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THE STATUS OF THE SUPERHILAC

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THE STATUS OF THE SUPERHILAC*

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Summary

The SuperHILAC is an Alvarez linear accelerator designed to accelerate all ions to a maximum energy of 8.5 MeV/u. It functions as an essential part of two research programs of national importance--first, as a supplier of beams for research at less than 10 MeV/u, secondly as an injector for the Bevalac facility, for nuclear physics and medical research at energies greater than 200 MeV/u. This duplication of effort from a single accelerator is made possible by the utilization of a technique known as timeshare--two different ion beams are accelerated independently through the same linac structure. Recent operation has been in the mass range $12 \leqslant A \leqslant 136$. Usually, a heavy ion ($A > 40$) is delivered to the SuperHILAC experimental area for nuclear physics experiments while concurrently delivering a lighter ion ($A \leqslant 40$) to the Bevatron for further acceleration (max. 2.5 GeV/u) to be used in experiments exploring the physics of very high energy heavy ions, in investigations of radiation biology, and in preclinical tests as a tool for cancer treatment.

Recent operating experience is reviewed. Also discussed are recent major improvements which have made to the accelerator, and a proposed improvement which will increase reliability and beam intensity for the very heavy ions ($A \gtrsim 84$) by adding a third injector of improved design.

Facility Description

The SuperHILAC (Fig. 1) provides a wide variety of heavy ion beams for use in programs of basic research. It is an Alvarez linac of large duty factor (~30%), and provides a range of continuously variable energies (2.4 to 8.5 MeV/u. The linac has been previously described.[1] The prestripper accelerates ions from 0.113 MeV/u to 1.2 MeV/u. After stripping the beam is accelerated in the poststripper to the final desired energy. The energy variation is accomplished by dividing the poststripper into six independently driven rf sections, each with about 1 MeV/u energy gain. Discrete jumps in energy are obtained by simply turning off the appropriate sections. A continuous variation of energy is obtained by proper adjustment of rf gradient in the last active section.

The SuperHILAC experimental area at present consists of 11 beam lines serving 8 experimental caves (Figs. 2 and 3). In addition, a transport line provides a beam for injection into the Bevatron, as part of the Bevalac facility.[2] Changes of ion, energy, or beam line are frequent--on the order of several times per week. Normal operation is the timeshare mode--i.e., simultaneous delivery of beams to a SuperHILAC user and to the Bevalac. In addition, the Bevalac facility may also have simultaneous users.

Operation of a facility of this complexity requires the orderly manipulation of a vast amount of data. A network of minicomputers is used to run the SuperHILAC, with disc storage of operating parameters required for different ions. Setup of a new ion beam starts with calling in the appropriate machine parameters from the disc. The computers contain a table of machine settings for each beam being timeshared. A timeshare table supplied to the computer determines the sequence of pulses devoted to the respective ions.

Multi-Ion Acceleration

In the linac, focusing is accomplished by means of quadrupoles incorporated in the drift tubes. The prestripper contains 135 quadrupoles and the poststripper 70. The quadrupoles, all but two of which are operated d.c., form a strong focusing channel which will accept a wide range of beam rigidities.

Acceleration will be possible only if particles have the proper energy at each point along the linac. However, ions with radically different charge to mass ratios q/u (and hence different rigidities) can be transmitted without loss providing acceleration conditions are met. For acceleration the electric gradient $\hat{E}$ must satisfy the relation $\hat{E}\ q/u > C$, where C is some constant. The rf is turned off after each pulse and turned on anew for the next pulse. For timesharing ions of different q/u, it is simply necessary that for each pulse, $\hat{E}$ be set appropriately for the ion being accelerated. Since the SuperHILAC contains eight independently driven rf tanks, the rf gradient for each tank, as well as the phase between tanks, must be set each pulse for the ion being accelerated.

The real problems which arise in multi-ion acceleration come from second order effects. In transverse phase space, beam wandering due to quadrupole misalignment depends upon focusing strength of quadrupoles, and will be different for the beams of different rigidity. The compact construction of the Alvarez linac leaves little possibility for observation and correction of misalignments within the linac. Consequently, while turning the linac for optimum transmission of an ion beam can be an exacting task, tuning the linac for simultaneous transmission of two ion beams of different rigidities is a task of much greater difficulty. However, several tunes for particle combinations have been successfully developed and are being used routinely.

Timeshare Operation

There are two injectors, each with its associated d.c. transport line, which converge at the entrance to the prestripper (Fig. 1). There a pulsed switching magnet (PM1) bends the appropriate ion into the linac. The switching magnet can be changed from maximum negative to maximum positive magnetic field in 8 msec. At the poststripper exit, another similar switching magnet (PM4) bends the ion beams into the appropriate transport line.

There are three modes of operation which are of interest with respect to time-sharing at present.

1) Sharing on a pulse to pulse basis between a SuperHILAC experimenter and the Bevalac, for example 34 pps going to the SH user and 2 pps to

the Bevalac. The Bevatron uses one pulse every 4 to 6 sec for acceleration, the remainder are used for tuning the transfer line.

2) In addition to 1, a parasitic SH user, takes perhaps 1 pps of either beam to test counting equipment, measure energy or charge state, etc. The potential advantage in using parasitic beams is enormous, for much important work can be done with these beams without lowering the duty factor of the primary user appreciably.

3) The primary beam being delivered to the SH users is shared between two users in such a way that duty factor is conserved. This is done by use of a "beam splitter" magnet with a thin septum. In this case the ion species and energy are the same for the beams delivered to the SH users. This beam splitter facility is not now available but is planned as a future improvement (see below).

The first timeshare operation occurred in April 1975. The pulsed components--rf and switching magnets--operated satisfactorily from the first. Interference between the tuning requirements for the beams was a serious problem at first but as the operators' skill in simultaneously controlling two different beams improved, the interference problems became much less severe. At present, when two different ions have been tuned up, the intensity of each beam is approximately what one would expect if the accelerator was running that beam alone. The computer control system, a vital ingredient in achieving smooth timeshare operation, will be discussed below.

Operating Experience

The SuperHILAC is operated for about 10 months of the year, with usually one major shutdown during the year to incorporate substantial improvements. This is a pattern that seems to work well because it combines a maximum of running time while allowing a satisfactory rate of improvement. During running periods, operation of the SH is as continuous as possible, in order to minimize time lost in start-ups. Operating staff is about 84 people, with 10 accelerator operators and 11 electrical maintenance technicians on shift duty to run the machine. The remainder of the staff provide support in the form of electrical and mechanical technicians and engineers, physicists, computer specialists and administrators. This operating staff is the minimum number which can run the SuperHILAC efficiently, with each person performing a necessary task and with no waste effort.

Utilization of the machine is determined by a Program Advisory Committee, composed of leading nuclear scientists, which accepts proposals for experiments to be performed at the SH and assigns time based on its' evaluation of the scientific worth of each proposal. A similar committee functions to assign Bevalac time. The operating schedule is then worked out by the operating staff in consultation with users' representatives. This is not a trivial task, for there are a great many constraints which must be taken into account if the operation is to go smoothly. A typical schedule for the SH/Bevalac covering a two week period is shown in Fig. 4. In this period, carbon is being used by the Bevalac, neon by the Bevalac and by a SH user, krypton by three SH users. The SH must be turned up to either a new beam or a new beam line, nine times.

These scheduling details, which might be considered superfluous in a technical paper, are introduced to underscore the following point: it is very important to us that the SuperHILAC operate reliably. Groups of scientists come from all over the United States, as well as many from outside the United States, to do experiments. An occasional interruption of a few hours can be tolerated, but if the accelerator is down for a day or more an experiment will be lost, causing great inconvenience to the group involved. Consequently we are making efforts to improve reliability. This takes the form of keeping failure records, redesigning and rebuilding components that are prone to failure, and improving control systems and operating procedures to eliminate wasted time.

Operational efficiency, as measured by the ratio of actual research hours to scheduled research hours, has averaged 80% over the last 18 months. Most months it has been between 70 to 90%. Since in this accounting, source changes are included in down time, 100% efficiency would be difficult, but something exceeding 90% would be a realistic goal. So far this has been approached for 1 month, September 1975 with 93%.

Detailed records which have been kept of SH operations show in the same 18 month period that if source changes are excluded, the mean time between failures (MTBF) has been 8.9 hours. The mean time to repair (MTTR) was 1.9 hours. The MTTR can be considered acceptable for a research machine, but to achieve an availability of say 95% the MTBF must be increased to 36 hours.

Table I lists the major beams which have been run at the SuperHILAC to date and their intensities. It should be borne in mind that at the poststripper exit more than one charge state is usually measured. The amount which can be used for an experiment varies from 100% to about 30% depending upon the ion and upon conditions of transport. Also, intensities achieved for a given beam depend upon frequency of use of the beam and upon the experimenter's intensity requirements.

TABLE I

SUPERHILAC BEAM INTENSITIES

Ion	Ave. Particle nA at Poststripper Exit
^{12}C	2900
$^{16}O(^{18}O)$	1700
^{20}Ne	2100
^{40}Ar	1700
^{48}Ca	250
^{56}Fe	30
$^{86}Kr(^{84}Kr)$	180
$^{136}Xe(^{132}Xe)$	38

Injector Status

The 750 kV Eve injector is used for ions of mass up to 40, and requires a charge/mass ratio q/u of at least 0.15 (e.g., $^{20}Ne^{3+}$) from the ion source. The 2.5 MV Adam injector is used for heavier ions of mass 40 or more. For Adam the q/u must be at least 0.046 (e.g., $^{238}U^{11+}$). These values of q/u for the two injectors provide ions of 0.113 keV/u, the energy required for proper acceptance by the first linac tank of the SuperHILAC.

The sources of both injectors are PIG type; the Adam source has been recently modified by the addition of a sputter electrode, permitting metallic ions to be run.[3] Performance has been gratifying--the output of iron, for example, is comparable to the output of krypton. A recent experiment used the sputter source to accelerate ^{48}Ca. The pure isotope was used and as this metal is extremely rare, a single sputter ring was used instead of the two normally used. Source output of $^{48}Ca^{3+}$ was still above 100 μA, and 0.14 particle μA of accelerated beam was delivered to the target. After the run, the anode cylinders were processed chemically to recover ^{48}Ca for reuse--this is possible because very little of the metal is actually used for the accelerated beam, nearly all of it condenses on the iron source, mostly the anode cylinder.

Other recent improvements to Adam include replacement of the telemetry system with one which is noise-free in operation, and installation of a new accelerating column supplied by National Electrostatic Corp. (Fig. 5). The new column is modular in 12 in. sections bolted together. Rings are titanium, with alumina spacers. Diaphrams with 2 in. diameter apertures are installed on 13 in. centers as electron traps. This new column has much lower electron loading than the old, consequently better voltage holding properties and less radiation due to X-rays.

Computer Control System

A computer control system was installed at the SuperHILAC after the accelerator had been running satisfactory with analog controls for 4 years. This was because the greatly increased complexity caused by the introduction of timeshare required an extensive revision of the accelerator controls. It was felt, as has proved to be the case, that shifting to a computer control system at this juncture would result in a more manageable system, with much more flexibility than would be possible with analog controls. A single computer control system was implemented in April 1975 together with timeshare operation. Although we were able to get the system installed and operating quickly we knew that it would not have enough band width to handle all of the parameters we eventually wanted to control. Consequently, a system possessing adequate flexibility and expansion capability was installed in April 1976.

A schematic of the computer control system is shown in Fig. 6. A central processor (Mod Comp IV) is linked to operator control consoles and to standard peripheral devices, including a 26 MW disc. It is also linked to two smaller processors (Mod Comp II's) which are used to control accelerator hardware on a real time basis. A third Mod Comp II is linked to the central in order to develop programs and operator displays utilizing operating data which is available to the control system. A graphics terminal is used for this work. The remote process I/O hardware (labeled "clusters" on the diagram) was procured commercially. Use of commercially available hardware has been a great benefit to the SuperHILAC system, resulting in a lower cost for an operating system, and a greatly reduced time for bringing the system into operation. These questions have been discussed in a paper by Belshe et al.[4] The large amount of core available permits much of the programming to be done in Fortran. Anticipated expansions of the system include installation of two more control consoles (for a total of four), addition of core to the central processor (for a total of 192 K). Additional accelerator hardware to be controlled in the future includes drift tube magnet power supplies, injection transport lines, injectors, and additional magnets and digital devices in the experimental area.

Control Room and Operator Consoles

The modernization of the SH control room facilities was completed in July 1976 (Figs. 7 and 8). This work, long overdue, was slowed by the necessity to execute the work during short shutdowns, and the need to remove and relocate masses of cables and piping which occupied the only available space. In the control room, three modular racks are arranged in a U shape, providing three work areas for operators, corresponding to the present need for acceleration of three timeshare beams. Each work area is large enough to accommodate several people, and the areas are sufficiently separated to permit these groups to function without interfering with each other. At the same time, the consoles are all easily visible from a central location, and operators can easily communicate with each other. All of these features are important. Setting-up a timeshare beam is a process requiring concentration and freedom from interference. At busy times, when beams are being tuned up, a dozen or more people might be working in the control room. At quiet times, it might be necessary for a single operator to keep his eye on the whole operation. The floor is carpeted, and the walls and ceiling are lined with acoustic tile. This has proved to be very effective in noise reduction. A quiet conversation at one console does not disturb people at other consoles, but a raised voice can be heard.

The consoles themselves were designed with the benefit of many years of LBL experience, to be comfortably used by a seated operator. The slant panel is reserved for the most used knobs, the table providing a resting place for elbows. The upper panel is slanted inward to permit easier viewing by the operator.

The central console consists of a large TV monitor, with attached pushbutton keyboard, and a knob panel with associated keypad (Fig. 9). The TV screen displays 48 lines of 72 characters each. The screen is divided into three control areas. Two are obtained by dividing the screen lengthwise into two equal halves. The upper half, not used at present, is for monitor and SH status information; the lower half contains a list of controllable devices which are continuously monitored, such as magnets and RF. The list of devices is long, however only 16 lines are displayed at a time, the list being scrolled on the display as necessary. The third area comprises a vertical strip along the right hand edge of the screen, 12 characters wide. In this area, 16 boxes are delineated, each box being associated with a push-buttom mounted along the right-hand edge of the screen. Characters appearing in the boxes serve to label the action which results from pressing the button. This pushbuttom table has many uses, the principal one being the control of two state devices, for example actuators for Faraday cups and on-off control of power supplies, etc.

A panel located below the TV monitor contains 4 knobs. The upper two are used for cursor control and display scrolling, respectively. The lower two are used for control of devices selected on the control display by means of the cursor. Names and associated parameters of devices selected for knob control are duplicated on the lowest line of the control display. To the right of the 4 knobs are located two keypads, for functions associated with use of knobs and for keying in numbers.

SH Experimental Area

In the spring of 1976 the experimental area at the SH was rebuilt (Figs. 2 and 3). Objectives in the rebuilding were--furnishing a new east cave area containing 3 caves with 6 beam lines, separation of the Bevalac beam line from other user beam lines, and the provision of a means of orderly future expansion of the experimental area (see Improvement Plans, below). Most beam lines now have adequate quadrupoles to permit flexible matching of beams emerging from the poststripper, a necessity for timeshare operation. All beam lines are now furnished with improved vacuum pumping. Steering magnets are placed at frequent intervals along the beam lines. In the experimental area, all control and monitoring of power supplies, vacuum valves, Faraday cups and other devices, is done via the control computer. This is supplemented by a local analog control where dictated by operational convenience--as with vacuum valves. Where personnel safety requirements dictate, as with the cave gates, analog interlocks with beam stops are employed, and override any computer command.

The new magnet M7 (Figs. 10 and 11) which switches beam at the entrance to the east cave area, is the largest magnet yet built employing the unique tapewound magnet technology, which was developed at LBL under the leadership of Bob Main.[5] This magnet is able to bend the stiffest SH beams of 2.5 Tesla-m through angles ranging from -60° to 38°. A conventional magnet with the same capacity would be considerably larger. The asymmetrical shape of M7 was chosen by its designer, Ron Yourd, so that the copper and iron would fit as closely as possible to the geometry imposed by the beam lines, thereby saving considerable materials and expense compared with a symmetrical design.

Another magnet of unique design is M1, the three-channel septum magnet (Fig. 12). The magnet provides independently controllable fields for the two outside channels which bend through -16° and +16° respectively. The center channel is field free except for a small region at the exit provided with its own small coil for steering purposes. The coils are constructed of stacks of copper sheets insulated from each other except for connections which permit one current path through the vertical stack. The stack of sheets is then milled to a shape that will fit the prescribed cavity in the magnet. Cooling is by freon which circulates in the gaps around each coil.

Drift Tube Alignment

In March 1976 a long shutdown afforded the opportunity to realign the drift tubes. The previous alignment was in October 1973, at which time the rms alignment error was lower than 5 mils rms. When measured in March prior to any realignment, the rms error was horiz. 5.1 mils, vert. 6.1 mils. Realignment was accomplished using the pulsed wire technique[6] together with a sensitive "electronic eyeball" to detect wire motion. Remeasurement established that rms fit was below 3.5 mils in both planes. However, it was also established by putting the tank under vacuum and them remeasuring that the drift tubes moved, increasing the alignment error by as much as 2 mils rms. This movement resulted because the drift tube support mechanism, which must admit fine adjustment, does not lock sufficiently well to prevent motion under atmospheric forces. In the future, it is anticipated that realignment will be done at 2 or 3 year intervals.

Improvement Plans

Magnets are under construction for the first phase of the stripper analysis system (Fig. 13). A pulsed bending magnet (PM2) located at the center of the stripper area will switch out selected pulses for analysis by the 72° magnet. At the focal plane of this system stripped charge states can be measured, as well as energy and phase of the beams. These measurements will facilitate tuning of the prestripper on a non-interfering basis. A possible future development in this area, also indicated on Fig. 13 is a "loop" to return charge states to the poststripper after analysis, for further acceleration. This would guarantee a single charge state for poststripper acceleration and produce very clean beams for experiments.

Plans for future expansion of the experimental area are shown in Fig. 14. At present most of the SH users are located on one of the three timeshared beam lines. Another pulsed magnet (PM5) will be installed on this line so as to timeshare between three lines. The switching magnet M3 will be replaced by a new three channel septum magnet similar to the present M1. In addition, a beam splitting facility will be installed, which will allow splitting a beam bunch into two or three channels, while conserving duty cycle. This splitter magnet (M2) will be located just downstream of PM5, so that the split beams can be fed into the three channels of M3.

Future cave expansion has been provided with three unfinished caves located in the North part of the experimental area. To the South, a large area has been reserved which will accommodate another cave area, as well as a large rotating spectrometer.

As part of an ambitious plan for supplying uranium beams to the Bevalac facility, a two part program is proposed. One part is the upgrading of the Bevatron vacuum from 10^{-7} to 10^{-9} torr to permit acceleration of partially-stripped ion beams. The other part is the addition to the SH of an injector capable of supplying intense heavy ion beams. The present injector (Adam) must accelerate high charge states--11+ for uranium--from a PIG source, necessarily at a much lower intensity than would be obtained from low charge states. The proposed third injector has been inspired by the great success at the Unilac of the Wideröe linac for low β acceleration. At the SH, a 400 kV Cockcroft-Walton will be used to supply 7+ U ions to a Wideröe, which will accelerate to SH injection energies, 113 keV/u. This machine is described in another paper at this conference.[7] The beam must be stripped to a higher charge state (11+ U) before further acceleration. The transport line between the C-W and the Wideröe will be designed as an analysis system, so that isotropic states can be separated. A schematic of the proposed system is shown in Figs. 15 and 16.

Another area where improvements are planned is in SH instrumentation. The present instrumentation does permit adequate delivery of beam to experiments, but it is destructive so that when beam is being monitored, it is not delivered to the experimenter, and when on the experimenter's target, it is not adequately monitored. New instrumentation is being developed for non-destructive profile monitoring, as well as energy and phase measurement. Other requirements to be satisfied by the new instrumentation is timeshare compatibility, i.e., ability to short out different mode pulses, and digital output which can be digested by the computer. Although analog instrumentation can be useful for specific situations, the computer provides the most economical means for handling the volume of complex data which will be generated by this instrumentation, and presenting it in useable form to the several control consoles.

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*This work was done with support from the United States Energy Research and Development Administration.

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Figure Captions

Fig. 1. Plan of SuperHILAC.

Fig. 2. SuperHILAC experimental area, August 1976.

Fig. 3. View of cave A, SuperHILAC experimental area. Foreground-intersection of lines E11 and E15.

Fig. 4. Typical SuperHILAC/Bevalac schedule.

Fig. 5. View of new Adam accelerating column, looking downstream.

Fig. 6. Schematic of computer control system.

Fig. 7. View of control room.

Fig. 8. View of computer room.

Fig. 9. Portion of SuperHILAC control console showing CRT monitor with scrollable list of elements in lower part of screen. Note labeled pushbuttons along the right hand edge of the CRT.

Fig. 10. M7 switching magnet during assembly. Lower yoke, coil, and vacuum chamber are in place.

Fig. 11. M7 installed in cave (foreground), prior to hookup of cables and vacuum pipes. Magnet in background is M22.

Fig. 12. View of the three channel septum magnet M1, with the top plate removed.

Fig. 13. Stripper area analysis system.

Fig. 14. Proposed future expansion of the SuperHILAC experimental area.

Fig. 15. Plan of proposed third injector for the SuperHILAC.

Fig. 16. Elevation of proposed third injector for the SuperHILAC.

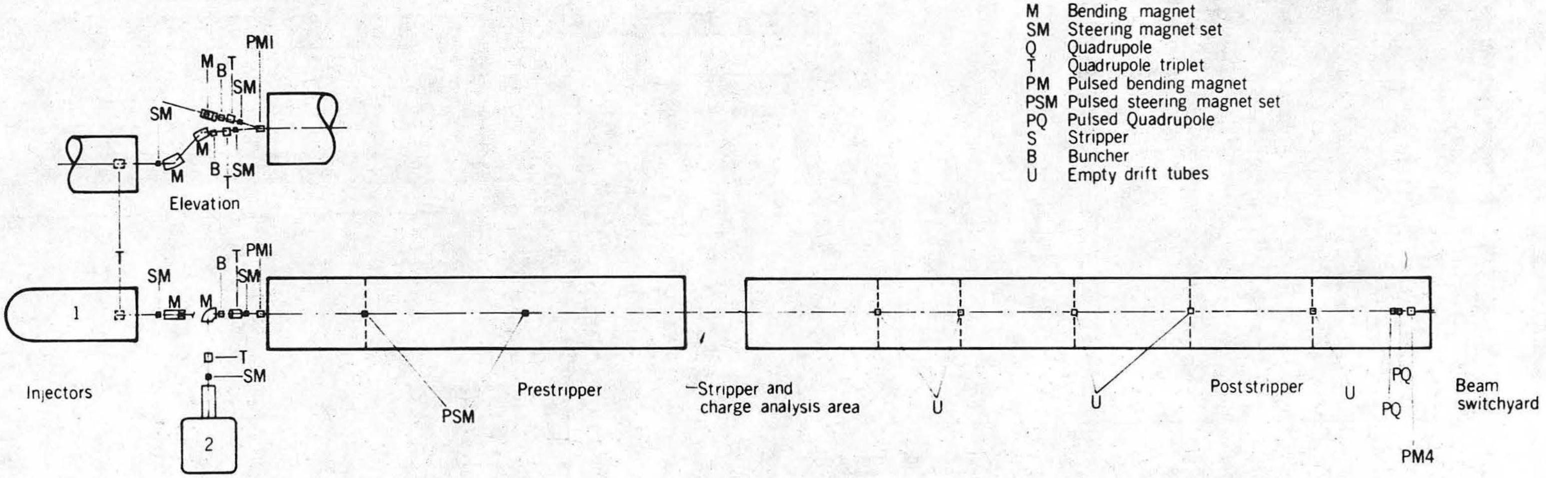

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Fig. 1

Plan of the SuperHILAC

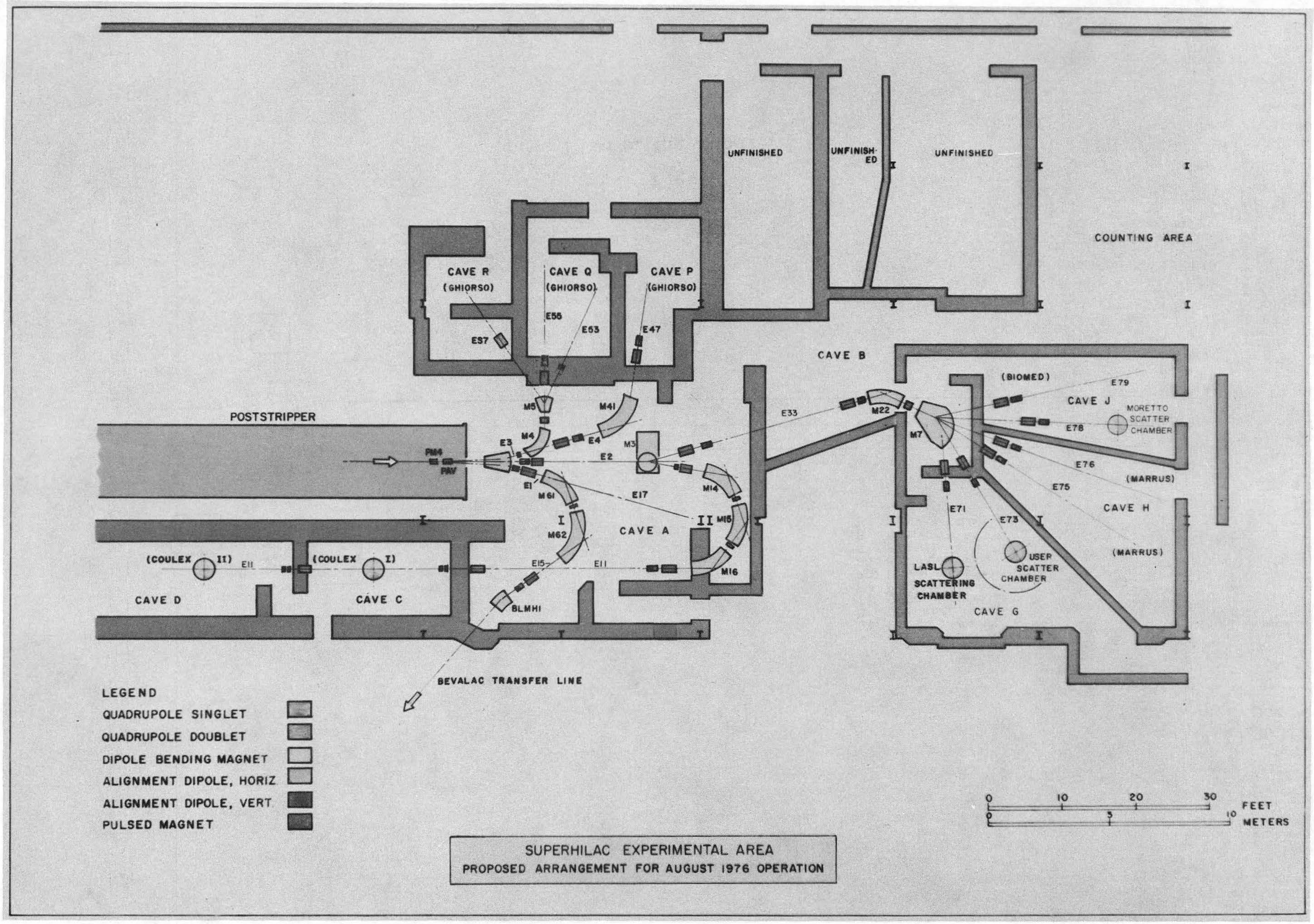
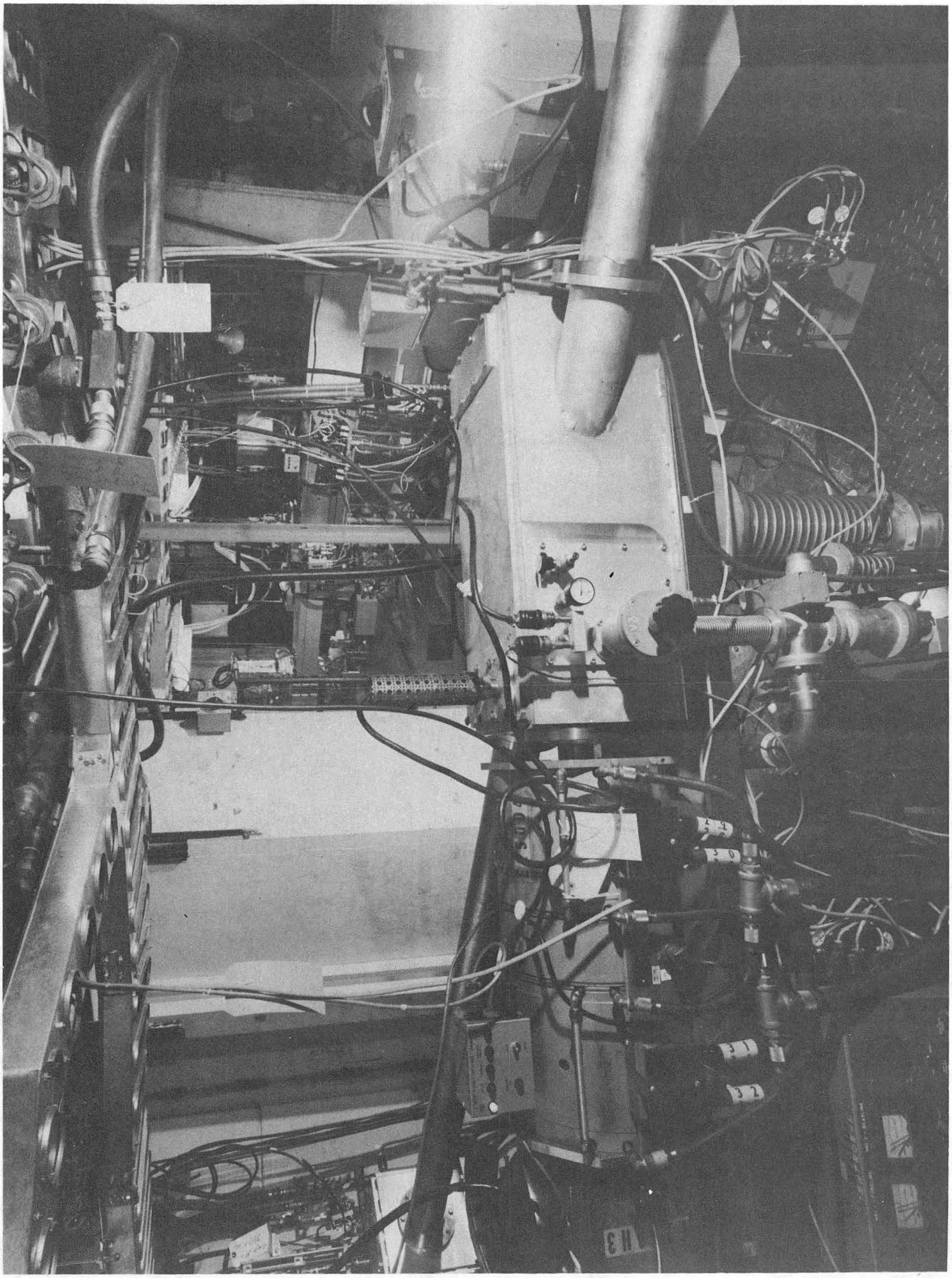


Fig. 2

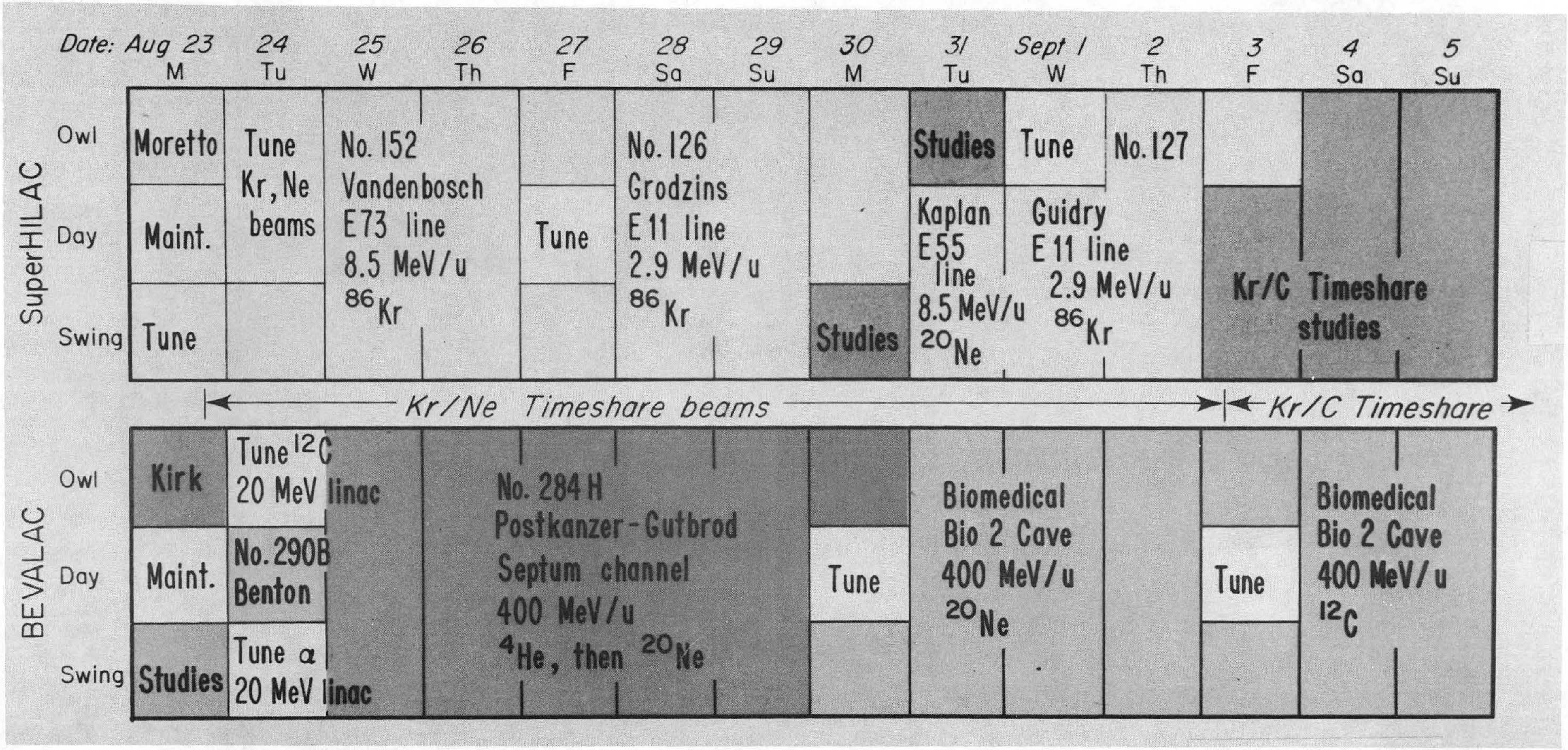
CBB 7512-8788A



CBB 768-7947

Fig. 3

SuperHILAC / BEVALAC Schedule
for the fortnight of August 23 to September 5, 1976



	Date:	Aug 23 M	24 Tu	25 W	26 Th	27 F	28 Sa	29 Su	30 M	31 Tu	Sept 1 W	2 Th	3 F	4 Sa	5 Su
SuperHILAC	Owl	Moretto	Tune Kr, Ne beams	No. 152 Vandenbosch E73 line 8.5 MeV/u ^{86}Kr			No. 126 Grodzins E11 line 2.9 MeV/u ^{86}Kr			Studies	Tune	No. 127			
	Day	Maint.				Tune				Kaplan E55 line 8.5 MeV/u ^{20}Ne	Guidry E11 line 2.9 MeV/u ^{86}Kr		Kr/C Timeshare studies		
	Swing	Tune							Studies						
			Kr/Ne Timeshare beams										Kr/C Timeshare		
BEVALAC	Owl	Kirk	Tune ^{12}C 20 MeV linac		No. 284 H Postkanzer-Gutbrod Septum channel 400 MeV/u ^{4}He, then ^{20}Ne					Biomedical Bio 2 Cave 400 MeV/u ^{20}Ne				Biomedical Bio 2 Cave 400 MeV/u ^{12}C	
	Day	Maint.	No. 290B Benton						Tune				Tune		
	Swing	Studies	Tune α 20 MeV linac												

CBB 769-7997

Fig. 4

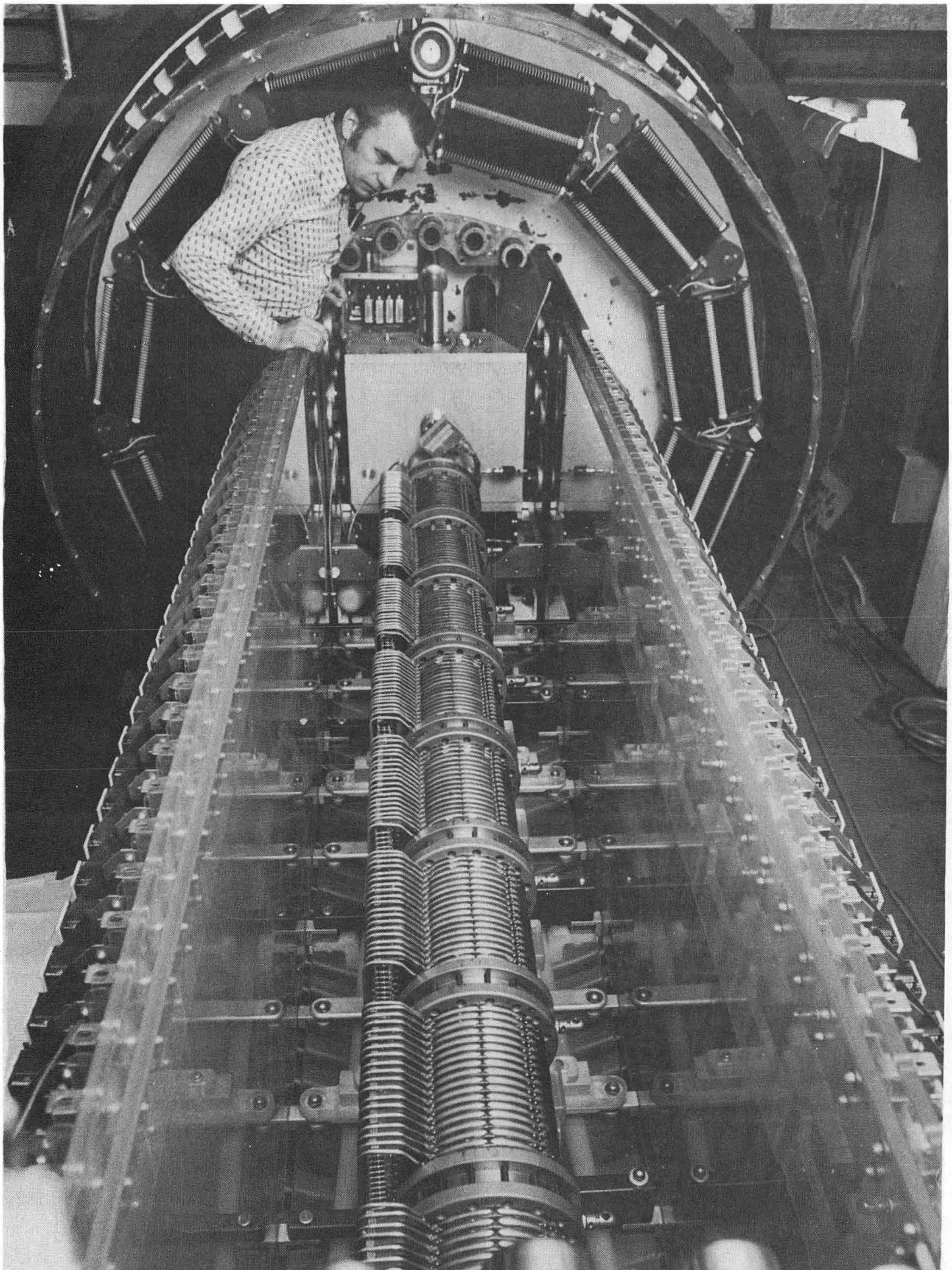


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Fig. 5

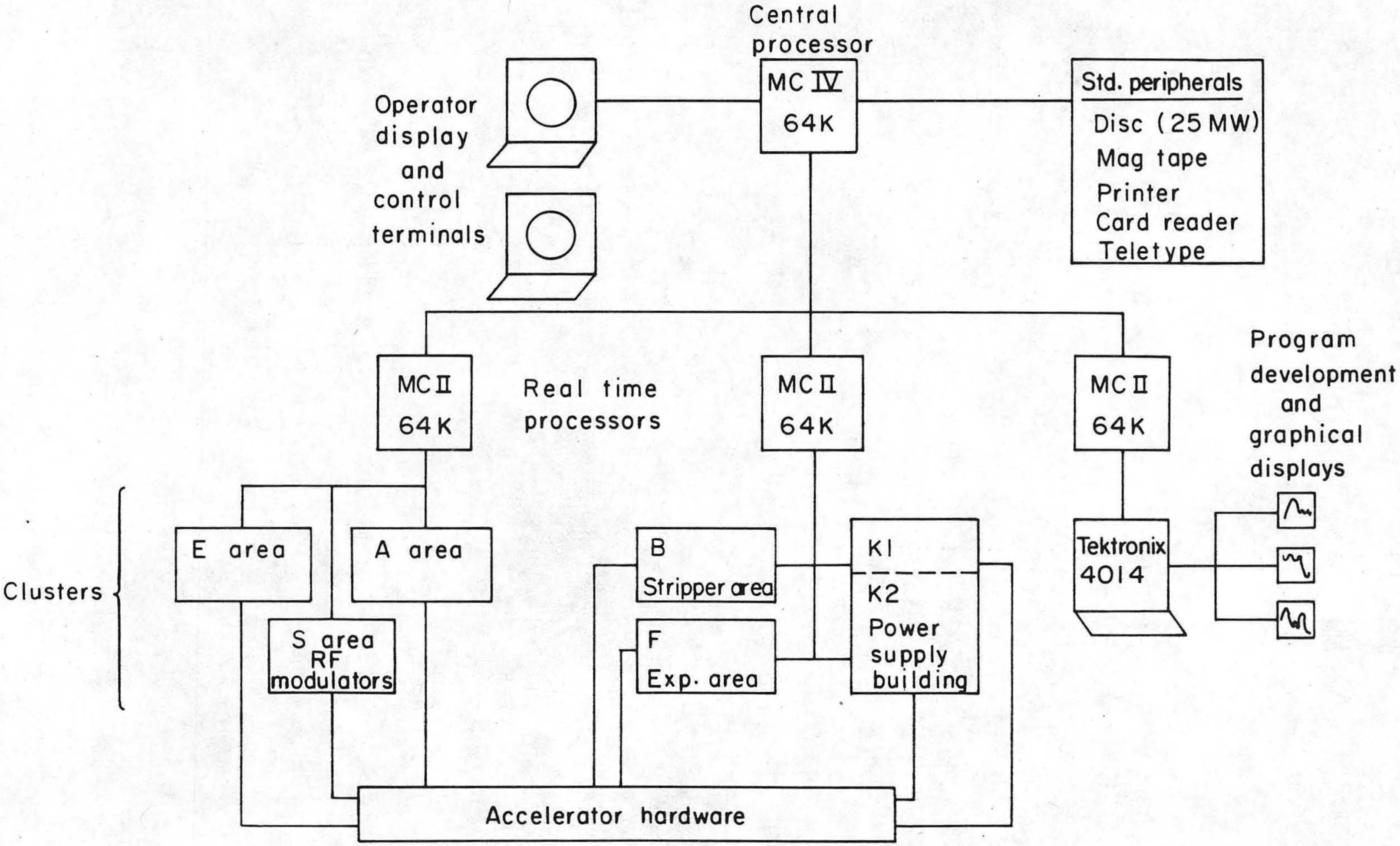

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Fig. 6

CBB 768-7945

Fig. 7

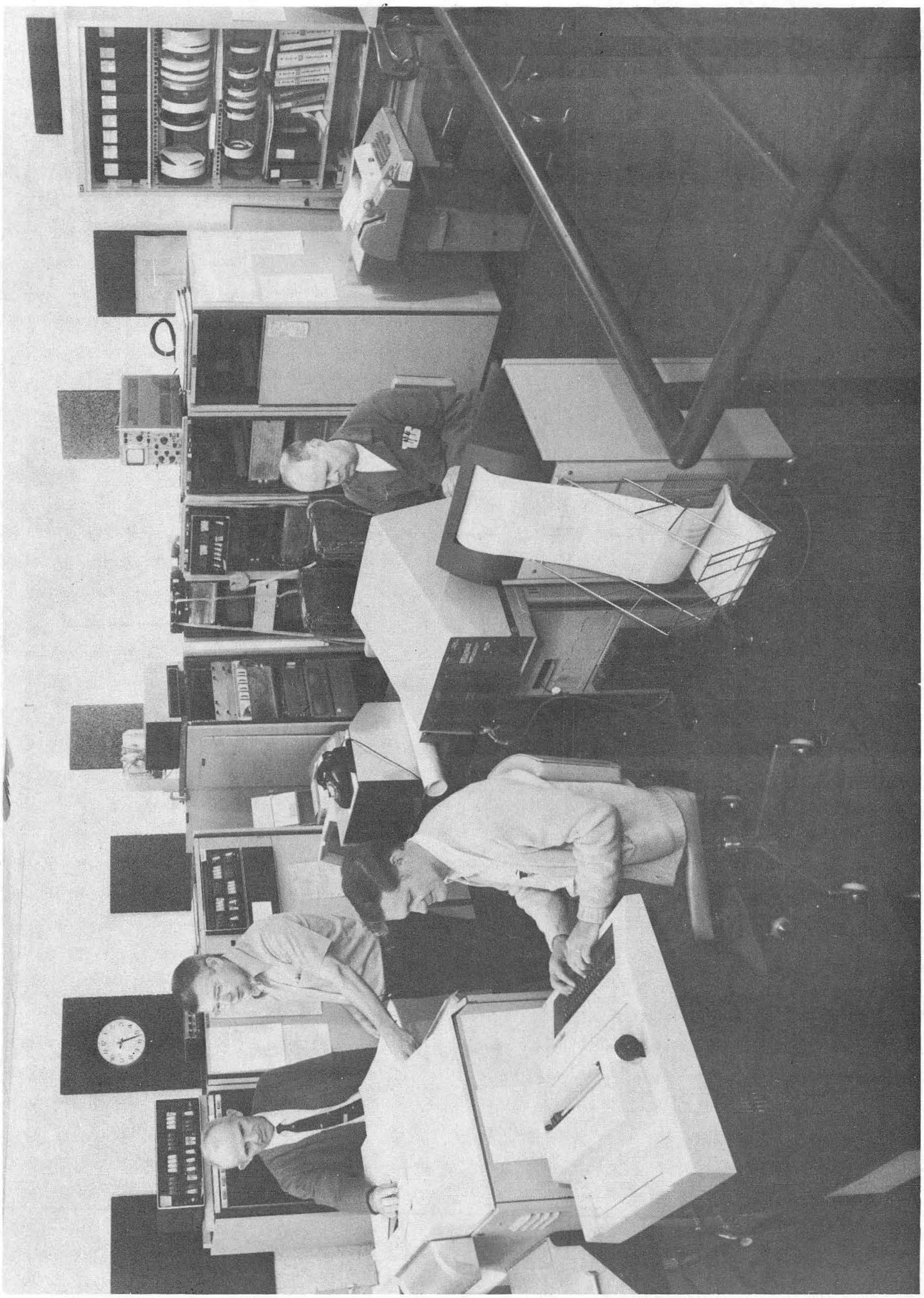

Fig. 8

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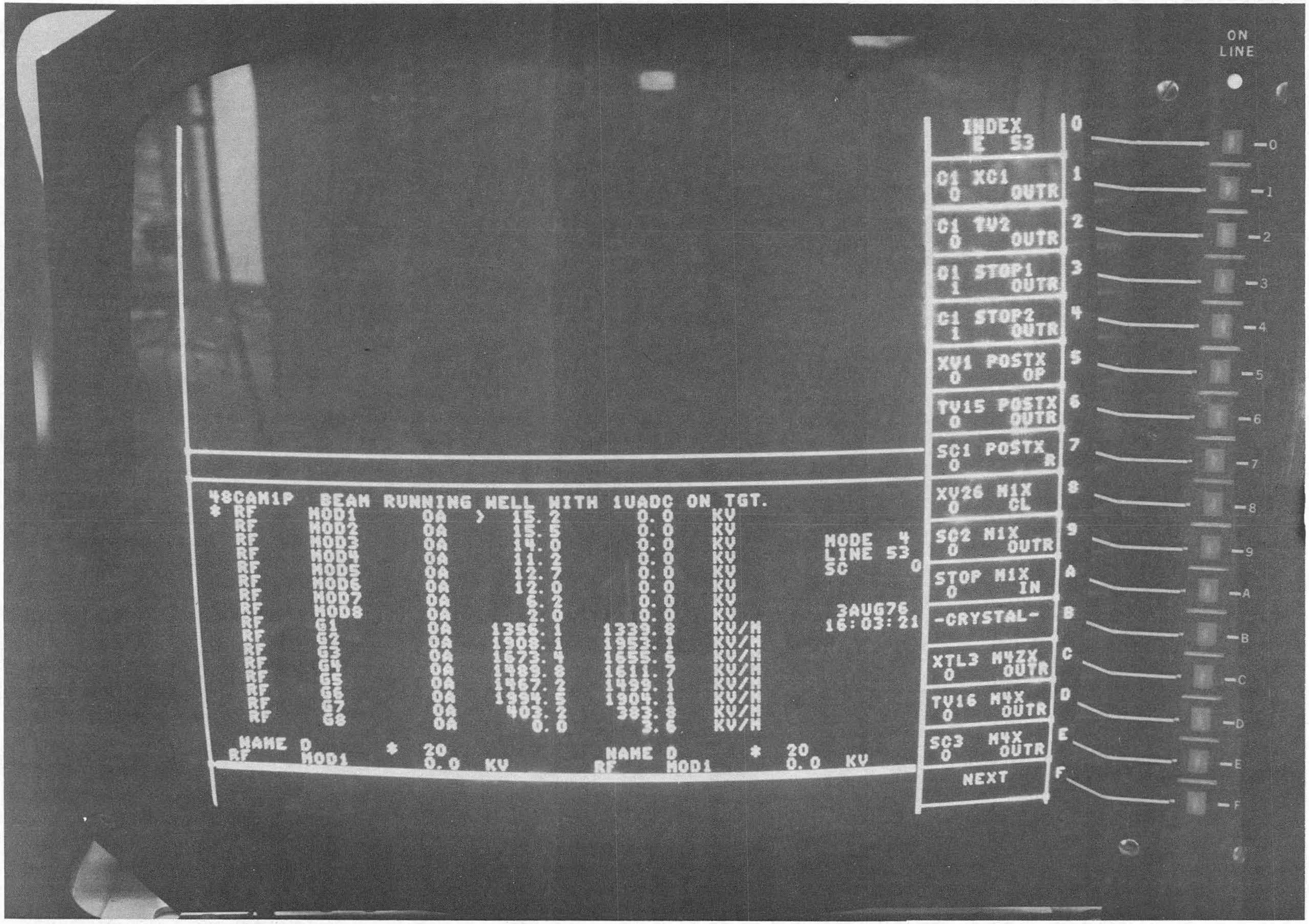

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48CAM1P  BEAM RUNNING WELL WITH 1UADC ON TGT.
* RF     MOD1     0A  >   15.2      0.0  KV
  RF     MOD2     0A      15.5      0.0  KV
  RF     MOD3     0A      14.0      0.0  KV         MODE   4
  RF     MOD4     0A      11.2      0.0  KV         LINE  53
  RF     MOD5     0A      12.7      0.0  KV         SC      0
  RF     MOD6     0A      12.0      0.0  KV
  RF     MOD7     0A       6.2      0.0  KV
  RF     MOD8     0A       2.0      0.0  KV          3AUG76
  RF     G1       0A    1356.1   1339.8  KV/M      16:03:21
  RF     G2       0A    1908.1   1953.1  KV/M
  RF     G3       0A    1673.4   1655.6  KV/M
  RF     G4       0A    1489.8   1611.7  KV/M
  RF     G5       0A    1467.2   1499.1  KV/M
  RF     G6       0A    1994.5   1904.1  KV/M
  RF     G7       0A     403.2    383.8  KV/M
  RF     G8       0A       0.0      3.6  KV/M
   NAME D        *  20            NAME D        *  20
 RF      MOD1       0.0  KV     RF      MOD1       0.0  KV
```

```
   INDEX
   E  53       0
C1 XC1
 0    OUTR     1
C1 TV2
 0    OUTR     2
C1 STOP1
 1    OUTR     3
C1 STOP2
 1    OUTR     4
XV1 POSTX
 0      OP     5
TV15 POSTX
 0    OUTR     6
SC1 POSTX
 0       R     7
XV26 M1X
 0      CL     8
SC2 M1X
 0    OUTR     9
STOP M1X
 0      IN     A
-CRYSTAL-      B
XTL3 M4ZX
 0    OUTR     C
TV16 M4X
 0    OUTR     D
SC3  M4X
 0    OUTR     E
   NEXT        F
```

XBB 768-6891

Fig. 9

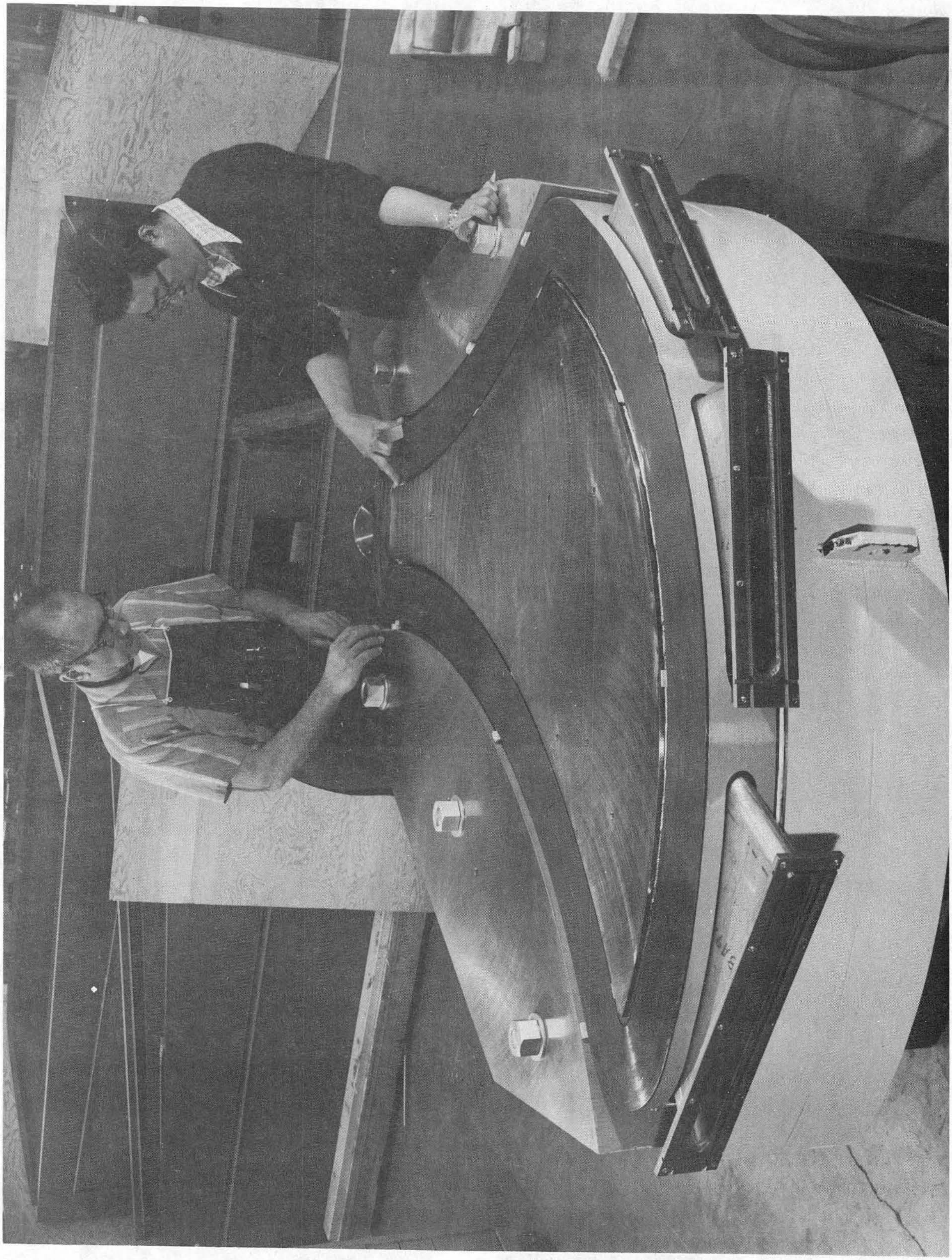
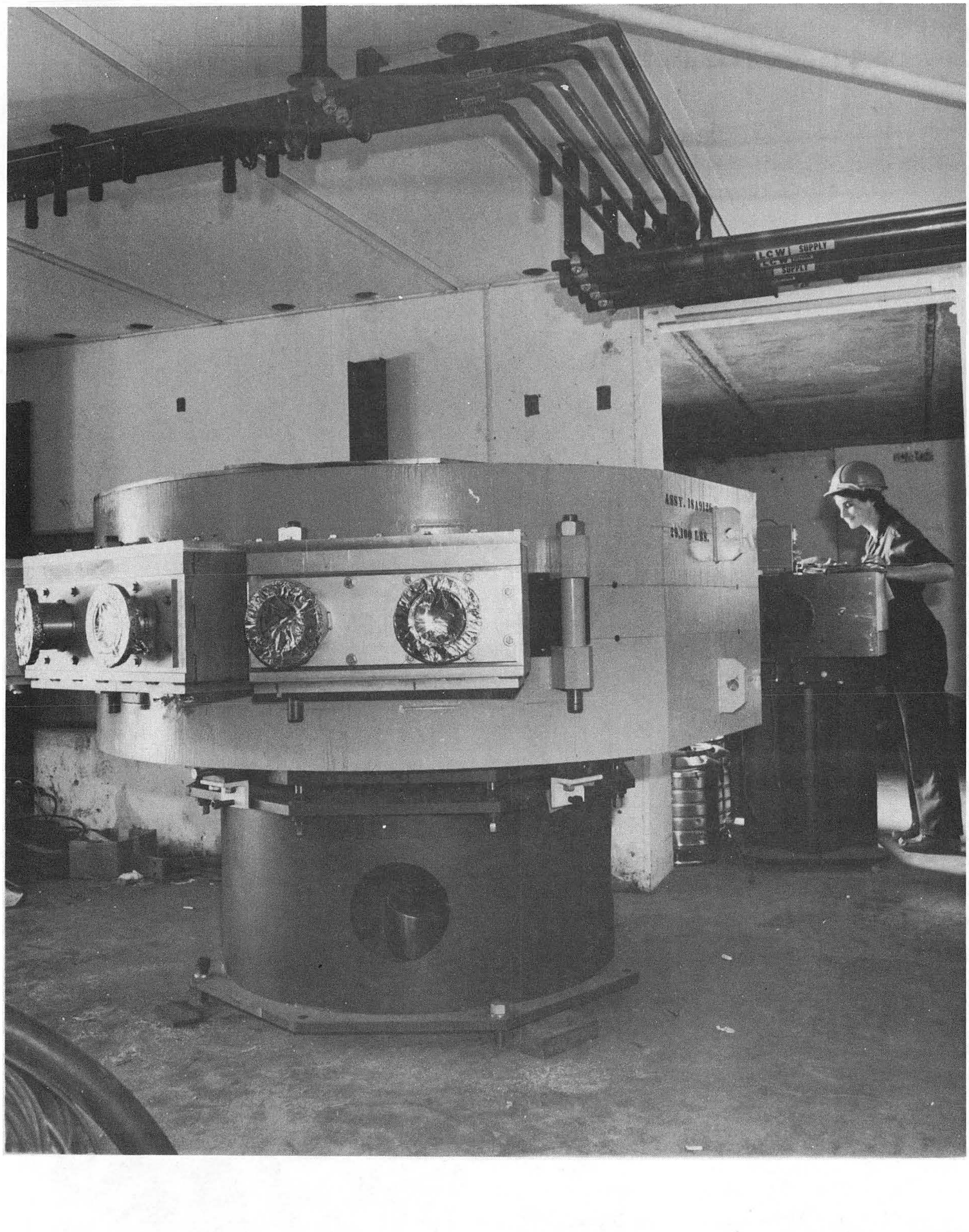


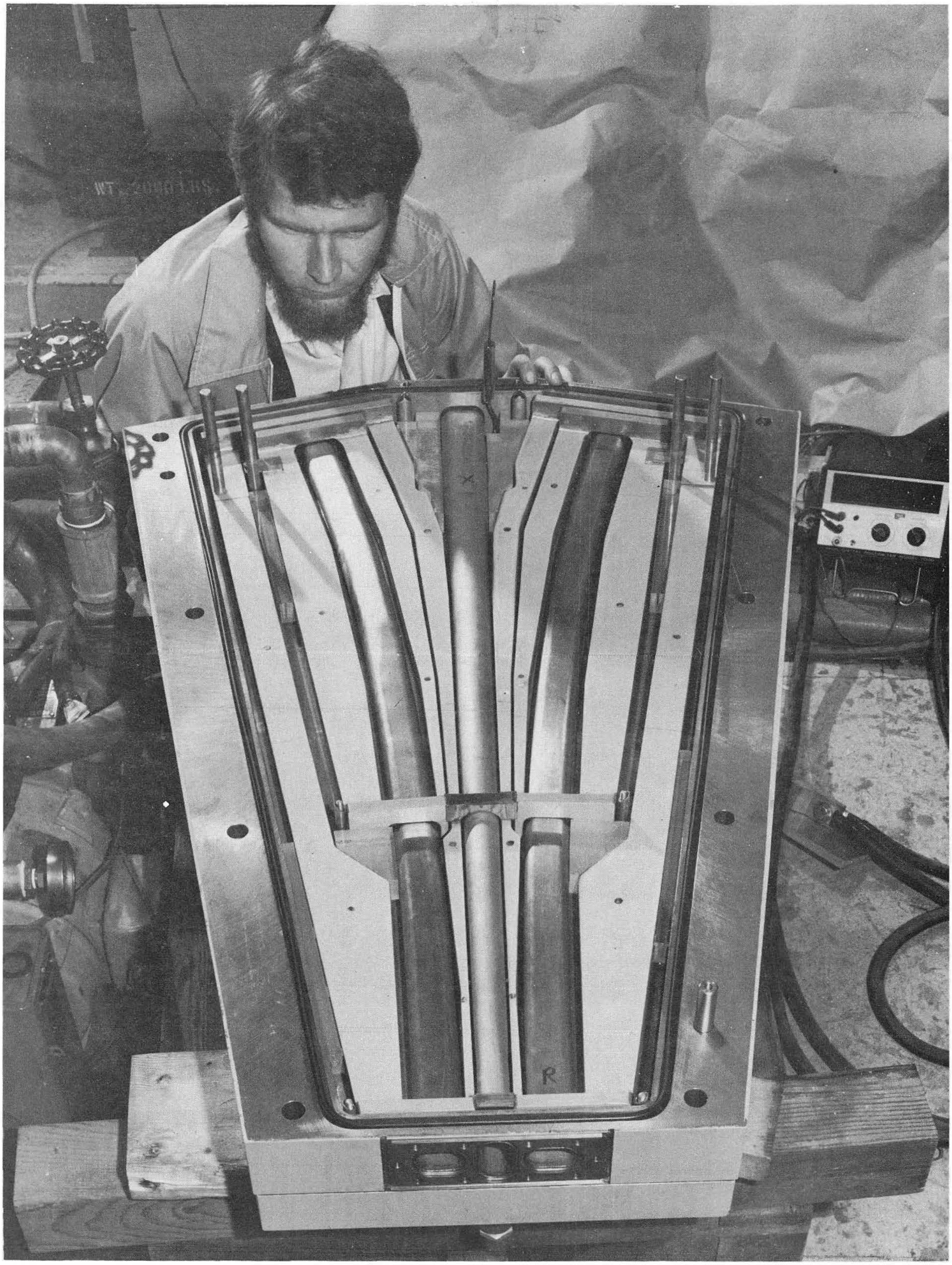
Fig. 10

CBB 762-1912



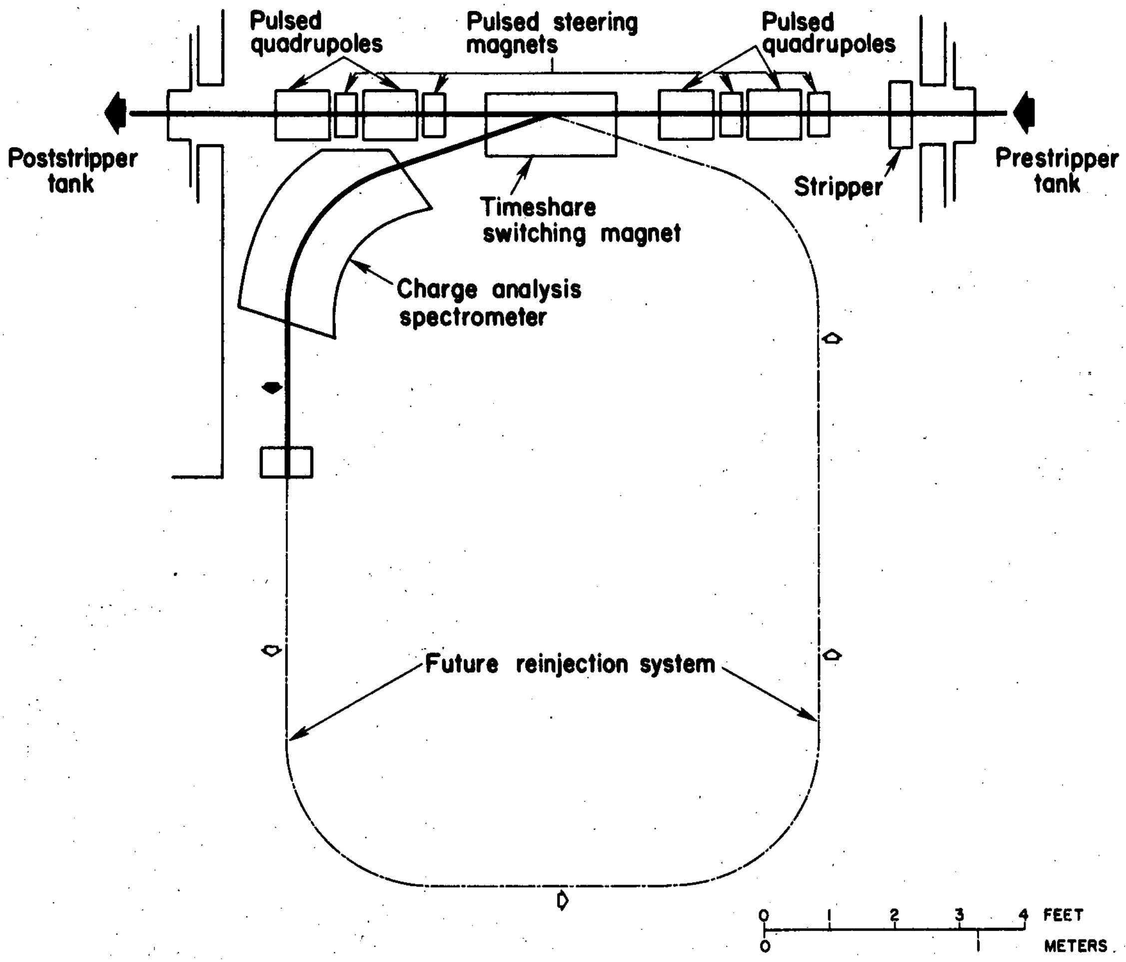
XBB 764-3719

Fig. 11



CBB 746-4053

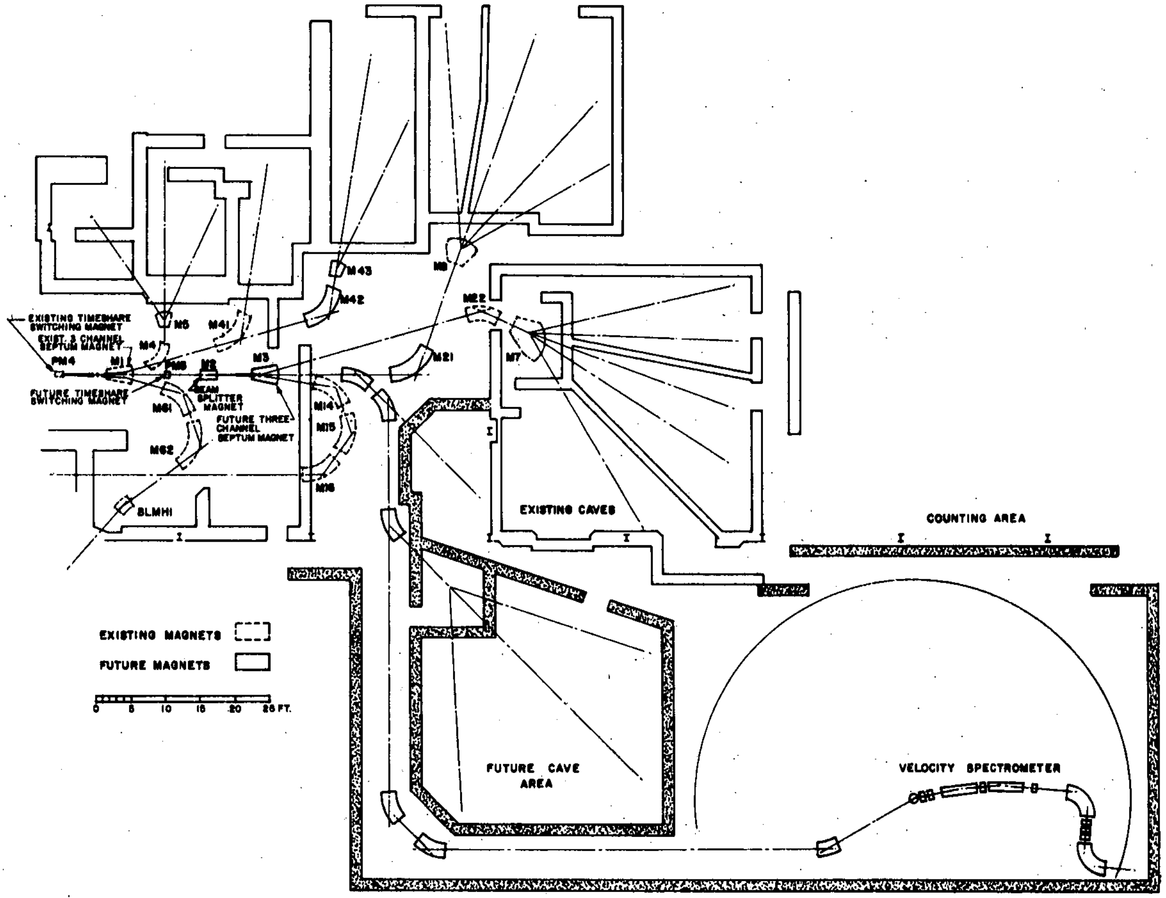
Fig. 12



STRIPPER AREA ANALYSIS SYSTEM

XBL 769-3908

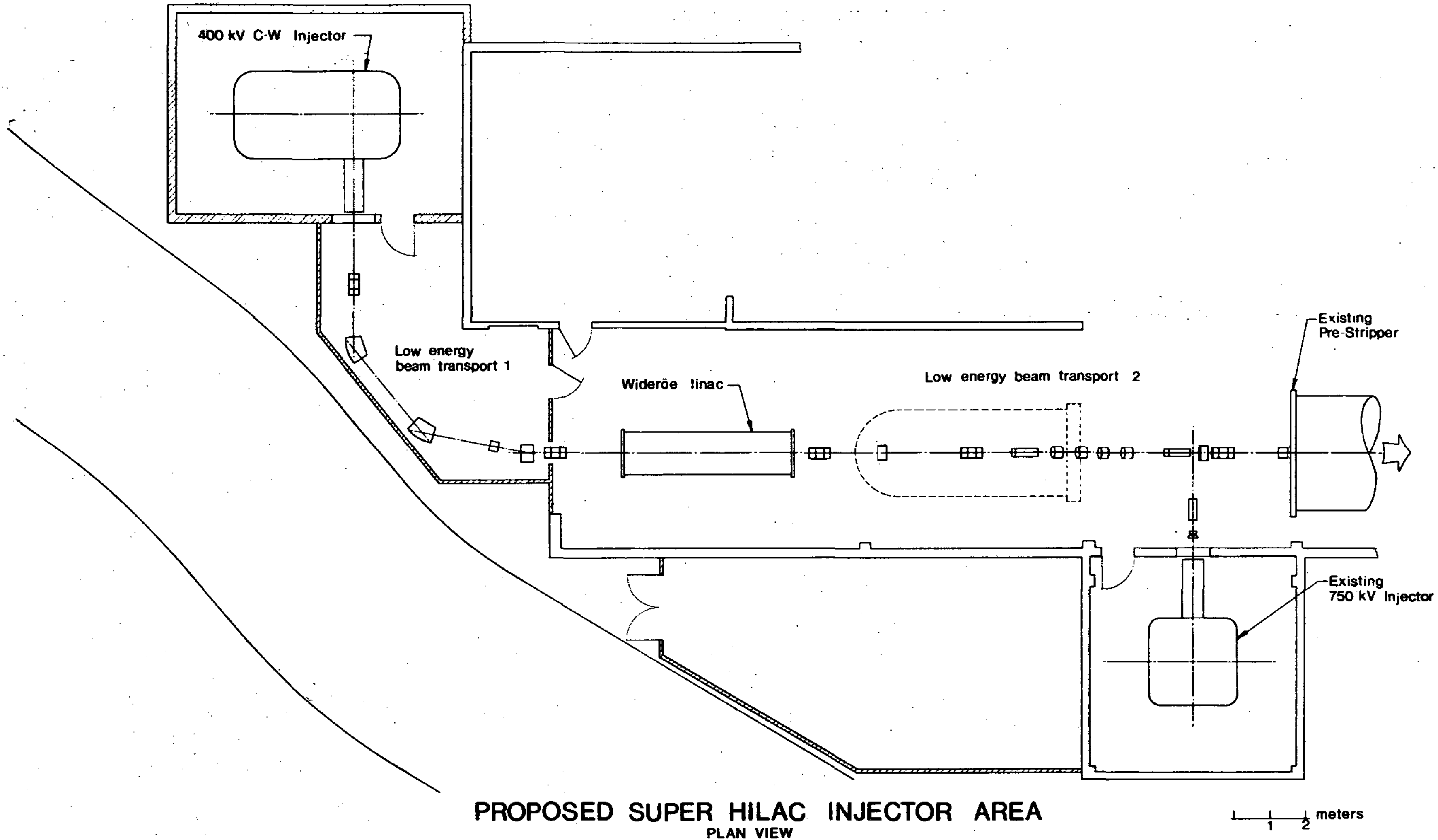
Fig. 13



SUPERHILAC
FUTURE ADDITIONS TO THE EXPERIMENTAL AREA

XBL 769-10329

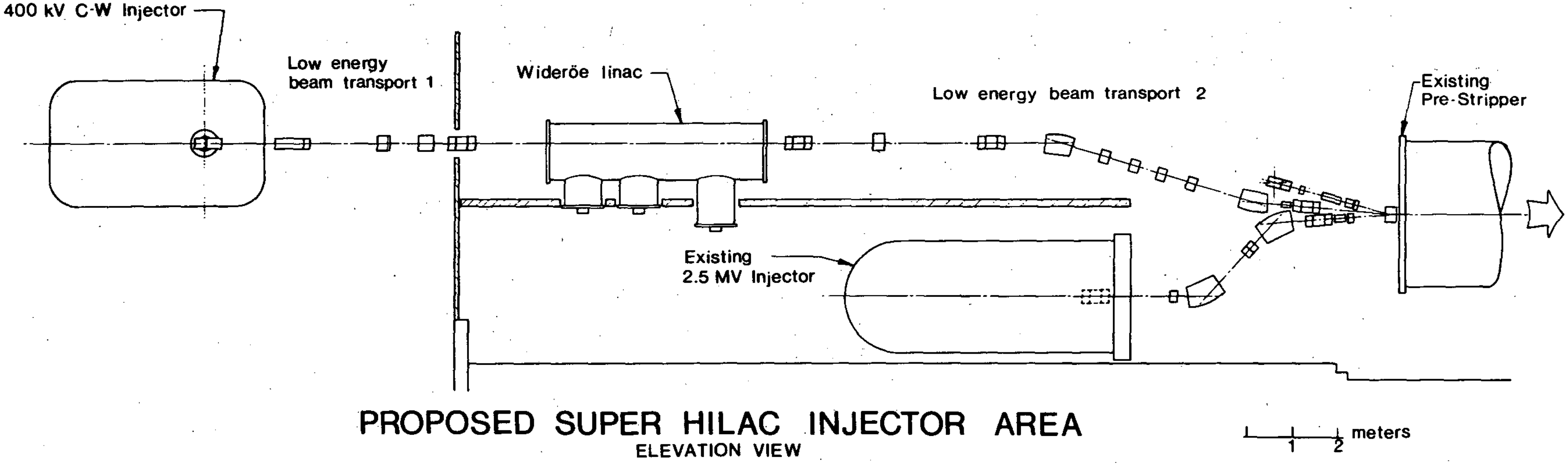
Fig. 14



PROPOSED SUPER HILAC INJECTOR AREA
PLAN VIEW

XBL 765-1862

Fig. 15



XBL 765-1863

Fig. 16

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