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1990-1991 Progress Report and Future Plans(1991-1993) for the U. C. Davis/Livermore Plasma Group

D. Q. Hwang, J. H. Rogers, J. C. Thomas, R. Evans, R. Foley, T. Hillyer

The experimental goals for the 1990-1991 period were the operation of the Davis Diverted Tokamak(DDT), the beat wave experiment, and the construction of the compact toroid injection experiment(CTIX). The experimental results from these areas are summarized in the posters given in the APS meeting past November. Here we shall describe the technical progress of the development of the diagnostic system for beat wave experiment, and CT injection especially in relation to the up coming injection experiments into DDT tokamak. The tokamak operation of DDT over the past year has been focused in two parameter ranges. The long pulse discharges (over 100 msec), and the low q short pulse discharges (about 10 msec). We found that the long pulse discharges required a position feedback more sophisticated than the simple passive program that we have. We are in the process of assembling this system. We also found an interesting low q(a) operating regime. Here an equilibrium can be established for a toroidal field between .5 and 1 kG. The typical plasma current is > 5kA. The density of the plasma is between 10^{12} and 10^{13} cm^{-3}. The plasma condition in these discharge are sufficiently mild that diagnostic probes can be used to measure various plasma fluctuations. We believe that this will be the regime best suited to study the interaction between the tokamak plasma and the compact toroid. A sophisticated probe system of both electrostatic and electromagnetic types similar to those used in the beat-wave experiment has been designed for the up coming experiments.

Beat Wave Experiment

The goal of the beat wave experiment over the past year is to correlate the measurement of the mixed wave with the particle current interacting with the plasma wave. An elaborate probe system was constructed to measure both the wave and a energy analyzing probe was constructed to obtain the particle distribution. The physics results were presented at the APS meeting, and the results are being prepared for publication. Here we shall described the capability of the probe system for both wave and particle detection.

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To measure both the amplitude and the wave number of the wave a special rotatable triple probe was made and together with a fast digital oscilloscope, the wave front and the wave phase can be obtain simultaneously. The data was acquired by a LSI-11 computer system and the wave number can be deduced. We found that the direction of the wave phase velocity is consistent with the direction of the higher frequency source. Several experiments were performed to ensure that the wave mixing is occuring in the plasma and not in the detection system.

In order to detect the effects of the wave on the electron distribution, a double grid particle energy analyzer was constructed to obtain the energy distribution, and a computer (LSI-11) controlled voltage sweeping system was employed to collect the data base needed for future experiment. The measured distributions show the flattening of the distribution about the phase velocity of the wave(see Fig 2). This is consistent with the quasi-linear model of Landau damping of the plasma wave on the electrons. A design of the longer pulsed (> L/R or 100μsec) source was developed with input from several RF engineers at LLNL. Due to the high instantaneous power requirement, a burst-mode radar type design was found to be the best. This ensures high instantaneous power, but relatively low averaged power. At present, we are modifying the modulator to a burst-mode system. With the longer pulse, we hope to see a net current from our Rogowski coil measurement.

Compact Toroid Experiment

CTIX has as a primary goal the understanding of the propagation of spheromak like compact toroids across magnetic field lines for the purpose of tokamak fuelling and density profile control. Here we shall discuss our progress culminating in successful formation and acceleration of compact toroids as presented at the 1991 plasma physics division APS meeting. The content is organized into four sections covering development of our fast pulse gas valves, the high voltage pulse power systems, the gun design and lastly diagnostics. For a summary of CTIX parameters refer to table 1.

The fast pulse gas valves used in operation of the experiment as reported at the 1991 APS embodied the third iteration on our first attempt at a fast

valve in the spring of 1991. Characteristics of this valve include a variable throughput of 10^{17} to 10^{19} molecules per pulse with a rise time of less than 200 μs and a pulse width of less than 500 μs. Fast opening is achieved by using electromagnetic repulsion of a light aluminum piston while a large dynamic pressure created by this fast opening results in the fast closing time.

Budgetary restrictions necessitated that we assembled the pulsed power systems with used components available here at LLNL. As might be expected with this approach, some problems were encountered such as pre-firing of the acceleration bank and some arcing. Both of these were taken care of and the system operated consistently for a period of about four weeks (roughly 1000 shots) before the pre-fire problem resurfaced. We have determined that the noise from the formation discharge pre-triggers the SCR in the acceleration bank ignitron firing circuit, apparently the SCR becomes increasingly susceptible to this problem over time. We are currently in the process of addressing this problem in a more permanent fashion than would be afforded by simply replacing the SCR again. Also the capacitance of the formation bank (500 μF) is about twice what it should be for a gun of the size used in CTIX. The primary consideration here lies in a comparison of the CT lifetime in the pre-acceleration flux conserver to the half cycle time of the formation current. Ideally these two times should be roughly equal while in the present system the formation pulse is about twice as long as the CT lifetime. This results in a low formation efficiency and prevents the gun from operating in the desired mode wherein the formation and acceleration pulses do not overlap as much as is now the case.

One of the greatest resources we were able to tap for help in the gun electrode design was the collective expertise of the RACE group here at LLNL. In particular the computational resources developed for the RACE program with their long track record of excellent agreement with experiment allowed us to compare many different geometries and to make judicious choices when it came time to finalize the gun design, particularly in light of our restricted budget. Many innovative and cost saving solutions were implemented in the gun construction. For instance, in the interest of cleanliness pure alumina was desired as the vacuum facing material in the dielectric break. The traditional techniques of ceramic to metal bonding were prohibitively expensive as would have been fabrication of a large alumina flange, especially one with tight

enough tolerances. Instead a comparatively thin alumina ring was used to make the o-ring seal and face the vacuum while mechanical support was provided on the air side by a thick delrin flange. Cost savings were achieved both by reducing the amount of alumina in each dielectric break and by relaxing tolerances on fabrication since it was far cheaper to machine the delrin flanges to match the alumina than vice-versa.

Diagnostics development has proceeded well over the past year. We can now calibrate our magnetic loop probes and have also significantly increased the signal to noise ratio as well as found a technique to reduce or eliminate ghost reflections in the co-axial signal transmission lines due to the impedance mismatch between the line and the passive signal integrators. The magnetic probes have been our primary diagnostic for evaluating gun performance. The magnetic probes are inserted from the outside and are mounted flush with the inside of the outer electrode surface. The probe ports are located at the middle of each ten inch modular section of the acceleration outer electrode and at the middle of the pre-acceleration compression cone. Data from the probes is used to determine the CT velocity (20 cm/μs to date), magnetic intensity (0.8 T so far), size (around 10 inches long) and magnetic structure. To the last point, we often observe what seems to be some sort of twisting behavior, particularly in the drift section (the inner electrode only extends half way down the gun at this time, leaving a hollow tube of 20 inches in length for the CT to transit before entering the target chamber). Other diagnostics in use but still under development are the He-Ne laser interferometer and Langmuir triple probes. These are used to measure the density of the CT in the acceleration and target chamber respectively. Also in use is a borrowed spectroscopy system to survey the optical spectrum of the plasma discharges and a fast framing camera.

DATA ACQUISITION UPDATE

Over the past year we have steadily developed a complex, yet reliable and user friendly data acquisition system for the DDT and CTIX projects. At the heart of the system is LabVIEW a software package that allows for interactive control of acquisition devices as well as analysis of the data acquired. Specifically programs utilizing LabVIEW (called drivers) have been developed for numerous CAMAC digitizers with sampling rates ranging from 5 kHz. to 100 MHz. with 8–12 bit resolution. The time scale of the diagnostic system for the

tokamak(msec) is much slower than that for the CT(μsec). For the tokamak operation the standard Camac-based digitizers were employed. For diagnostics on CTIX ,where fast sampling are required, drivers have just been developed for our recently acquired fast digitizing oscilloscopes. These oscilloscopes give us 8 channels with sampling rates of 250 MHz. or when needed 2 channels at 1 gigasample per second. All of the CAMAC and fast digitizing scopes are to be integrated together into one large acquisition package of over 25 channels allowing us to view numerous diagnostics over a large range of time scales. The data acquisition system is outlined in figure 1.

Future Experimental Plans

The experimental program at U. C. Davis/ Livermore for the period covering March 1992 to September 1993 will be composed of five parts:
1) injection of compact toroids (CT) into a test stand to determine the propagation and particle deposition characteristics of CT in a vacuum magnetic field; 2) design and construction of a more compact and rep-ratable pulse power system and an appropriately modified CT gun in order to investigate CT gun operation issues at average power densities relevant to a large tokamak fueller (approximately 1 MW per cubic meter); 3) using the rep-rated gun on the DDT tokamak; 4) collaboration with the CFFTP group on CT fuelling studies at TdeV in Canada and 5) continued interaction with the RACE group on gun development and improvement.

The experimental programs of all five tasks are interrelated and compliment each other. First the vacuum field propagation experiment will give a fundamental starting point for theoretical work and a zeroth order guide for the upcoming tokamak injection experiments. Second the rep-rated gun operation will explore CT formation and acceleration in a significantly different and likely better environment as impurity mono-layers on the electrode surfaces will not have time to reform after being ablated during the previous shot as is now the case. We also expect to learn valuable information on other issues such as electrode erosion, heat load handling and high power repetitive switching all of which should expedite the final development of an effective large tokamak

fueller should that step be warranted. Third, our tokamak injection experiments on DDT will focus on two main areas not readily accessible to the CFFTP experiments at TdeV. First, the design layout of DDT emphasizing maximal access required a smaller number of very large toroidal field coils than typical resulting in a substantial region (about 0.5 meter radially) of vacuum field that the CT must propagate through before encountering the tokamak plasma as would be the case in any future experiment on a large tokamak. As such, various schemes to optimally transport the CT from gun to target can be investigated appropriately on the basis of their effect on the final CT tokamak plasma merging. Second, DDT can operated in a regime of repetitive discharges at low q (about 3 at the edge) with DC toroidal field and plasma current of 5 kA for a short pulse of a few milliseconds. This has the advantage of allowing probes full access to the plasma column and resulting in the collection of large bodies of data in a timely fashion.

One of the areas that has not been explored theoretically in great detail are the instabilities that can be generated in a tokamak plasma after the penetration of a fast moving CT. Some idealized calculations have been done by W. Newcomb for the case of a slow moving superconducting sphere. In these calculations it is shown that slow Alfven and acoustic waves will be generated from the source of free energy (the CT). Furthermore, as the CT penetrates and distorts the tokamak, one would expect that turbulence could be generated. These effects can best be studied using probes. At the conclusion of these experiments, we hope to provide a complete data base that can be compared with and guide the development of theoretical models.

As to the impurity influx, we will use the spectrometer on loan from to first give a general mapping of the effect. The Zeff of the tokamak can be studied using the visible Bremsstrahlung method (Z-meter). A more comprehensive survey of impurity issues is planned for the CT injection experiments on future confinement dominated large tokamaks. Our view is that the more confinement related experiments for CT fueling can be done on elsewhere, while we will concentrate on the detailed physics issues relating to the tokamak plasma stability and equilibrium that will be needed for a complete understanding of the fueling process.

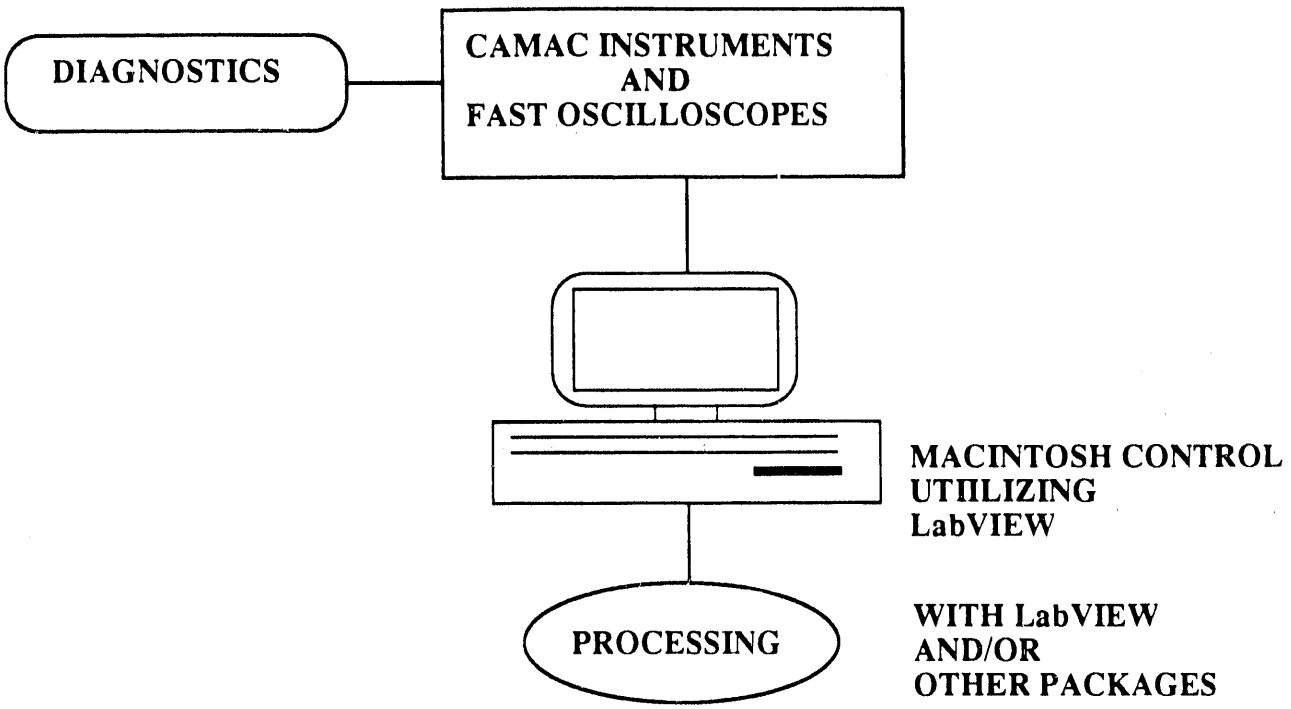

Fig. 1

Table 1: CTIX Parameters

CT:		velocity	200 k
		mass	15 μg
	diameter	7.5 cm	
		$B_{poloidal}$	0.1 to
Formation:	capacitance	500 μF	
		voltage	7 kV
		half cycle time	40
Acceleration:	capacitance	90 μF	
		voltage	15 kV
		half cycle time	14 μs
Fast valves:	rise time	<200 μs	
		pulse width	<500
		throughput	10^{19} p

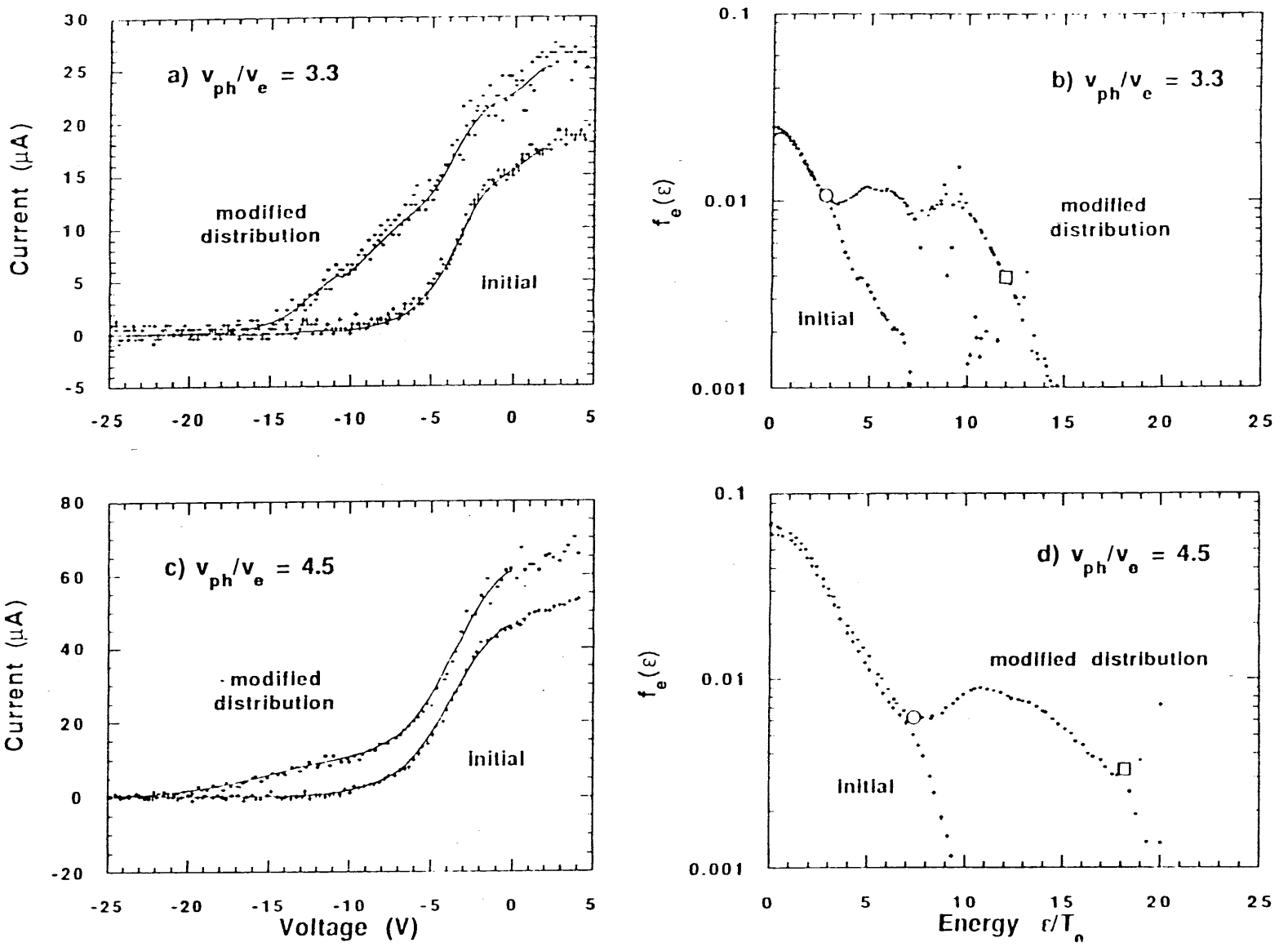
a) v_{ph}/v_e = 3.3
modified distribution
initial
Current (μA)
b) v_{ph}/v_e = 3.3
modified distribution
initial
$f_e(\varepsilon)$
c) v_{ph}/v_e = 4.5
modified distribution
initial
Current (μA)
Voltage (V)
d) v_{ph}/v_e = 4.5
modified distribution
initial
$f_e(\varepsilon)$
Energy ε/T_n

Figure 2

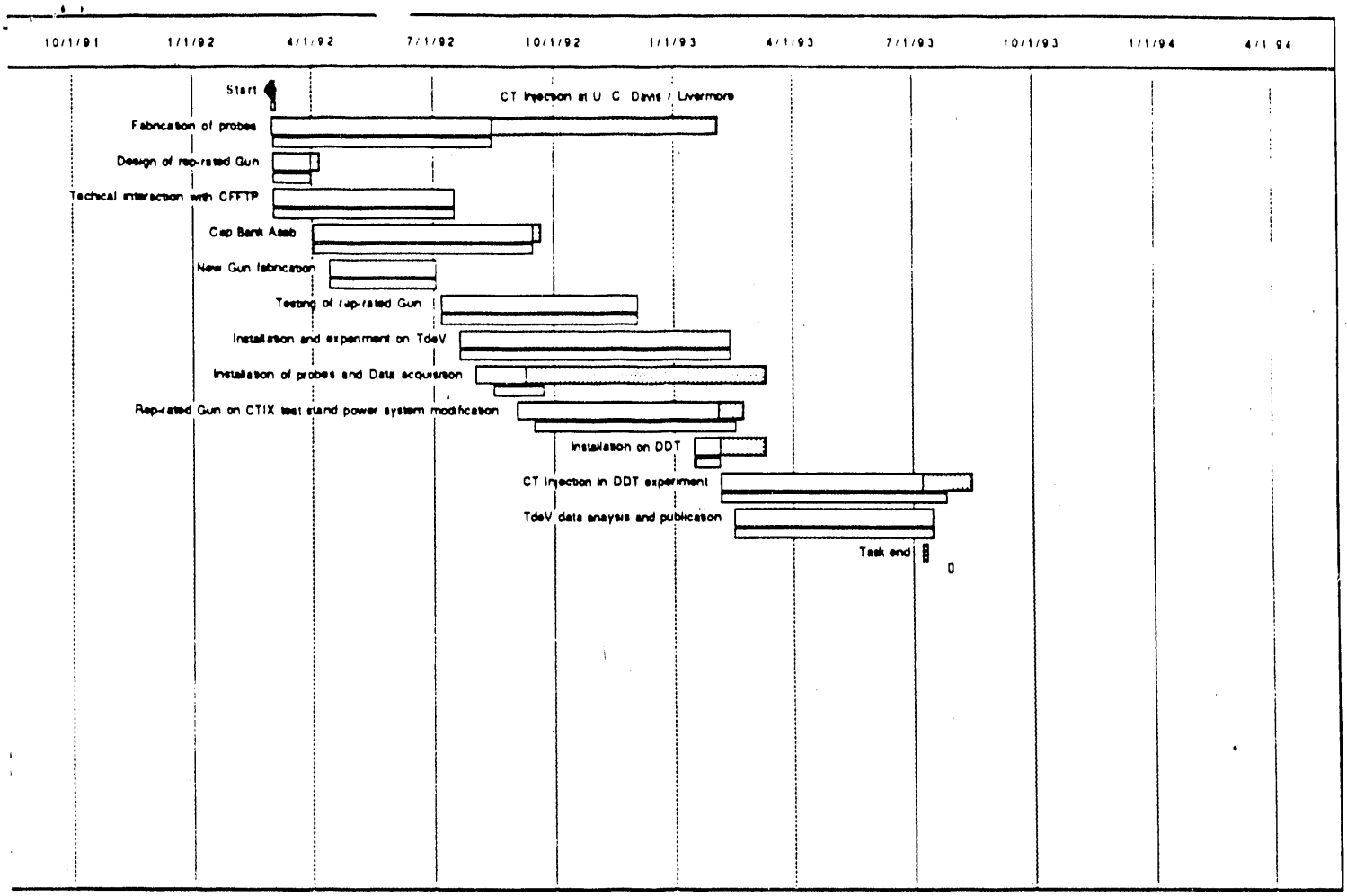

Figure 3

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