240715

①
MASTER I-344

UCID- 19245

DIAGNOSTICS FOR THE ATA BEAM - ✓
PROPAGATION EXPERIMENTS

T. J. Fessenden, W. L. Atchison,
W. A. Barletta, J. F. Campbell, J. C. Clark,
L. D. Clendenen, R. B. Fiorito,
A. M. Frank, F. D. Lee,
H. A. Koehler, and K. W. Struve

November 11, 1981

Lawrence
Livermore
Laboratory

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DIAGNOSTICS FOR THE ATA BEAM-PROPAGATION EXPERIMENTS*

T. J. Fessenden, W. L. Atchison, W. A. Barletta,
J. F. Campbell, J. C. Clark, L. D. Clendenen,
R. B. Fiorito, A. M. Frank, F. D. Lee,
H. A. Koehler and K. W. Struve

Lawrence Livermore National Laboratory, University of California
Livermore, CA 94550

ABSTRACT

This report contains a discussion of the diagnostics required for the beam propagation experiment to be done with the ATA accelerator. Included are a list of the diagnostics needed; a description of the ATA experimental environment; the status of beam diagnostics available at Livermore including recent developments, and a prioritized list of accelerator and propagation diagnostics under consideration or in various stages of development.

DISCLAIMER

*The Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy under contract number W-7405-ENG-48.

This work is performed by LLNL for the Department of Defense under DARPA (DDO) ARPA Order 3718, Amendment #33, 34 and 41 monitored by NSWC under Contract No. N60921-81-LT-W0009, Amendment No. 1 and N60921-81-LT-W0026.

INTRODUCTION

This report is meant to provide a guide to the diagnostics that will be needed to study the propagation of the ATA beam in air at pressures at or near one atmosphere. It is aimed at the particle beam research community in general, as well as those of us at Livermore engaged in the study of electron beam propagation in air. The report only considers diagnostics necessary for studying the propagation characteristics of the ATA beam in gas.

In order to expect propagation of the ATA beam in air, its parameters at injection must correspond adequately to those obtained from theory. To experimentally study propagation, the beam parameters must be determined as the beam propagates through the atmosphere. Thus, the ATA gas propagation diagnostics must establish the beam size, sweep, risetime, etc. as the beam enters the gas and the beam location, pulse evolution, size, etc. as it propagates through the air. Also of interest is the way that the beam stops (Ohmic range, instability, misaiming, etc.) and the response of the air to the passage of the beam.

The development of systems for adequately diagnosing the ATA beam presents many interesting and challenging problems. For many of the phenomena the time scales of interest extend well into the picosecond regime. The radiation environment in the beam vicinity requires that all diagnostic systems be adequately shielded from gamma rays and neutrons and that the systems be remotely operated (this tends to preclude film as a data recording medium). The size of the experiment requires that all phenomena be monitored from distances of hundreds of feet. These and other considerations reveal that the ATA experiments will require diagnostic systems and techniques that are yet to be developed or are at the edge of what can be done.

The tremendously important question of identifying the stable propagation regimes of the ATA beam can be answered in a simple way with a closed-circuit television that views the beam in the gas. It is even possible to determine if the ATA beam tracks the channel created by previous pulses with this simple diagnostic system. However, it will not provide the quantitative data to compare with theory that is required to give us confidence that results obtained from ATA can be used to scale the propagation physics to other parameter regimes.

Although many of the techniques developed for ETA will be used for ATA, the harsh radiation environment and high beam power of the ATA prevent the use of most beam-intercepting diagnostics. The problem is most serious in the gas-filled experimental sections where the current density is much higher than in the vacuum regions of the accelerator. For this reason diagnostics for the ATA must be heavily oriented toward non-intercepting and optical diagnostics.

It is almost certain that we will wish to study beams propagating in an unstable as well as a stable fashion. Indeed, it is not assured that a stable propagating regime exists for the ATA beam in air at one atmosphere. Consequently, only at and near the point the beam enters the gas can one be absolutely certain of a priori knowing the beam location. Hence, of every diagnostic one must ask whether it can be used to study unstable beam propagation or can it only be used to study stable beams. If the diagnostic presupposes stable beam propagation, its utility is diminished.

The above considerations suggest that not only are the ATA diagnostic systems likely to be expensive, there is a considerable danger of investing large sums of money in systems that because of the gammas and/or neutron flux, are unable to function during the ATA pulse. Consequently, in assessing a potential beam diagnostic we must determine that it can survive and function in the ATA environment and that it can be operated remotely. In addition, each diagnostic must be made to work on ETA to protect against wasting valuable ATA operating time.

DIAGNOSTIC REQUIREMENTS - WHAT IS NEEDED

The following list is generated from the viewpoint of what experimental information is desired to compare with theory in order to understand the propagation of energetic electron beams in gas.

Perhaps the most important diagnostics required by the particle beam program are those that give information as to the trajectory of the beam electrons. In particular, one would like to determine the beam current density to an accuracy of approximately 10% over the entire range of propagation. This diagnostic must be able to track beams that propagate in an unstable (hose or sausage) fashion as well as beams that propagate stably.

These instruments should locate and resolve the beam to an accuracy of approximately one millimeter in the transverse plane and approximately one-tenth nanosecond (3 cm) in the direction of propagation. They must measure the beam size at the head, body and tail and be able to distinguish between nose erosion and tail chopping. These systems are required to determine the beam location and would be used to study most of the issues relevant to the propagation of electron beams in the atmosphere.

Almost as important are the diagnostics that measure the electric and magnetic fields in the vicinity of the beam. Of interest are the electric fields principally at the beam head, the plasma or return current density induced by the beam and the pinch magnetic fields that focus the propagating beam. These diagnostics also should resolve the fields and currents to an accuracy of approximately one millimeter in the transverse plane and a few centimeters in the propagation direction.

A third class of diagnostics includes those that measure the electrical conductivity of the gas generated by the passage of the electron beam. There are two time scales of interest. A fast time scale comparable to that of the beam pulse. Here the conductivity can be expected to approach $10^0 \Omega\text{-cm}$ as the electron density exceeds $10^{16}/\text{cm}^3$. It is also important to study the long time conductivity decay following the passage of the beam. This information is needed to establish the initial channel conditions for the second and later pulses of a burst. We also need to study the gas temperature versus time both on the time scale of the pulse to understand how energy couples into background gas affecting the air chemistry and on the time scale of the channel to study how the gas eventually cools back to ambient.

Not unrelated to the gas temperature diagnostics are systems that detect and measure the size, location and evolution of the gas channel or bubble created by the hole-boring process. Knowledge of the channel density profile is needed to understand the channel tracking phenomenon that is essential for the WIPS mode of beam propagation. Moreover, the manner in which the channel cools and thereby disappears affects how rapidly bursts of WIPS pulses can be fired. At this point experiments most recently at NRL(1) but also with the Astron beam suggest that the channel cools by convective mixing. However, these phenomena are of continued interest and diagnostics capable of detecting and measuring the gas bubble created by the ATA beam for periods of up to 100 msec are desirable.

Finally, the diagnostics that monitor the ionizing radiation and noxious gas products produced by the ATA must be considered. These systems have the highest priority because they are essential to maintain the safety of the personnel working on the experiment and the lifetime of components, cables, etc. The first such instruments will determine the shielding requirements for optical windows and sensitive electronics that may have to be located in the pit. They are also useful for determining the regions of beam spill and may act as detectors for systems that inhibit the accelerator if the beam spill occurs at the wrong place.

THE ATA EXPERIMENTAL ENVIRONMENT

The ATA is currently under construction at Site 300 - which is located approximately 15 miles from and operated by the Lawrence Livermore National Laboratory. It is expected that the accelerator checkout will begin in the fall of 1982. Beam-in-gas experiments could begin in early CY 83, if funding levels permit.

Two sketches of the ATA experimental area are shown in Figures 1 and 2. The first is an artist's cutaway drawing showing the experimental tank inside the earth shielding. Visible are the port extensions through the shielding that can be used to bring coaxial signal cable to the diagnostic bunker. In the event that transparent interfaces or windows on the experimental vessel prove impractical, the extensions can be used to bring them out of the radiation field as sketched in Figure 1. Also sketched is the orientation of the atmospheric beam range with respect to the diagnostic bunker and experimental tank. More specific information on the tunnel dimensions is shown in Figure 2.

Experiments in the tank at pressures of one atmosphere and below will occur in an aluminum tank similar to that sketched in Figure 2. This tank has ports that line up with the port extensions through the ceiling of the experimental tunnel. The tank is modular and will be extended in length as we learn how far the ATA beam propagates for specific experimental conditions. After passing through the experimental tank, the beam will be dumped in a pile of SiO_2 (sand) that is continuously stirred to remove the heat and prevent the formation of glass nodules.

The radiation environment inside the ATA experimental tunnel will vary widely from point to point and will only be precisely known after experiments actually begin. Estimates show that the gamma radiation near the beam dump can approach 2000R/pulse with peak flux during the pulse of 4×10^{10} R/sec. The radiation generated by the beam striking the gas will be approximately 50R/pulse or 10^9 R/sec peak at one atmosphere. Furthermore, we estimate that each pulse will generate approximately 10^{12} neutrons leading to a dose comparable to that generated by the gammas. High Z shielding is not as effective in shielding neutrons as it is with gammas.

Experiments with ETA(2) suggest that the EMP in the region around the experimental tanks may approach 500V/m in the frequency range 1-10 MHz. Inside the tank these fields may be much larger depending on experimental conditions.

Each beam pulse will produce approximately 0.2 g of ozone, 5% of which will be generated outside the vessel in the experimental tunnel. As discussed in Appendix 1, this ozone concentration can accumulate to ~.4% inside the tank and to approximately 8 ppm in the tunnel. These are the maximum concentrations of ozone that could be produced by several thousand beam pulses stopped in air at one atmosphere with no ventilation. If the beam is stopped by a low Z (carbon) dump, we estimate that approximately 25 times less ozone will be produced in the tunnel. As discussed in Appendix 1, the beam also produces NO_2 in passing through air. However, the NO_2 appears to constitute less of a hazard than the ozone, but it does not decay. During ATA operation a negative pressure will be maintained within the ATA tunnel which will result in some ventilation of the ozone and NO_2 . After operation and before people are admitted to the tunnel the air will be completely exchanged.

These hazards will restrict access to diagnostic equipment placed inside the tunnel. We estimate that after firing more than 10 ATA pulses into the experimental vessel, one must wait approximately an hour to enter the pit to allow the activation products (principally O^{15} and N^{13}) and the ozone to decay.

ATA DIAGNOSTIC DEVELOPMENT AT LIVERMORE

During FY81 planning and experiments on diagnostic development for ATA were begun. The plan for diagnostic development was initiated with an ATA diagnostic conference held at Livermore in November. Attendees at this meeting included people from NRL, SNL, SRI, AFWL, MCD, PSI, NSWC, MRC and CSDL as well as LLNL. Later in the year a series of in-house meetings and study sessions were held in which various diagnostics were individually considered. Participants were mainly physicists and engineers from our group and the LLNL Weapons Diagnostics Division.

From these meetings a plan was formulated for developing the data handling systems and many of the diagnostics that will be required for the ATA experiments. This plan is elaborated on in the next section. It is to be noted, however, that the development plan cannot be complete. It is generally felt that the need for other diagnostic systems will become apparent as we learn more about the interaction of intense E-beam with gases. It is also possible that diagnostics that were initially rejected because of their expense or difficulty might later become necessary in spite of the cost or difficulty.

Fortunately, much of the experience gained in operating and diagnosing the Astron and ETA beams can be applied to ATA. Many of the diagnostics developed for these accelerators will be used with or are being adapted for ATA.

Fast pulsed voltages at many points through ATA will be monitored with a resistive divider or a fast capacitive probe⁽³⁾. This capacitive probe is in extensive use on ETA and has a subnanosecond rise time and a voltage attenuation of 10^4 or 10^5 depending on whether it is used in oil or water.

Beam current at various points along the ETA beam path is monitored with resistive current shunts that interrupt the return current flowing on the conducting boundary surrounding the beam. These monitors (at Livermore these are called "beam bugs") evolved from similar monitors developed for the Astron beam⁽⁴⁾. The ETA "beam bugs" feature a rise time of less than one nanosecond and are able to measure the position of the beam centroid inside the beam drift tube.

On ETA the beam size and emittance are determined by an "emittance box/beam dump". This device contains a collimator consisting of many small slots that divide the beam into beamlets. The beamlets are allowed to drift freely and then impinge on a phosphor, creating light that is detected by an intensified TV system. The size and shape of the light patterns generated by the beamlets are used to obtain the beam emittance, beam size, and the uniformity of beam current density. The system is able to measure emittance in times as short as 10 ns. The beam intercepting portions of the emittance box are remotely removable. Thus in normal experimental operation, the ETA beam is first evaluated using the emittance box. Then the beam dump portion is "pulled" and the beam allowed to pass undisturbed through the "emittance box/beam dump" to the experiment. Because of the higher energy of the ATA beam, it may not be possible to design a collimator suitable for obtaining good emittance measurements. However, beam size and uniformity measurements will be possible and are of considerable value in evaluating the ATA beam.

The on-line energy analyzer⁽⁵⁾ used successfully on the Astron accelerator has been adapted for and used with ETA. This analyzer employs a small portion of the electron beam that is scattered from the primary beam by a fine wire. This device must be redesigned for ATA.

A CO₂ Michelson⁽⁶⁾ interferometer used with the Astron experiment is ready for deployment on ETA. This system is able to measure electron line densities down to $10^{14}/\text{cm}^2$ and has a response time of 20 ns. We have also developed a Mach Zehnder interferometer using a He-Ne laser that is intended to study the response of the gas to the passage of the ETA beam. Both of these systems will be modified for ATA.

Experiments with the Astron and ETA beam have benefited from gated television systems developed more than ten years ago for the Astron beam experiments. These TV's are used both to view the beam directly in gas and as detectors for several of our diagnostic systems. These systems will be replaced with faster and newer technology for the ATA beam.

Development on several diagnostic devices specifically for ATA started this year. An ATA resistive wall current monitor (beam bug) was built and successfully tested. Its design, which is scaled to fit the ATA beam tube and flange dimensions, is based on the ETA beam bug. It features an improved rise

time (300 ps vs 1 ns), and more voltage pick-up ports, which allows better frequency response in beam offset measurements. This diagnostic is currently under construction for ATA.

Measurements have also been made on optical emissions of the beam in gas with the goal of finding suitable lines to be used in beam current and position monitors. As anticipated it was found that the emission at the 391.4 nm line follows the beam current for pressures above 100 Torr. However, for very small beams (high beam current density), the electric field at the beam front and tail can become large enough to cause significant excitation of the 391.4 nm line by plasma electrons. This tends to confuse the simple determination of the location of the beam electrons based on 391.4 nm emission. However, the diagnostic may then prove useful for monitoring the strength of the beam induced electric field. More experimental and theoretical work is needed to unravel this important area of physics. It is also possible that light emitted from higher energy states will follow the beam current density more precisely and thereby form a better basis for following the beam electrons. We are presently engaged in both a theoretical and experimental search for line radiation from higher energy states that could serve as a better basis for an optical beam current density monitor. Results⁽⁷⁾ from this study have been submitted to Physical Review Letters.

Work has also proceeded on a technique to measure the position and size of the beam at several locations along the ATA accelerator and transport by remotely inserting a probe in the beam and observing x-ray emissions with a scintillator and photomultiplier tube. So far this work has been troubled by background x-ray emissions which mask the desired signal. At present, we are in the process of improving the collimation and shielding of the detector to enable development of this potentially useful diagnostic. We are also investigating the use of a Cerenkov emitter as a beam detector.

Initial measurements are also being made on ETA with Cerenkov and fluorescent foils placed in the beam path. The goal is to match these detectors with a streak camera to provide picosecond response time monitors of the beam position and with the gated TV systems to obtain nanosecond monitors of the beam size and shape. We are also in the process of adapting the fast readout television cameras developed by the Livermore Weapons Program to the ETA and ATA requirements.

Finally, designs for the ATA emittance box and energy analyzer have been initiated. The designs are modeled after the ETA devices, but must account for the higher beam energy of the ATA. The energy analyzer, for example, will have a larger diameter scattering wire and larger bending coil to account for these effects. No hardware has been built for either of these devices, however.

ATA DIAGNOSTICS DEVELOPMENT - WHAT NEEDS TO BE DONE

In developing a set of diagnostics the primary concerns are to make measurements that are of most value. Thus, it is most important to determine the beam trajectory in both the single pulse and burst mode. Thereafter, two other measurements are of almost equal importance; (1) measurement of plasma currents and fields around the beam, and (2) measurement of gas channel properties. Finally, any proposed diagnostic must be practical. The relative cost versus data obtained must be considered.

Other key considerations used in developing the proposed set of diagnostics include: (1) Safety: The diagnostics must assure the safety of the operating personnel and assess the hazards to the equipment. (2) Optical diagnostics will necessarily play a strong role in ATA experiments. (3) Beam diagnostics should use and/or extend planned ATA accelerator diagnostics wherever possible. (4) Flexible systems must be developed which can be used by others as well as ourselves. (5) Most, if not all, propagation diagnostic outputs must be stored at least temporarily.

ATA Accelerator Diagnostics - For the accelerator, a number of diagnostics are being built and/or are already developed. Since these will be required first, they must have the highest priority. In order to protect the ATA, a beam spill monitor that can crowbar the accelerator in the period between pulses in a burst (one millisecond) is required. A prototype of the resistive wall current monitors (called "beam bugs") has been built and successfully tested. Radio frequency loops similar to those used on ETA are required to monitor transverse beam oscillations in the accelerator that could result from accelerator instabilities. The energy analyzer will essentially be identical to that used on ETA. However, the scattering wire will need to be retractable, and the angles and magnetic field strengths must be changed to

accommodate the higher beam energies. The ETA beam dump/emittance analyzer must also be redesigned. A system for monitoring the beam profile inside the accelerator and transport sections is required. This system will be used to check the predictions of the computer code TRANSPORT. In this way we can build up confidence in our ability to predict the envelope of the beam through the accelerator. By using tomographic reconstruction techniques a beam profile and emittance monitor is possible but expensive since three gated TV's and computer reconstruction are required. It works by viewing residual gas fluorescence in the accelerator from several angles at three axial positions.

Beam Conditioning Diagnostics - Before the beam is admitted to the propagation experiment, the beam front will be "cleaned up" with a beam conditioning section. This section will remove or adequately reduce any residual transverse oscillations or sweeps imparted to the beam by the accelerator. The diagnostics must determine the transverse motion of the beam at the inputs and output of the conditioning section. Radio frequency loops and "beam bugs" will be used for this task. However, the principal diagnostic will likely be a gated or streak TV system that observes the Cerenkov light generated by the beam in passing through a dielectric foil. With these systems, the beam size and position at a plane can be determined on time scales extending to below 0.1 ns. The Cerenkov TV diagnostic is currently under development on ETA.

Diagnostic Research - We must continue the study of the line radiation from air using the ETA. Since we are relying increasingly on the beam induced emissions as the source of diagnostic signals for the gas propagation experiments, we must understand what the signals are telling us.

Data Handling - The TV systems, transient digitizers and computerized data handling systems make up the major hardware costs and are the "backbone" of the ATA propagation diagnostics. These systems must "match" to the ATA control and monitoring equipment and be flexible so that diagnostics developed by others can be easily connected to the ATA data handling channels. Much of this hardware must be inhouse and working at the commencement of the gas propagation experiments that could begin as soon as 1 1/2 years from now. Many of these systems are "long lead" items. The computer and the TV systems require almost one year to obtain once the purchase order is written. It is essential that a majority of these items be developed and ordered in FY82 or early in FY83 if gas propagation experiments are not to be delayed.

Open Air Experiments - Although most of the quantitative beam experiments will be performed within the tunnel and experimental vessel, the open air propagation experiments are essential for demonstrating that a powerful electron beam can propagate and be aimed in an "open" environment. For these experiments, methods of observing and tracking the beam in the open air are required. The study of the line radiation from air is intended to lead to a diagnostic that will allow me to "see" the ATA beam electrons in the open air using the TV systems. Personnel from the Draper Laboratory have suggested a method of developing an optical beam tracker using two TV systems. This or a similar diagnostic is ideally suited for these open air experiments.

Hazards Analysis - Finally, more attention to the consequence of the various hazards generated by the beam is needed. Although the system will be operated so as not to endanger personnel, we need to know what impact on the diagnostic systems these hazards produce. Is it practical to use glass windows on the experimental tank or must the tank be extended up the diagnostic ports set in the tunnel? What precautions are required to operate TV cameras in various parts of the tunnel? Some of these questions will only be answered by experiment. However, they obviously require more attention at this time.

DIAGNOSTICS BY PRIORITY

The proposed diagnostics are summarized in Table 1 (accelerator diagnostics) and Table 2 (beam diagnostics). The individual diagnostics are prioritized according to the following considerations: Priority 1 means "impossible to run without ." Priority 2 means "essential for the experiments," and thus should be available at the start of the gas propagation experiments. Priority 3 means "it would greatly aid physics knowledge of the ATA beam experiments." Finally, Priority 4 means "nice diagnostic, but of limited impact relative to cost." These lists contain systems principally for determining issues related to beam propagation.

Priority 1

These diagnostics include: the beam spill monitor that protects the accelerator; the "beam bugs" that monitor the beam current and position within the accelerator and transport; and the beam dump/emittance analyzer that stops the beam. Without these systems ATA cannot be operated.

Priority 1.5

These systems include the energy analyzer that measures the energy of the ATA beam; the rf loops for detecting and measuring transverse accelerator instability; a beam profile monitor for checking the predictive capability of the accelerator beam diagnostics code (TRANSPORT); and the gateable TV systems that are essential for all beam viewing diagnostics. Other diagnostics include nearly all those necessary for diagnosing the ATA beam in the accelerator and transport. With the TV systems, one could begin gas propagation experiments.

Priority 2

These systems will begin to provide quantitative information and how the ATA beam propagates in air. The optical beam bug will permit position measurement of the beam electrons to be made in times as short as 0.1 ns at full atmosphere if a streak camera is used. Similar information using PM tubes is also obtainable at rise times set by the oscilloscopes. The use of a Cerenkov foil with the streak camera will permit determinations of the beam electrons in a plane at any pressure in times as short as 50 ps. The optical tracker will allow the beam trajectory to be determined in three dimensions in

Table 1. Accelerator Diagnostics

Priority	
1	Beam spill monitor - needed to protect the system
1	Beam bug development in good shape, essentially complete for accelerator.
1.5	Energy analyzer requires redesign: basic idea should be usable (wire survivability?).
2	ETA beam dump/emittance analyzer will have to be redesigned for emittance measurements. Beam size and uniformity measurements are of great value.
1.5	Radio frequency loops for detecting and measuring beam instability of the accelerator.
1.5	Simple beam profile monitor under development
3	Tomographic beam profile and emittance monitor possible but expensive (works by viewing residual gas in accelerator at 3 stations) (3 TV's and lots of analysis).

times as short as one nanosecond. The CO_2 Michelson interferometer will give us information on the plasma densities created by the beam over the range of 10^{14} to 10^{18} electron/cm². With a faster detector this system has a response time down to 5 nsec. (a single pass interferometer must be used to obtain faster response times). The interferometer will also "see" the formation of the gas bubble that occurs on the time scale of a few microseconds. The He-Ne Mach Zehnder system will principally view the shock wave structure associated with the formation of the gas bubble. It can also be used to study the channel cooling phenomena. Also, here are the B field probes that can be used to investigate the currents and fields flowing around the beam. Note that the laser interferometer systems require that the beam propagation be stable for optimum use.

Priority 2.5

For a detailed understanding of beam propagation, the diagnostics in this category are required. A fast He-Ne interferometer capable of .3 ns response can provide information on the ionization rate at the beam front as well as track the plasma decay. A single pass CO_2 interferometer using a high power pulsed laser can use detectors with 50 ps response time and provide the same information. Thus, these systems are in competition and need evaluation. By measuring the intensity ratios of various nitrogen lines, the gas temperature rise during the pulse can be measured. Such a system is currently under development at SRI. In addition, there are indications that other optical diagnostics can be developed. Work of Yu and Frank(7) indicates that by comparing the waveshapes of light at 337.1 nm and 391.4 nm it may be possible to determine the induction electric field at the head and the tail of the beam pulse. Note that these diagnostics also require that the beam location be well defined.

Table 2. Summary of Beam Diagnostics

Item	Measures	Priority	Status	Comment
Bugs	$I_{net}(x,y)$	1	Here	
PM on 3914	$I_{beam}(x,y,t)$	2	Close	Versatile, cheap
TV-Systems		1.5	Close	
TV 2D array	$J_b(r), J_{net}(r)$	2	Develop	Optical Faraday Cup
TV Streak	$J_b(y,t)$	2	Develop	ps but slow readout
TV + foil	$J_b(x,y)$	2	Develop	No inversion, fast
Optical Beam Tracker	$I_b(x,y)$	2	Develop	Uses TV systems
<u>CO₂ Interferometer</u>				
Michelson (a) cw	n_p, n_g to	2	Here	$T_r = 20ns$; needs improvement
(b) pulsed	1014	2.5	Develop	$T_r = 20$ ps
Mach Zehnder	"	2.5-3	Needs detector	Two dimensional
<u>He Ne</u>				
Mach Zehnder	n_g	2	Here	Two dimensional
Michelson	n_g, n_p to	2.5	Idea	$T_r = 0.3$ ns
	1014?			
Nitrogen line ratios	T_p, T_g	2.5	SRI	During beam After beam
Microwave absorption	n_p/v_c to	2.5	Develop	Needs effort
X-ray absorption energy analyzer	(z)	2.5-3	Under study	May be useful for measuring energy loss in gas
Miscellaneous B field rf loops capacitive probes		2-3	Here	Unavoidable
Other optical diagnostics	?	2.5	Strong feeling that several useful things will pop up!	

FINAL COMMENTS

These diagnostics, when developed, will not provide all the information desirable as summarized in Section 2. Missing are those diagnostics that give detailed information about the spatial extent of the currents flowing around the beam. Also, a good measure of the electrical conductivity on long time scales is needed to determine how the charge relaxes from the system. There is also a need to determine the EMP signature of the beam in the air, the microwave cross-section of the beam and the optical emissions generated by the beam. These diagnostics are not prioritized because they are aimed at issues other than beam propagation.

This diagnostic plan is by no means complete. The diagnostics that are needed will continuously evolve as programmatic needs change, new experiments are contemplated and new diagnostic techniques developed.

REFERENCES

- (1) J.P. Boris and J.M. Picone,
NRL Memorandum Report 4327, 1980.

M. Raleigh, J.D. Sethian, L. Allen,
J.R. Grieg, R.B. Fiorito and R.F. Fernsler,
NRL MR 4220.
- (2) Cabayan et al, "Preliminary Assessments of the Electromagnetic Environment in the Immediate Vicinity of ETA", UCID-18631, April, 1980.
- (3) T.J. Fessenden, "Capacitor Voltage Probes", ATA Note 50, August 23, 1978.
- (4) T.J. Fessenden, B.W. Stallord, G.G. Berg, RSI 43, 1789, 1972.
- (5) T.J. Fessenden, RSI 43, 1090, 1972.
- (6) J.C. Clark, "CO₂ Laser Interferometer with Feedback Stabilization", ATA Note 96, November 27, 1979.
- (7) A. Frank, S. Yu and J.A. Masamitsu, "Inductive Electric Field Effects on Optical Emissions from the Interaction of an Intense Relativistic Electron Beam with Nitrogen", UCRL 86571, October 15, 1981, to be submitted to Phys. Rev. Letters.

APPENDIX 1

Ozone Production in ATA Beam*

To estimate ozone production during ATA operation in the experimental tunnel we must distinguish production within the tank from production in the tunnel atmosphere.

For the tank we can assume that most of the ozone is produced within a couple of beam radii. In this region the radiation dose rates are extremely high ($>10^{10}$ rad-Si/sec). However, the bremsstrahlung production can be neglected because the beam energy is well below the critical energy (~ 100 MeV in air). Under these conditions the radiolytic yield of ozone is about 10.3 molecules per 100 eV deposited. If the average collision mass stopping power is taken to be $2 \text{ MeV-cm}^2\text{-g}^{-1}$, then the yield P in air is

$$P (\text{L/s}) = 5.8 I_{av} L \quad (1)$$

I_{av} is the average current in amps and L is the electron path length in meters.

For a high current machine like ATA, more convenient expression is the yield per beam pulse. Let the beam current be I_b and the pulse length be T_p . Equation (1) becomes

$$P (\text{L/pulse}) = 5.8 \cdot I_b (\text{amps}) \cdot T_p (\text{sec}) \cdot L (\text{m}) \quad (2)$$

For a typical 10 kA, 50 ns beam pulse we expect

$$P = .12 \text{ L/pulse}^{**}$$

for the beam in a 40 m tank.

* APPENDIX 1 from ATA Note 147, W. A. Barletta, April 1981.

**Liters at STP

A tank diameter of 4 ft. corresponds to a volume of 46.5 m^3 or $4.65 \times 10^4 \text{ l(at STP)}$. Therefore, ozone concentrations will increase initially by 2.6 ppm per beam pulse. With an average rep-rate of 0.5 pulses/sec this means that the ozone concentrations increase by 1.3 ppm per second, initially. Ozone decomposes spontaneously, however, reacting chemically with air impurities and other materials and decomposing via the radiation itself. The effective decomposition time will therefore depend on the experimental environment: tunnel size, materials, temperature and on the ozone concentration itself.

In research installations, decomposition times of 50 minutes are typical. The concentration buildup is described by:

$$C(t) = P \frac{\bar{T}}{V} \left[1 - \exp(-t/\bar{T}) \right], \quad (3)$$

where t is beam on time, V is the volume and $\bar{T}$ is determined by the removal processes. These may be decomposition or venting. If the air exchange time is $\bar{T}(\text{vent})$, then

$$(\bar{T})^{-1} = (\bar{T}(\text{vent}))^{-1} + (\bar{T}(\text{decomp}))^{-1}, \quad (4)$$

If the tank is not vented, the ozone concentration will build up to a saturation value, C_s ,

$$C_s = P \frac{\bar{T}(\text{decomp})}{V} = 3.9 \times 10^{-3}. \quad (5)$$

Given a concentration which will distort the air chemistry for our beam physics studies, we can design a venting system for the tank.

A second problem is the ozone buildup in the experimental tunnel. For this estimate we consider the tank to be a cylindrical source of radiation of radius R_t . At the tank wall, we have estimated the instantaneous radiation level to be

$$D = 1.4 \times 10^9 / R(\text{m}) \text{ Rad-Si}$$

during the pulse. The duty factor is the pulse length times the rep-rate RR; therefore,

$$\langle \dot{D} \rangle = \frac{70}{R} \cdot RR(S^{-1}) \text{ Rad-Si/sec.}$$

For the 4 ft. tank,

$$\langle \dot{D} \rangle = 115 \cdot RR(\text{Sec}^{-1}) \text{ Rad-Si/sec.}$$

The instantaneous rate is low enough that a radiolytic yield of 7.4 molecules per 100 eV should be used. Then the yield of ozone in the tunnel can be estimated as

$$P(\ell/\text{sec}) = 2 \times 10^{-7} \cdot \langle \dot{D} \rangle \cdot AL_w, \quad (6)$$

where A is the surface area of the tank in m^2 and L_w is the distance to the tunnel wall in meters.

For our set up $A = 153 m^2$ and L_w can be taken as 1.5 m as an average value. With these values we obtain a yield of

$$P(\ell/\text{sec}) = 5.3 \times 10^{-3} \cdot RR(\text{Sec}^{-1}) .$$

For $RR = .5$, the saturation value of ozone in the tunnel with no ventilation is

$$C_s = \frac{1.6 \times 10^{-1} (\ell/\text{min}) (50 \text{ min})}{V} .$$

The tunnel volume is $\sim 10^6 \ell$; therefore, $C_s = 7.9 \text{ ppm}$, which is eighty times higher than the threshold limit value T_{LV} , (max concentration averaged over any 8 hour shift).

We emphasize that these values are maximum levels which assume the full 40 m path length in air and full atmospheric density. As a comparison we can

estimate the ozone production cause by the bremsstrahlung from the beam dump. A rough approximation for a low Z (carbon) dump is

$$P(\ell/\text{mm}) = 10^{-4} L(\text{m}) P(\text{kW}). \quad (7)$$

The beam power is 25 kW $RR(\text{sec}^{-1})$ and $L = 5$ m, in which case

$$P(\ell/\text{sec}) \approx 2 \times 10^{-4} \cdot RR(\text{sec}^{-1}).$$

Thus, beaming onto the dump will produce about 25 times less ozone than beam-in tank experiments. This corresponds to a 3 T_{LV} saturation level.

The predominant oxide of nitrogen produced is NO_2 . For in-tank production (high dose rate conditions), the radiolytic yield is less than 0.15 molecules per 100 eV. This value is 1.5×10^{-2} smaller than the yield for ozone. The ozone projections may be scaled accordingly to obtain

$$P(\text{NO}_2) \approx 1.7 \times 10^{-3} (\ell/\text{pulse}).$$

In the tank this means 4×10^{-2} ppm per pulse. Since the NO_2 is stable, the concentration remains proportional to the number of pulses before venting.

For production in the tunnel, the low dose rate radiolytic yield is ~ 4.8 molecules per 100 eV or only 65% that of ozone yield. This yields

$$P(\text{NO}_2) = 3.4 \times 10^{-3} \cdot RR(\text{sec}^{-1})(\ell/\text{sec}),$$

or in 50 minutes a concentration of 5 ppm, which is the maximum permissible concentration for occupancy at any time. The production near the vacuum beam dump will be

$$P(\text{NO}_2) \approx 1.3 \times 10^{-4} RR(\text{sec}^{-1})(\ell/\text{sec}).$$

These estimates imply the need for the use of an air exchange system before the tunnel can be entered if there has been a significant amount (> 2 min) of operation. It has been determined that a gas scrubbing system will not be necessary.

0006A/0048b

ATA EXPERIMENTAL FACILITY

Figure 1

ADVANCED TEST ACCELERATOR EXPERIMENTAL AREA

Figure 2

ATA

Experimental Tank

Diagnostic Ports (every 10ft)

4- 18" diameter

2- 6" diameter

Tank I.D. 45.87" Wall 0.5"

Material: Aluminum

2 - 5ft sections

4 - 10ft sections

2 - 40ft sections

Figure 3