

Detailed simulations of resistive and ideal MHD behavior for DIII-D plasmas close to β limit are being compared with experimental measurements. The prominent MHD phenomena observed include mode cascade at high β and low q , confinement deterioration at high β_N , edge localized modes (ELMs), and the sawtooth oscillation. We hope to understand the development of MHD turbulence as the β limit is approached and to describe the deterioration in confinement.

Modeling codes for MHD studies include GATO for ideal MHD, CART for resistive MHD and BALLOON/CAMINO for ballooning modes. An example of MHD modeling is shown in Fig. 3.

2. PLASMA TRANSPORT

There are at least four long standing theoretical issues in modeling DIII-D transport: why does confinement time scale favorably with $I \propto B/q$ rather than B as suggested by most electrostatic turbulence? What accounts for the central plasma pinch? Why does confinement improve with atomic mass? What is the trigger for the L-H transition? Following the thesis that the current scaling is due to edge processes, theory is collaborating with experiment to study the effect of a controllable additional error field on confinement. Additional physics will be required to explain the plasma pinch and mass dependence. Our neoclassical H-mode boundary physics study has been successful in quantifying a number of experimental observations and forms the theoretical basis for the Advanced Divertor Program. We have also initiated new studies to improve the physical basis for scaling tokamak discharges to ignition. DIII-D tokamak discharges have the same collisionality and beta as ignited tokamaks. Thus, we need only understand the scaling with respect to relative gyro-radius keeping the other dimensionless parameters similar. It appears that diffusion processes scale as gyro Bohm or Bohm. If we can experimentally determine which dominates, the size and field scaling to ignition may be determined.

Transport modeling is carried out with ONETWO for analysis and prediction, the Waltz 3D simulation code and the Waltz/Dominguez steady state 1D code.

3. CURRENT DRIVE

The DIII-D current drive program focuses on ECH, ICH, and NBI. Detailed comparison of ECH current drive on DIII-D with theory is being carried out with special focus on the role of fast electron transport. In ICH, we are improving our understanding of antenna coupling to H-mode plasmas and refining electron absorption profile for evaluating fast wave current drive efficiency. Modeling of fast ion losses during NBI on DIII-D will be pursued, assuming the fast ion loss is driven by the Alfvén instability. These theoretical studies are important steps towards a long term goal of demonstrating steady-state current drive in high β plasmas.

Modeling of rf heating and current drive is carried out with the TORAY code coupled to ONETWO, as well as with the CQLD3 rf Fokker Planck code, and General Atomics' ICH codes for FWCD prediction and antenna design.

X. TOKAMAK TECHNOLOGY

The DIII-D confinement program is serving as a center for a number of OFE Development and Technology-related activities. This work is being carried out by General Atomics as well as by numerous collaborators from the U.S. and international fusion community. The proximity of CS and D&T research activities at GA is mutually beneficial. The research focuses on rf technology, divertor materials, disruption studies, and tokamak design studies.

1. RF AND MICROWAVE TECHNOLOGY

The DIII-D ECH system is the most advanced and highest power ECH system outside of the Soviet Union. General Atomics has been developing needed waveguide components for developed gyrotrons being developed by the D&T branch.

The DIII-D ICH program is collaborating with the ORNL rf technology group. Antennas developed by D&T benefit DIII-D and subsequent tokamak operation experience benefits CIT ICH antenna designers. Carried out in parallel at GA and benefiting from the DIII-D program are D&T-supported advanced ICH development tasks (tetrode development and tuning systems).

2. DIVERTOR MATERIALS AND DISRUPTION STUDIES

The DIII-D advanced divertor program couples to several divertor and materials oriented programs at ANL, LLNL, ORNL, Sandia and UCLA. International collaborations include Textor and JET. Since DIII-D has configuration, power loading and pulse length comparable to CIT it is a natural test bed for CIT. The extensive divertor diagnostics and divertor modeling will provide much of the needed information for ITER. *In situ* divertor erosion studies will be enhanced with the Divertor Materials Exposure System (DIMES) being developed by D&T for installation on DIII-D for real-time divertor material evaluation in the presence of actual tokamak phenomena such as ELMS and disruptions.

Disruptions are a major concern for next generation tokamaks. The extensive diagnostics and electromagnetic capabilities at GA make DIII-D an ideal center for these disruption studies. DIII-D is being relied on as a major source of information on disruptions for models used on ITER. Preliminary results are shown in Fig. 15.

3. CIT, ITER, AND ARIES DESIGN STUDIES

DIII-D personnel play key leadership roles in ITER and CIT physics design work. This involvement brings their tokamak experience to the designs and enhances their awareness of the machine designers needs.

General Atomics' scientists also provide leadership and technical contributions to the ARIES tokamak design study, with emphasis on innovative current drive and impurity control techniques. DIII-D physics personnel integrate the latest DIII-D results into ARIES and the ARIES study stimulates visionary experiments on DIII-D, including aspect ratio experiments, and advanced current drive and second stability studies.

Fig. 15. DIII-D measurements and electromagnetic modeling indicate that substantial vessel forces are produced by currents from plasma through wall following disruptions. The measured currents produce the observed forces and a predictive model has been developed.

XI. PROGRAM COSTS, RESEARCH ELEMENTS, AND PRIORITIES

In this section we summarize DIII-D program costs, research elements and priorities for increased and decreased funding. A more detailed description and discussion is given in the DIII-D FY92 Field Task Proposal.

The following tables show:

- A. Program costs
- B. Elements in the base DIII-D program
- C. Incremental requests
- D. Elements of DIII-D program with incremental funding
- E. Priorities for FY91 incremental funding
- F. Priorities for FY92 incremental funding
- G. Priorities if funding is reduced by 10% in FY91 and FY92.

Table A. OFE GUIDANCE FOR DIII-D PROGRAM

	FY89	FY90	FY91	FY92	FY93
Research Operations (M\$)	24.7	23.4	25.7	28.4	
Research Operations (FTE)	151	122	129	135	
Upgrade Fabrication (subtotal M\$)	(7.6)	(8.4)	(5.5)	(4.3)	
Diagnostics	2.6	3.2	1.2	1	
Particle Control (Advanced divertor, Pellet)	0.6	1.1	0.2	1.6	
ECH	2.3	3.7	4.1	0.9	
ICH and FWCD	0.1	0.4	0	0.6	
Neutron Shielding	2.0	0.0	0	0	
Total (M\$)	32.3	31.8	31.2	32.5	
Total FTE	179	155	146	145	
GA 5-Year DIII-D Contract Proposal (M\$)	31.5	39.5	48.0	52.3	38.1
Cummulative Shortfall (M\$)	—	6.9	23.7	43.5	

Table B. DIII-D RESEARCH OPERATIONS TASKS/ACTIVITIES
(Without Incremental Funding)

	FY90	FY91	FY92
Operations Staff (FTE)	122	129	135
20 MW Neutral Beams			
2 MW 60 GHz ECH			
2 MW IBW			
Operating Schedule (weeks)	14	16	20
Transport Diagnostics	Correlation Reflectometer Phase Contrast Imaging Multipulse Thomson CER Upgrade	$j(r)$, Li beam, Superhetrodyne ECE Bolometer	Phase Contrast Imaging Bolometer Beam Emission Spectroscopy
Advanced Divertor	Install ring	Design pump	Fab. pump Bias power supply
110 GHz ECH	Complete 0.5 MW	Operate 0.5 MW Complete 2 MW Begin JAERI Fab.	Operate 2 MW Fab. JAERI
FWCD	Install antenna	Operate 2 MW	Operate 2 MW Increase to 4 MW
Pellet Injector			Fab. 50%

Table C. DIII-D PROGRAM INCREMENTAL REQUEST

M\$	FY91	FY92*
Onsite Research Operations	2.5	2.8
Diagnostics and Computers	1.1	1.8
Particle Control (Advanced divertor and pellet injector)	1.2	0.9
4 and 8 MW FWCD	0.7	6.2
Total	5.5	11.7

*Assumes no FY91 Incremental Funding

Table D. DIII-D RESEARCH OPERATIONS TASKS/ACTIVITIES

(Assumes FY91 Incremental Funding)

	FY90	FY91	FY91(I)	FY92	FY92(I)
Operations Staff (FTE)	122	129	140	135	146
Operating Schedule (weeks)	14	16	16 - 20	20	20-24
Transport Diagnostics	Correlation Reflectometer Phase Contrast Imaging Multipulse Thomson CER Upgrade	$j(r)$, Li beam, Superhetrodyne ECE Bolometer	Multiple lasers Central Thomson Upgrade Computer	Phase Contrast Imaging Bolometer Beam Emission Spectroscopy	Multiple lasers Central Thomson Upgrade Computer
Advanced Divertor	Install ring	Design pump	Fab. pump Bias Power Supply	Operate pump Fab. cryo	
110 GHz ECH	Complete 0.5 MW	Operate 0.5 MW Complete 2 MW Begin JAERI fab.		Operate 2 MW Fab. JAERI	
FWCD	Install antenna	Operate 2 MW	Increase to 4 MW	Operate 4 MW	Initiate 8 MW
Pellet Injector			Begin	Operate	

Table E. DIII-D INCREMENTAL BUDGET PRIORITIES

FY91 - (34.5 M\$ case)	K\$
1. Onsite Research Operations Staff and Materials/Services	1300
2. Particle Control (Advanced Divertor Pumping, Pellet Injector)	1200
3. Diagnostics - Multilasers and Data Computer	600
4. Divertor Bias Power Supply and 3 MA Flexibility	200
	<u>3300</u>
FY91 - (36.7 M\$ case)	
1. Staff and 4 weeks additional operations	1000
2. Second FMIT - FWCD (after coupling 2 MW)	700
3. Diagnostics - Central Thomson	500
	<u>2200</u>
Total	5500

Table F. DIII-D INCREMENTAL BUDGET PRIORITIES

[Assumes FY91(A) Incremental Funded]

FY92 - (35.6 M\$ case)	K\$
1. Onsite Research Operations Staff and Materials/Services	1700
2. Diagnostics - Central Thomson, Multilasers and Data Computer	1400
3. 3 MA Flexibility and Divertor Bias Power Supply	300
	<u>3400</u>
FY92 - (42.1 M\$ case)	
1. Staff and 4 Weeks Added Operations	1100
2. ICH Antenna Improvement	100
3. 200 MHz FWCD (based on 60 MHz results)	5400
	<u>6600</u>
Total	10000

Table G. REDUCED DIII-D BUDGET CASES (10%)

FY91 (28.2 M\$ case)	K\$
1. Drop all new diagnostics except $j(r)$, and Li-beam	600
2. Reduce 60 GHz ECH availability and neutral beam power	400
3. Reduce staff and operations from 16 to 8 weeks	2000
	<u>3000</u>
FY92 (29.5 M\$ case)	
1. Drop Pellet Injector	800
2. Drop FWCD second FMIT	700
3. Reduce staff and reduce operations from 20 to 14 weeks	1500
	<u>3000</u>