II. OPERATION AND DEVELOPMENT OF ATLAS

OVERVIEW

Highlights of the operation of the Argonne Tandem Linear Accelerator System (ATLAS) as a national user facility and related accelerator physics R&D projects are described in this chapter. ATLAS is used for basic research in nuclear physics and occasionally for other areas of research and development, including atomic physics and material science. ATLAS is also used as an accelerator mass spectroscopy facility applied to a wide range of scientific interests. Over half of the beam time is allocated to experiments for which the spokesperson is an outside user. Recent ATLAS operating performance and related development projects are described in the next section. ATLAS personnel are also involved in developing technology in support of a future advanced facility, based on ATLAS technologies, for beams of short-lived nuclei. Projects related to the exotic beam facility are described in the third section below.

Due to budgetary constraints, the ATLAS operating schedule was reduced in June 2001 from a 7 day-per-week schedule to a running schedule averaging 5.33 days per week. Even with the reduced operating schedule ATLAS provided over 5700 hours of beam for research and provided thirty-four different isotopic beams. Statistics about beam hours and users are given in Table II-1.

ATLAS continued to provide a range of radioactive species with intensities generally in the range of 10^5 to 10^6 particles per second. This year 3% of all beam-time went to radioactive beams. Beams of long-lived ($T_{1/2} > 2$ hours) species produced at other facilities and placed in the ATLAS tandem ion source and beams of short-lived species produced in-flight by inverse-kinematics reactions have been developed at ATLAS. See the Heavy-Ion Research section for a summary of recent physics results from experiments using radioactive beams.

TABLE II-1. SUMMARY OF ATLAS EXPERIMENTS AND USER STATISTICS

	FY2001 (Actual)	FY2002* (Extrap.)	FY2003* (Pred.)	FY2004 (Pred.)
Beam Use for Research (hr)				
Nuclear Physics	4740	3360	5050	5260
Atomic Physics	90	50	100	70
Accelerator R & D	194	120	150	174
Accelerator Mass Spectroscopy	570	400	500	400
Other	122	70	100	100
Total	5716	4000	5900	6004
Number of Experiments Receiving Beam	42	35	53	53
Number of Scientists Participating in Research	123	120	200	200
Institutions Represented				
Universities (U.S.A.)	22	22	19	19
DOE National Laboratories	4	4	5	5
Other	22	22	27	27
Usage of Beam Time (%)				
In-House Staff	49	59	35	35
Universities (U.S.A.)	31	30	38	38
Other DOE National Laboratories	5	5	12	12
Other Institutions	15	15	15	15
Total	100	100	100	100

*Assumes 5-days/week operations, started June 1, 2001, continues through FY2002 and 7-day/week operation resumes in FY2003.

A. OPERATION OF THE ACCELERATOR

(R. C. Pardo, D. Barnett, J. Bogaty, B. E. Clifft, S. Daley, A. Deriy, G. Gribbon, R. Jenkins, A. Krupa, E. Lindert, S. McDonald, F. H. Munson, Jr., D. R. Phillips, D. Quock, A. Ruthenberg, R. H. Scott, S. Sharamentov, J. R. Specht, P. Strickhorn, R. C. Vondrasek, and G. P. Zinkann)

a.1. Operations Summary

ATLAS provided a total of 34 different isotopes for research in FY2001. The distribution of species is shown in Fig. II-1. This is a significant increase in the diversity of requested beam species over past years and is a new record for ATLAS. Even with this large array of beams provided, ^{58}Ni stood out in popularity, commanding over 22% of all beam time. Beams heavier than nickel were provided 27.6% of the time.

The tandem injector was used for beam delivery approximately 22% of the scheduled time. A new SNICS-II ion source was procured over a year ago and has now become the most used source on the tandem. In addition, a new extraction optics system obtained when the new source was purchased was installed near the end of the year and has resulted in a significant improvement in analyzed beam from the source as well as a 15% improvement in transmission to the tandem from the source. The total improvement is difficult to quantify, but appears to be as much as a factor of 5 in total efficiency.

The tandem corona voltage grading system is now eight years old and has begun to show serious signs of deterioration. We are now unable to properly regulate current flow in the four separate sections of the system due to deterioration of the needle assemblies. This also impacts voltage stability and beam quality by increasing longitudinal emittance of the beams from the tandem.

The in-flight radioactive beam program was able to resume when a new 6-Tesla superconducting solenoid was received and installed in early 2001. This solenoid replaces an older solenoid that developed an open condition in the coil winding which could not be repaired. Acceptance tests of the new solenoid showed a factor of two improvement in beam transmission compared to the old solenoid, possibly due to better field uniformity.

The rebuilt ECR-I ion source has developed into an excellent performing source. The source has demonstrated over 200 eμA of Ar^{9+} and 17 eμA of Ni^{17+}, excellent results for a 10 GHz source. The source operating modes have clearly demonstrated the need to go to increased solenoid field strength, presently limited by the existing power supplies. New supplies allowing a 20% increase in coil current will be purchased in the coming year to allow further improvements in source performance.

In support of a significant new research initiative to search for super-heavy elements at ATLAS, work to obtain higher beam currents from ECR-II has been undertaken. High intensity beams including ^{58}Fe, ^{50}Ti, and ^{86}Kr are needed for the super-heavy element search program. A new traveling-wave tube transmitter, tunable over a frequency range of 11-13 GHz, has been purchased for two-frequency operation on ECR-II. In two-frequency mode a beam current of over 210 eμA of $^{86}Kr^{14+}$ was obtained.

In another test, 7.5 pμA of $^{86}Kr^{15+}$ was accelerated through the PII linac and studies of the linac performance and stability were made. No accelerator instabilities were observed during these tests. In order to make use of these high intensity beams, a revision of the ATLAS Safety Assessment Document and associated Safety Envelope and Operations Envelope was initiated. The approval of a new SAD and Safety Envelope is expected to be granted during 2002. Upon approval of the new SAD and Safety Envelope, preparations for tests of acceleration of multi-particle microampere beams through the entire accelerator facility will commence. Automatic beam interruption systems will be developed to interrupt these high power beams when an accelerator failure is detected. Without such safety features in place, in the event of a beam-delivery failure equipment damage could result.

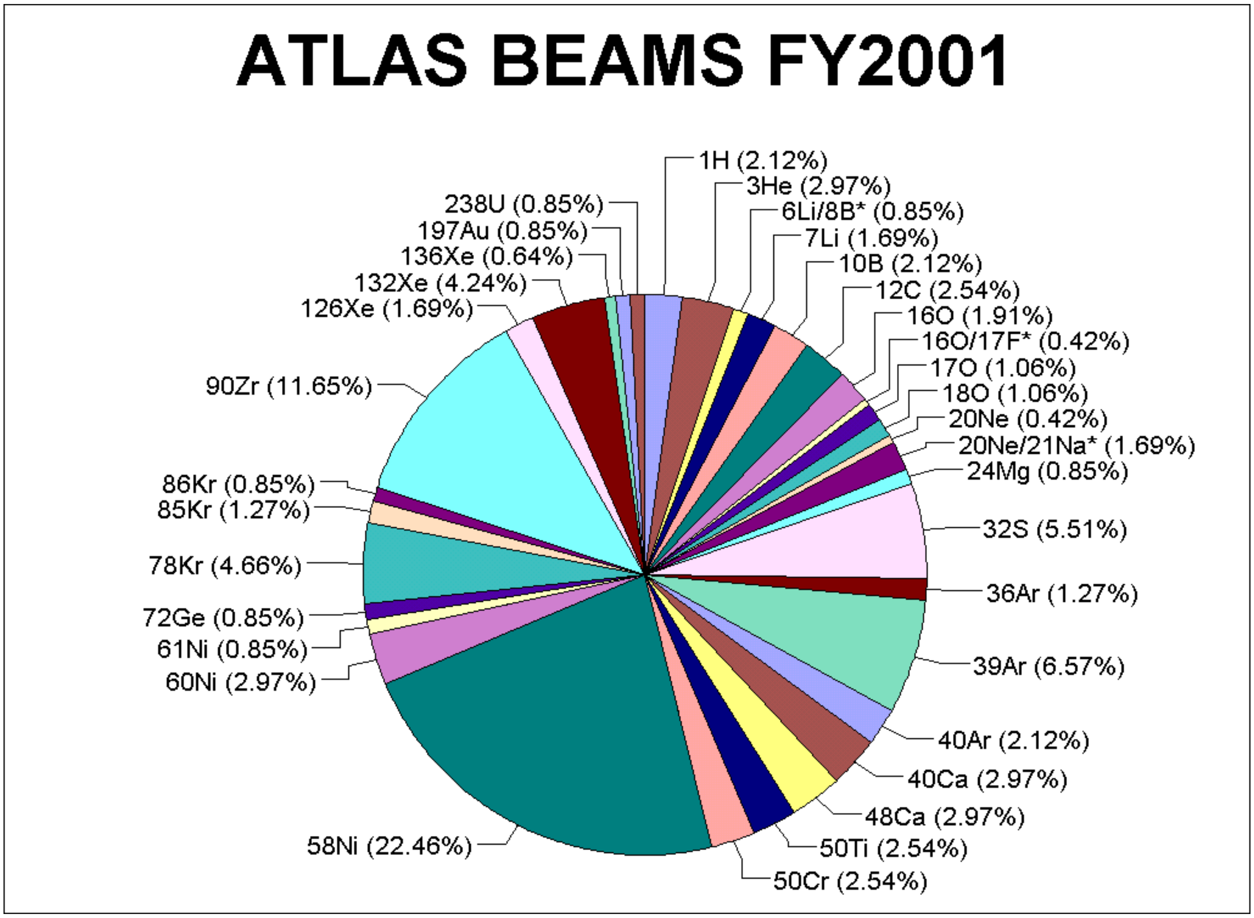

Fig. II-1. Distribution of beam time by isotope provided by ATLAS in FY2001. A total of 34 different isotopes were provided to the research program. Radioactive beams, indicated by an "" in the chart, comprised 3% of all beam time in FY2001.*

B. DEVELOPMENTS RELATED TO ATLAS

b.1. Status of the ECR Ion Sources (R. C. Vondrasek, R. H. Scott, and R. C. Pardo)

The ECR 1 rebuild, described in the previous status report, was completed in October 2000 and the source returned to full operation in 2001. The upgrade has produced a marked increase in the available beam currents for many ion species, as detailed in Table II-2, and has greatly simplified and stabilized source operation. The sputter performance of the source has been exceptional. The peak charge state of ^{58}Ni has increased from 13+ to 17+ with a corresponding factor of 25 increase in beam current. The speed of sputter sample changes has also been improved with the use of an air-lock system. The time from shutting off one sample, changing to the next, restarting the source, and delivering beam to the linac is typically 30 minutes.

The source performance continues to improve as new operational modes are reached, and the behavior of the source indicates the need for higher magnetic fields. An increase in the axial magnetic field will be accomplished through an upgrade of the solenoid power supplies. The resulting improvement in the plasma confinement should lead to an increase in beam intensity and charge state distribution.

TABLE II-2. PRE AND POST UPGRADE PERFORMANCE OF ECR-I FOR VARIOUS ION SPECIES

BEAM SPECIES	PRE-UPGRADE INTENSITY (euA)	POST-UPGRADE INTENSITY (euA)	% INCREASE FROM OLD ECR-I
Oxygen 16/5+	31	225	625
Oxygen 16/6+	54	263	385
Oxygen 16/7+	4	52	1200
Nickel 58/15+	1.6	11	585
Nickel 58/16+	1.1	15	1260
Nickel 58/17+	0.6	16	2565
Krypton 86/13+	9.5	92	870
Krypton 86/15+	8.8	99	1025
Krypton 86/17+	3.8	61	1505
Krypton 86/18+	1.5	38.5	2465

Development work at ECR 2 has focused on improving beam currents for the super-heavy research program. A ^{50}Ti beam was delivered for an experiment designed to produce ^{257}Rf. The titanium was introduced into the source via a high temperature oven which operated at ~1600°C. To achieve this high operating temperature the oven was shifted from a radial to an axial position, allowing additional heating from the plasma. A beam of ^{50}Ti^{11+} (70% enrichment) was delivered on target for a period of 7 days with a maximum intensity of 72 pnA.

The high operating temperature of the oven was at the thermal limit of the alumina structural elements, and during the run the oven failed two times due to breakdown of the alumina body. New oven bodies, constructed of a higher purity alumina with a maximum operating temperature ~250°C higher than that of the previously used material, have been purchased and will soon be tested.

The production of an iron beam has been pursued using the MIVOC method (Metal Ions from VOlatile Compounds). In this method volatile compounds having metal atoms in their molecular structure are introduced into the plasma. The compound used for the production of an iron beam is ferrocene – $Fe(C_5H_5)_2$ - which has a high vapor pressure at room temperature (~10^{-3} Torr). The material is placed in a chamber attached to the gas inlet valve of the ion source, the air in the chamber is evacuated, and the high vapor pressure of the material allows for the injection of the iron compound into the source as a gas. This has produced a peak charge state of ^{56}Fe^{15+} with an intensity of 25.0 euA. At present the efficiency and beam production of this method is superior to that of a high temperature oven. The ferrocene produced 56% more beam in the 15+ charge state with a decrease in material consumption from 1.05 to 0.88 mg/hr and an increase in efficiency from 0.13 to 0.32% for beam into the 15+ charge state. Work continues with this method to reduce the consumption rate and improve the efficiency.

During an AMS experiment designed to detect ^{39}Ar in ocean water samples, a quartz liner was used in the source to reduce background contamination. The stable isobar for ^{39}Ar is ^{39}K and is naturally present in the ion source. In an effort to reduce the potassium contaminant, the aluminum plasma chamber wall was covered with a quartz liner to provide a clean and less porous surface to the plasma. This method was successful with a factor of 10 reduction in the potassium background with no effect on the ^{39}Ar output.

The use of the liner revealed a problem with the radial magnetic confinement of the plasma provided by a permanent magnet hexapole constructed of six NdFeB bars. During the experiment the source performance degraded and the decision was made to open the source in order to investigate the cause. A 1.0 cm hole in the quartz liner produced by a concentrated loss of plasma was discovered. The plasma loss was the result of a localized 45% drop in the magnetic field of a 1.0 cm section of the hexapole bar at the hole location. The bar was replaced with a spare and the experiment resumed within 7 hours. It was later determined that the bar was originally damaged in 1997 during a cooling water failure which allowed a section of the bar to reach its Curie temperature (~50 °C) and induce a partial demagnetization. Over the next several years, the weakened state of the bar allowed the plasma to concentrate its loss at the damaged area and locally heat the bar, further lowering the field.

Work has been taking place in collaboration with Fartech, Inc. under an SBIR grant to model the charge state distribution in an ECR plasma. The model attempts to use ion source parameters such as RF power, magnetic field, and gas flux as input parameters to predict the core plasma properties. This could become a powerful predictive tool for the behavior and performance of an ion source before construction takes place.

As part of this effort, a technique for the discrete injection of a diagnostic impurity into the ECR plasma was developed in order to measure the transient extracted currents of the impurity. This technique functioned as a core plasma diagnostic that allowed the accuracy of the Fartech steady-state ECRIS core plasma code to be determined. Previously only solid materials in conjunction with a pulsed laser were used to produce the required discrete material pulse. With this new technique the pulsed laser was replaced with a fast high voltage pulse applied to a gold sputter sample. The high voltage pulse had a rise time of 100 nsec and a variable pulse duration. The resulting rise times of the gold charge states are shown in Fig. II-2. The ariation in the rise times was studied as a function of RF power, gas mixing, and magnetic fields. This information was then utilized by the Fartech group to optimize their plasma model.

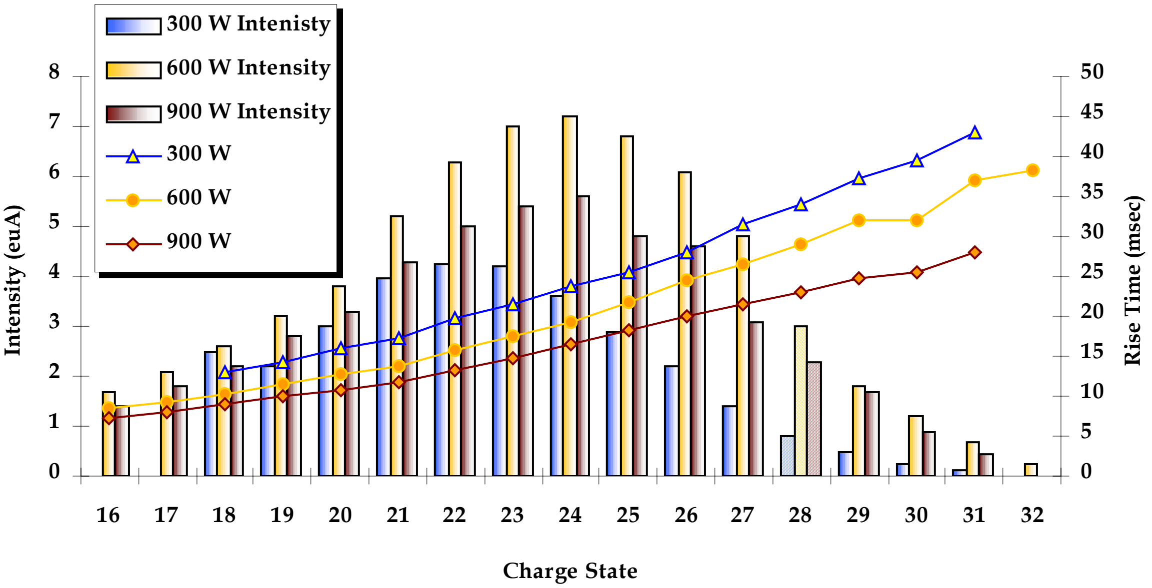

Fig. II-2. Rise times and beam intensities of ^{197}Au as a function of RF power.

b.2. Two-Frequency Operation of ECR 2 (R. C. Vondrasek, R. H. Scott, and R. C. Pardo)

The use of two frequencies is utilized to improve beam production as well as source stability. The two frequencies create two nested ECR zones leading to a higher density of energetic electrons. This increases the production of the high charge state ions and improves the overall plasma stability. ECR 2 originally took advantage of this condition through operation at 10.5 and 14.0 GHz, and ECR 1 has been designed to operate with two frequencies but has not yet run in this mode. The unit used to provide a second frequency for ECR 2, a 10.5 GHz magnetron, failed in 1998 and no replacement magnetron was available. To replace the failed unit, a traveling wave tube amplifier (TWTA) with a tunable range of 11.0-13.0 GHz was recently purchased. The tunable aspect of the TWTA allows the transmitter to operate as either the primary or secondary frequency for either ion source.

The first test with two-frequency heating at ECR 2 was performed with ^{16}O and was intended to find the optimum operating frequency of the TWTA. The source output and stability was found to improve as the gap between the primary (a 14 GHz klystron) and the secondary frequencies was increased. A shift in frequency from 11.67 GHz to 10.85 GHz produced an 11.5% increase in $^{16}O^{7+}$ beam production as well as improved stability. Further testing demonstrated that the increase in beam output was not a result of the higher overall RF power being launched into the source but rather was due to the two distinct ECR zones established by the two frequencies. This is demonstrated in Fig. II-3., which shows the performance of $^{16}O^{7+}$ at various TWTA frequencies as well as RF power levels. The source was optimized on O^{7+} using only 445 watts from the 14 GHz transmitter. The TWTA was then energized and its power output set to 60 watts, resulting in a 46.2% increase in beam current. The source was again optimized at these RF power settings with a further extension in improvement to 69.2%. De-energizing the TWTA reduced the beam current to the original output level, and the addition of 60 watts from the 14 GHz klystron could not duplicate the 66.0 euA achieved with the combined frequency operation.

Further tests were performed with ^{56}Fe from ferrocene material and 99% enriched ^{86}Kr with the results shown in Fig. II-4. The peak charge state for ^{56}Fe shifted from 13+ to 15+ with the addition of 150 W of RF power at 10.85 GHz accompanied by a factor of 2 increase in the beam intensity. The goal of the ^{86}Kr test was to produce 15 pμA of $^{86}Kr^{14+}$. This beam would meet one of the requirements for the RIA driver linac. This goal was achieved with the production of 210 eμA of $^{86}Kr^{14+}$ from the ion source with 974 W of 14 GHz RF power and 400 W from the TWTA at 10.81 GHz.

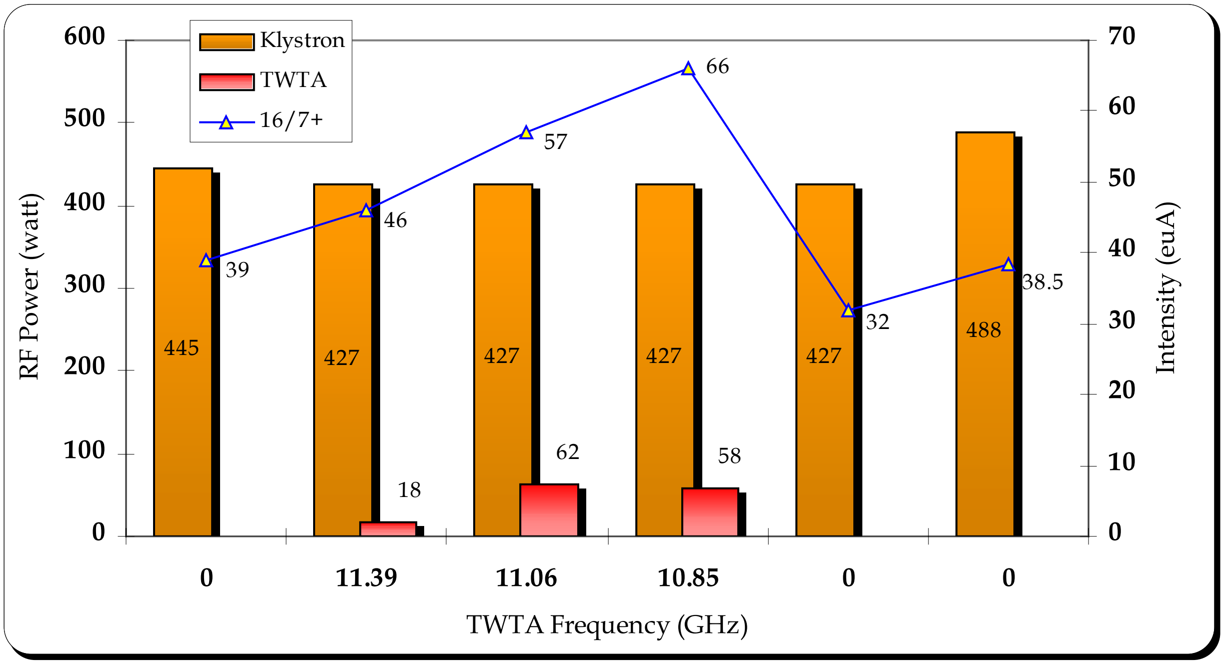

Fig. II-3. Oxygen 7+ performance from ECR 2 as a function of RF power from the 14 GHz klystron and the tunable TWTA.

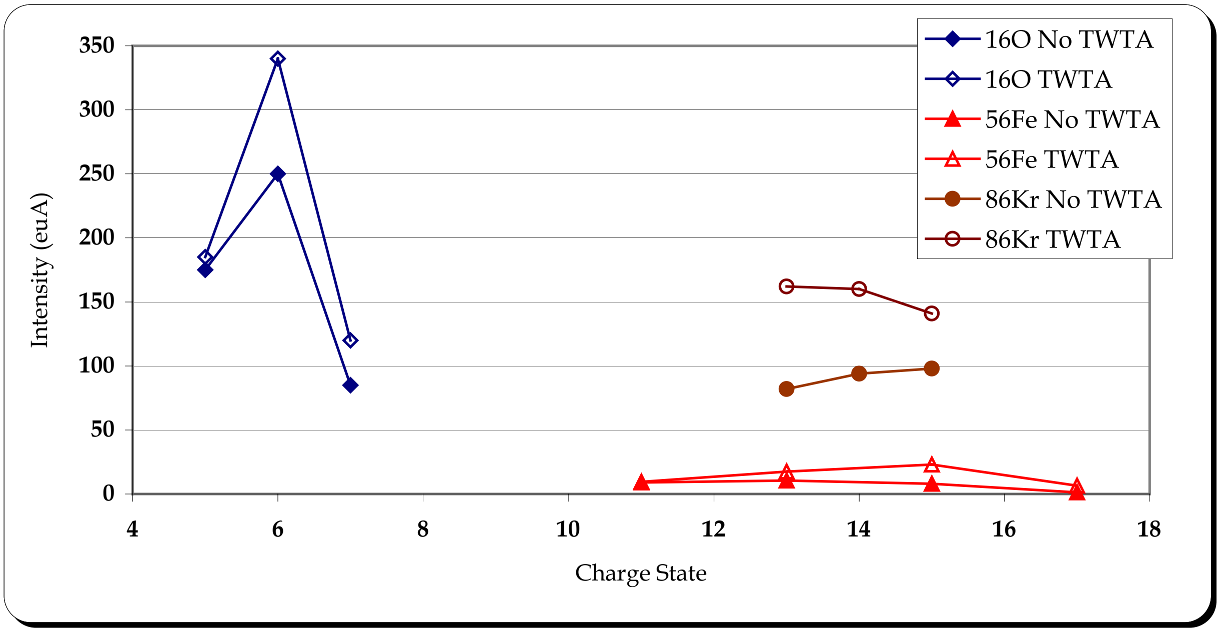

Fig. II-4. Increase in beam intensity of various ion species due to two-frequency heating.

b.3. PII Transmission Line Traveling Wave Chopper (J. M. Bogaty, S. Sharamentov, B. E. Clifft, and R. C. Pardo)

The Transmission Line Traveling Wave Chopper is now fully operational at 12.125 MHz. In routine use since early January 2002, the new chopper is reliable and easy to use. Three computer-controlled operating modes are available to make PII beam tuning easier. The high power vacuum tube RF output stage has all critical voltages and currents continuously monitored. Monitoring circuitry insures against accidental damage to sensitive components and allows automated change over from one operating mode to another. Modes are selected by computer menu, which makes beam tuning more efficient.

To date, we have chopped ions as light as neon and as heavy as nickel. Chopping voltages are within expected levels and the necessary voltages for heavy ions like lead and uranium are available. Operationally, beam transmission through PII has improved to as high as 75% with the implementation of the full bunching system. A photograph of chopper output voltage shows how wide beam bunches are at the choppers location. The thirty-nanosecond window of zero deflection voltage was determined by experimentation. This shows why a sine wave chopper is not an acceptable alternative for this bunching geometry, as beam quality would be severely degraded.

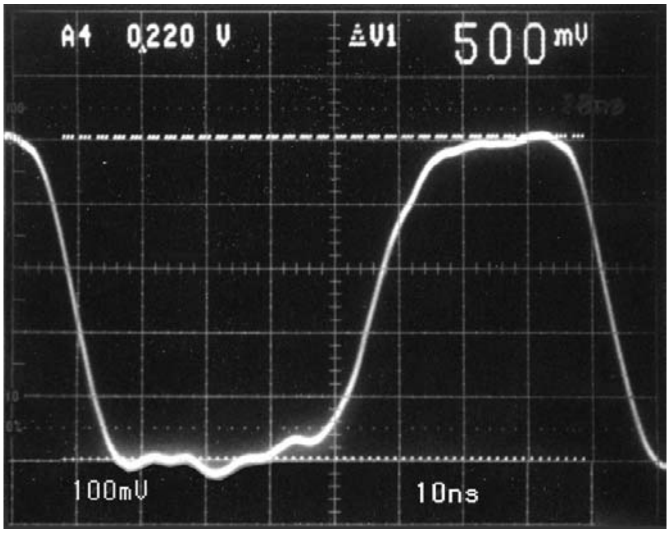

Fig. II-5. Transmission-Line Traveling-Wave Chopper voltage waveform shown is 550 V at a 12.125 MHz repetition rate.

b.4. **ATLAS Control System** (F. H. Munson, D. Quock, S. Dean, and K. Eder)

The foundation of the real-time aspects of the ATLAS control system is the commercial product known as Vsystem marketed by Vista Control Systems. Recently, on a prototype off-line system, it has been demonstrated that a port of Vsystem from the VMS operating system to PC-based operating systems provides a relatively low cost approach to distributed CAMAC I/O processing. The prototype system is capable of performing CAMAC I/O to a local crate, as well as accessing Vsystem databases on the main VMS server via Ethernet. This enables the PC to modify parameters of CAMAC modules located in CAMAC crates that are connected to the main CAMAC serial highway as well as module parameters in the crate connected directly to the PC. This is the first time Vsystem has been run on a platform other than VMS/Alpha since Vsystem was first introduced at ATLAS.

The control system's primary relational database system is Oracle Rdb, which runs on a VMS server. The method of access to this system, most often used by the operator, is a second relational database system called Paradox. This PC-based database system retrieves data form the Oracle Rdb database via Ethernet and archives accelerator parameters for individual experiments. Paradox provides an inexpensive graphical view of these archived parameters and can be used to restore the accelerator to a previous configuration. Recently this system has been upgraded to Version 9.0 the current offering of this product.

The control system intranet and WEB site that was established last year now has expanded features. Using a standard WEB browser, links provide the user access to data stored in the control system's Oracle Rdb relational database, an on-line control system manual, and a "bulletin board" describing recent changes to the control system.

A sampling of new or upgraded processes include a new "Tandem Calculation" process that performs much like a calculator, a new process and interface that scales beam line devices with energy changes, a new process that enables the selection of one magnet for a "fast scan" mode of operation for gauss meter readouts, and a new process and interface to control a new solenoid located in the post SCM beam line that is used for the latest radioactive beam experiments.

b.5. **ATLAS Cryogenic System** (J. R. Specht, S. W. MacDonald, and R. C. Jenkins)

The cryogenics group has continued to provide support to both the ATLAS accelerator and the SRF groups. Our responsibility is to provide the required cooling to all the accelerator superconducting components as well as providing many cool-downs and operations for tests using the test cryostat.

The model 1630 liquid helium refrigerator was removed from the ATLAS cryogenic system. This allowed its internal adsorbers to be replaced and internal heat exchangers to be flushed and cleaned with solvents. The refrigerator was then reinstalled. A planned ATLAS shutdown, for the removal of Gammasphere, provided the time required for this maintenance activity. The refrigerator had been in continuous use for 15 years.

Because of the required maintenance to keep the model 1630 operating, a replacement refrigerator using turbine expanders instead of pistons is desired. A model 2800 and three compressors were located at Lawrence Livermore National Laboratory. These units were about to be removed from their facility because of programmatic needs changes. We helped remove the equipment and shipped it to Argonne. Presently we have two similar model 2800 refrigerators operating. The model 2800 refrigerators use turbine expanders instead of pistons and provide additional cooling capacity. This would reduce maintenance and thus increases accelerator operation time. The planning for this installation will be done next year.

Partial installation of a computerized vacuum readout system was installed this year. When completed next year, the system will monitor all LHe and LN_2 distribution line vacuums. Individual, outdated, and expensive readouts are presently installed in a few locations, which have proven to be very useful. The new expanded readout system will also allow the readings to be consolidated into the existing ATLAS control system.

b.6. **New Solenoid for the In-Flight Production of Radioactive Beams at ATLAS** (R. C. Pardo, C. L. Jiang, K. E. Rehm, J. Specht, B. Zabransky, and A. Heinz)

In 2000 the 2.5T superconducting solenoid used in the in-flight radioactive beam program at ATLAS failed by developing an open state in the coil winding. Inspection of the device convinced us that it was not repairable and so a replacement solenoid, with a significantly higher field was procured. The new 6T maximum-field solenoid, made by American Magnetics, was received in February 2001.

Installation proceeded quickly and initial tests using a ^{17}F beam made by the d(^{16}O,^{17}F)n reaction were carried out in April 2001. Results confirmed the proper operation of the new solenoid. Total transmission appears to be slightly improved over the old solenoid. Most importantly is the increased focusing field available which allows improved performance for other RIBs at higher energies than could be adequately captured by the previous device.

b.7. **Super-Conducting Resonator as Beam Induced Signal Pickup** (S. Sharamentov, P. Ostroumov, B. Clifft, R. Pardo, and G. Zinkann)

A new method which can be used for longitudinal tuning of super-conducting linac resonators has been experimentally tested both with the first few 48.5 MHz PII resonators and with a 97 MHz booster resonator. The new idea is to use a downstream super-conducting resonator as a beam-induced RF field detector. By changing accelerating conditions at an upstream resonator (varying the amplitude and phase of the RF field) and measuring the amplitude and phase of the beam induced signal in a downstream resonator, one can get information which can be used to set the proper amplitude and phase in the upstream resonator.

An experimental implementation of this method for PII resonators is shown in Fig. II-6.

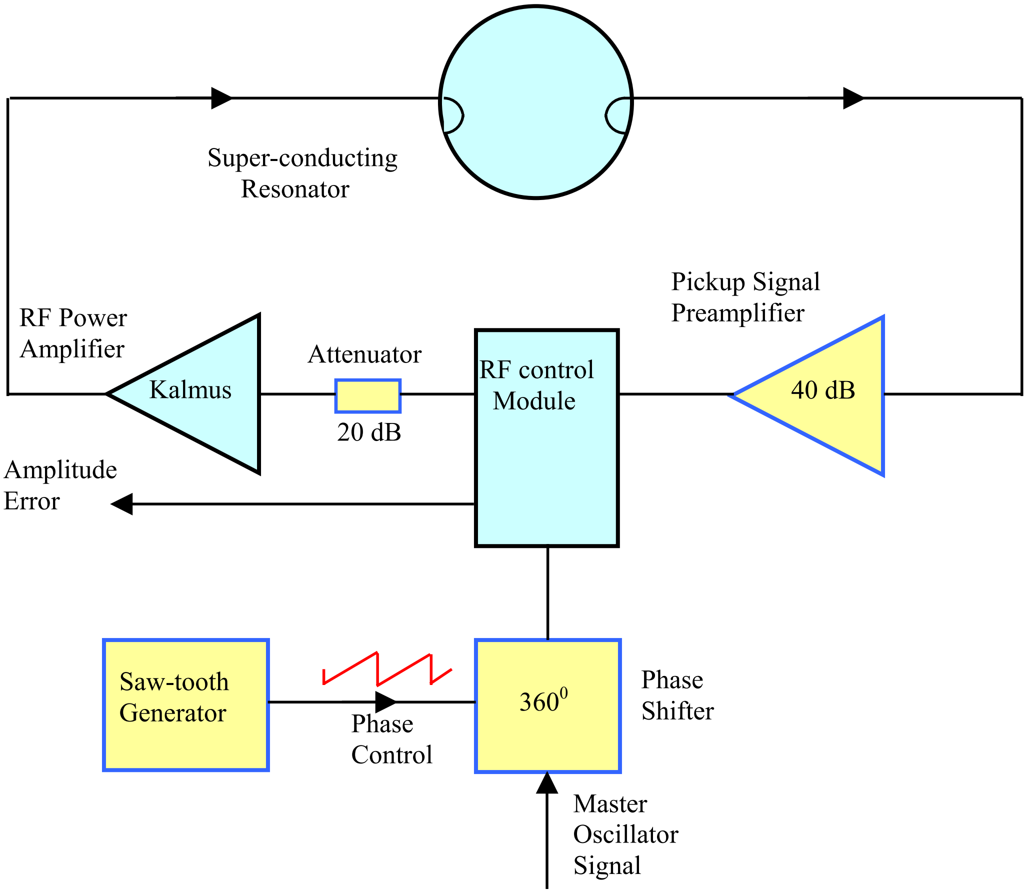

Fig. II-6. Experimental implementation of the new method. New elements designated in yellow color.

As in a normal accelerating configuration, the detector resonator works in a self-exited loop. An additional preamplifier with gain ~40 dB is added in the resonator pickup line that allows the amplitude, phase and slow tuner feedback loops to be locked at extremely low amplitude of the RF field. The low amplitude of RF field is necessary to prevent additional acceleration of the beam in the detector resonator. An external linear phase shifter, with 360° range, controlled by a saw-tooth shape signal is installed in the master oscillator line. Parameters of the phase modulation are adjusted in such a way as to get continuous circular rotation of the RF field vector in the resonator, with 6-7 Hz rate. Because of the interaction between the rotating RF field vector and the beam-induced RF vector inside the resonator, an amplitude error signal in the amplitude feedback loop is also modulated. An example of this modulation is shown in Fig. II-7.

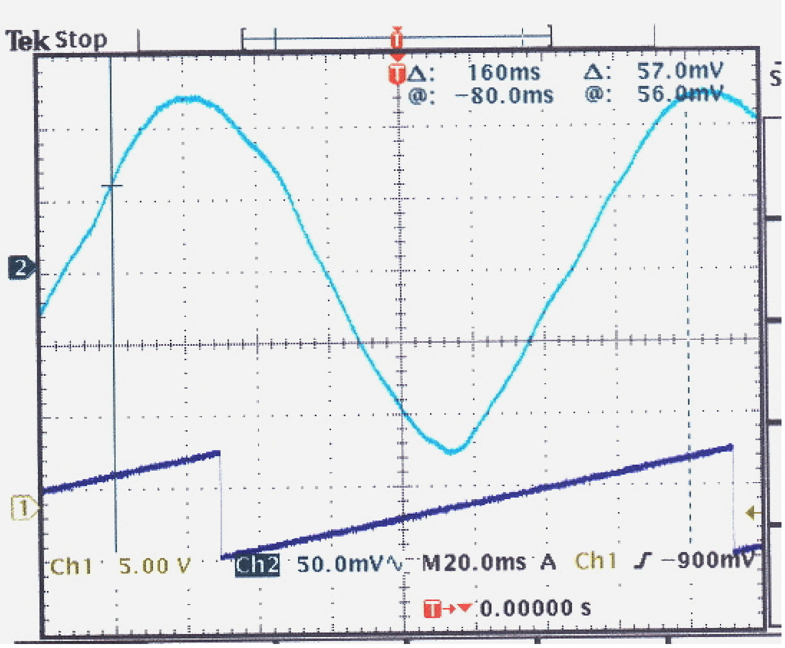

Fig. II-7. Amplitude error (top trace) and saw-tooth modulation (bottom trace) signals for R112 resonator.

Figure II-8. shows experimental results of the relative phase of the amplitude error signal for resonators R112, R113 and R114 as a function of resonator R111 RF field phase, for the $^{20}Ne^{8+}$ beam at energy of 1.99 MeV. An interpretation of the experimental curves is that the bunched beam gets maximum energy gain (maximum velocity) at R111 RF phase equals to ~300º. In other words, the value of R111 RF phase 300º corresponds to a peak value of the sinusoidal RF field.

These first experimental results, using a downstream resonator as a detector of the beam induced signal, show that this method can be successfully used for tuning the first few PII resonators. The next steps will be to modify the electronic hardware and elaborate on the setup configuration to make the measurements a routine procedure.

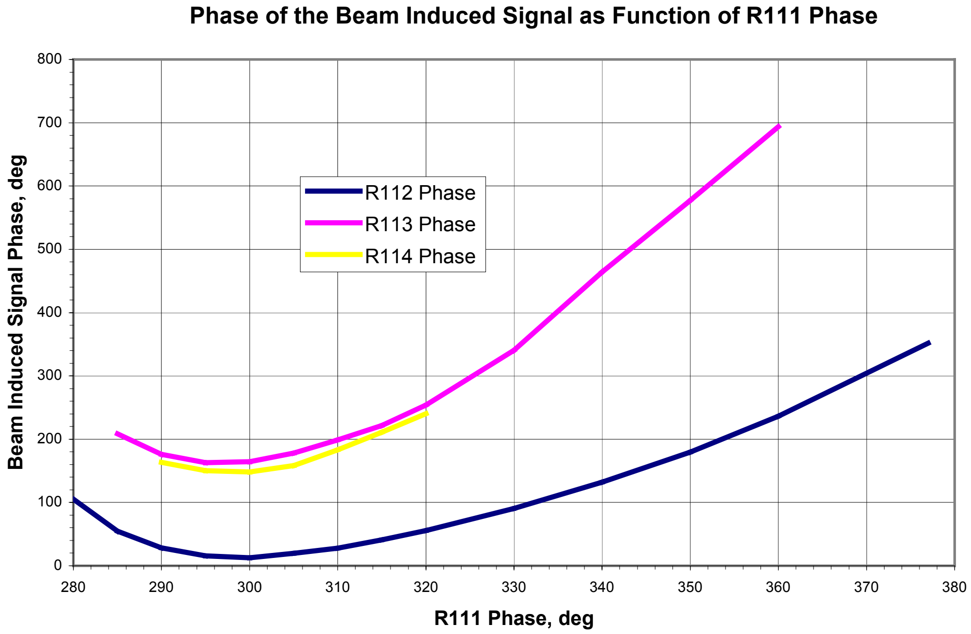

Fig. II-8. The dependence of the phase of the beam induced signal for R112, R113 and R114 PII resonator vs. R111 RF phase. R111 RF amplitude equals to 4.0 V.

b.8. **Superconducting Surface Treatment** (G. P. Zinkann, M. Kelley, M. Kedzie, and R. Jenkins)

A high-pressure rinse (HPR) using 1400 psi de-ionized water has been applied to 12 of the superconducting high-beta cavities in the ATLAS accelerator. The goal of this process is to restore past resonator accelerating field levels by removing accumulated particulates and water-soluble materials from the inner resonator surfaces.

The HPR application was performed in three stages. For the first stage, a high beta cavity (H29) was rinsed and tested in the Superconducting Research Facility's off-line test cryostat. The results of the HPR of cavity H29 are displayed in the Q curve in Fig. II-9. One sees a dramatic improvement in the maximum filed performance for this resonator.

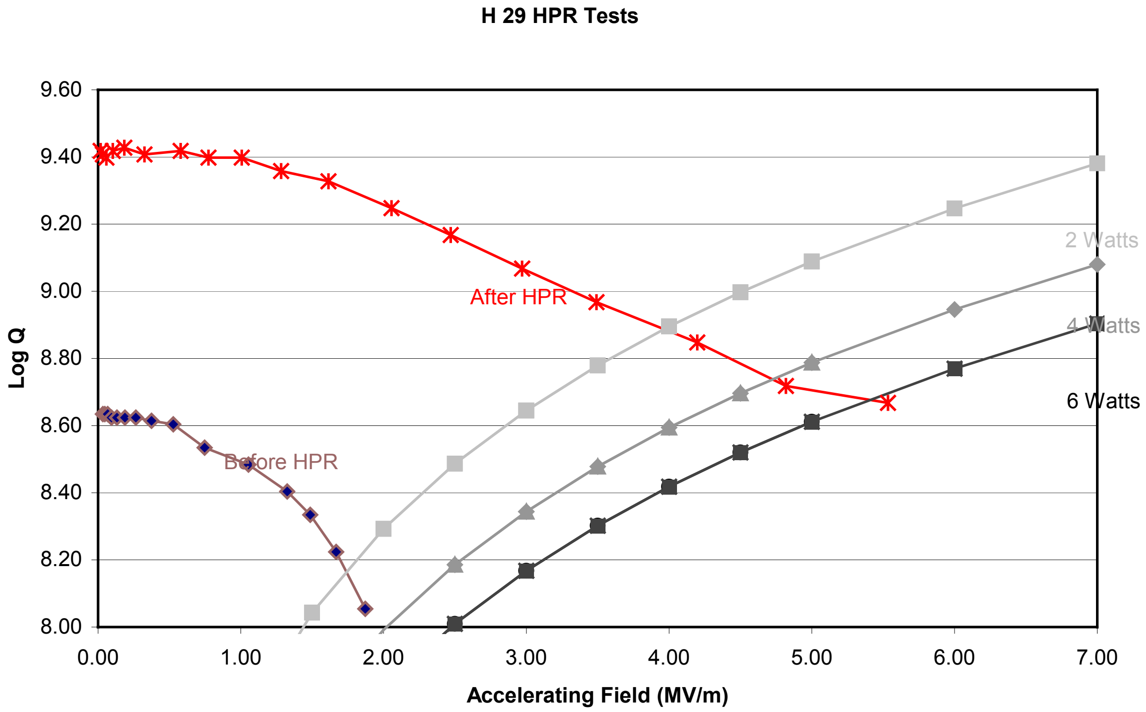

Fig. II-9. Resonator H-29 field performance before and after high-pressure water rinsing in off-lines tests before and after rinsing. The ATLAS cryogenic system is designed to have an average cooling capacity of 4 watts for each resonator.

Based on the successful results of this test rinse, all six high beta cavities in "C" Cryostat were removed and underwent the HPR process. After the HPR the total accelerating field increased by 48.1%. The before and after results are listed in the bar chart in Fig. II-10.

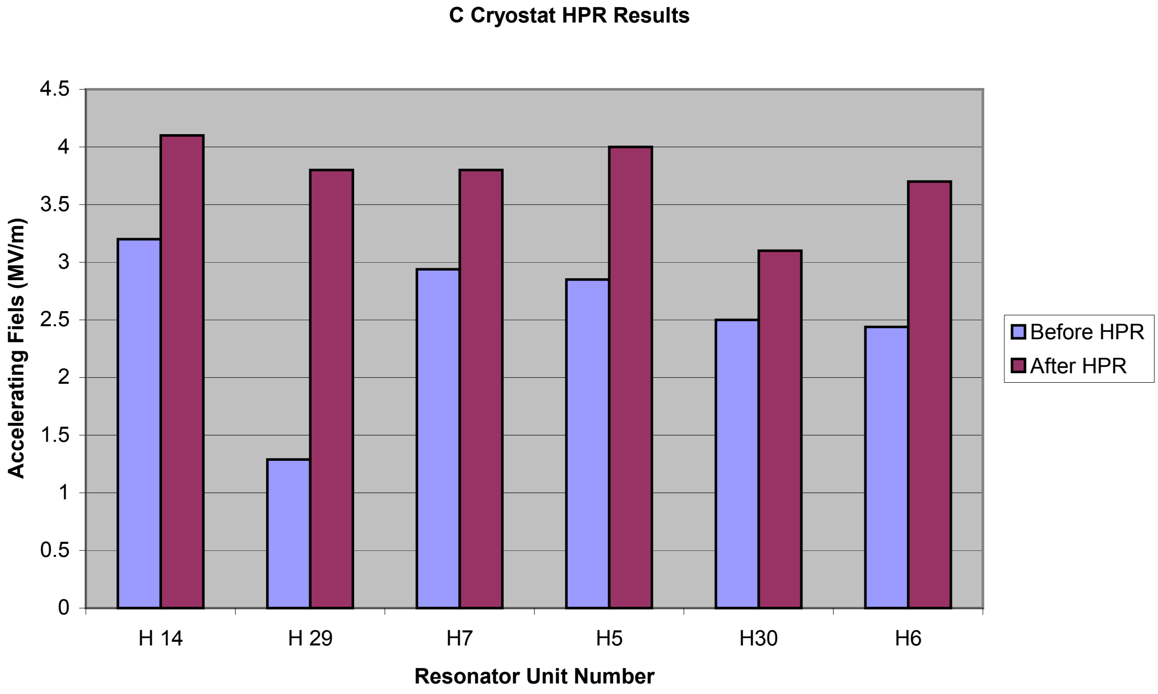

Fig. II-10. Maximum accelerating fields achieved by resonators in the Booster linac "C" cryostat before and after high-pressure water rinsing of the resonators.

The third stage of the rinse program has just been completed. Six resonators in "F" Cryostat have been removed from their cryostat and given the high-pressure rinse cycle. The evaluation of the accelerating field levels will be performed as the operating schedule permits. At this time, only the first cavity has been conditioned and evaluated. The results for this cavity show an increase in operating field from 3.75 MV/m to 5.3 MV/m.