MSUCP-45
January 1986

TECHNICAL STATUS
OF
NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY
IN REGARD TO
CONTROL SYSTEM, CRYOGENICS, SAFETY PROCEDURES, MANAGEMENT AND PLANNING
AS OF AUGUST 1985

BASED ON PROGRAM REVIEW DISCUSSIONS
WITH
CONSULTANT R. POWERS OF POWERS ASSOCIATES
ON AUGUST 29-30, 1985

EDITED BY N. ANANTARAMAN

This report is based on presentations made to consultant R.J. Powers of Powers Associates, Inc., Swampscott, MA on August 29-30, 1985 by the following NSCL staff members:

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PROGRAM REVIEW DISCUSSIONS WITH CONSULTANT R. POWERS
AUGUST 29-30, 1985

I. CONTROL SYSTEM

II. CRYOGENIC SYSTEMS

III. OPERATING PROCEDURES/SAFETY/HAZARDS

Hazardous Systems and Past Problems

IV. MANAGEMENT AND PLANNING

PROGRAM REVIEW DISCUSSIONS WITH CONSULTANT R. POWERS

AUGUST 29-30, 1985

SESSION I. CONTROL SYSTEM--Seminar Room, 11:00-12 am, Aug. 29

Control System Overview--Richard Au

I want to conduct this in a reasonably expeditious fashion--6 talks in one hour, so each gets 10 minutes, including time for questions. What I wish to do is to give you an overview of our control system. Table 1 lists the devices that we wish to control. The control requirements are determined by several characteristics of the devices: COMPLEX, SETTING or SETTABLE, LOGGING, MANUAL CONTROL and SCANNING. These are defined at the end of Table 1. We notice that there are some devices that are very complex and require a large amount of computer power, and others for which all that is required is to log where they are at. There is an entire range of functions, range of requirements that we have. The particular method we are using to achieve this is to take a distributed processing system, which has three parts to it--the Data Base, the man-machine interface, and the Low Level Network interface. What I am going to discuss is just the general overview of the system, maybe some philosophical statements on why it was chosen to be this way; the later speakers will discuss the details in the areas of their expertise.

Given this multiplicity of devices and requirements, what we have learned from past experience is that one cannot centralize the control system or have everything go into one computer. We tried putting it into a PDP11, we tried an old Sigma 7--all these sooner or later overload. The

TABLE 1

CONTROL SYSTEM DEVICE LIST

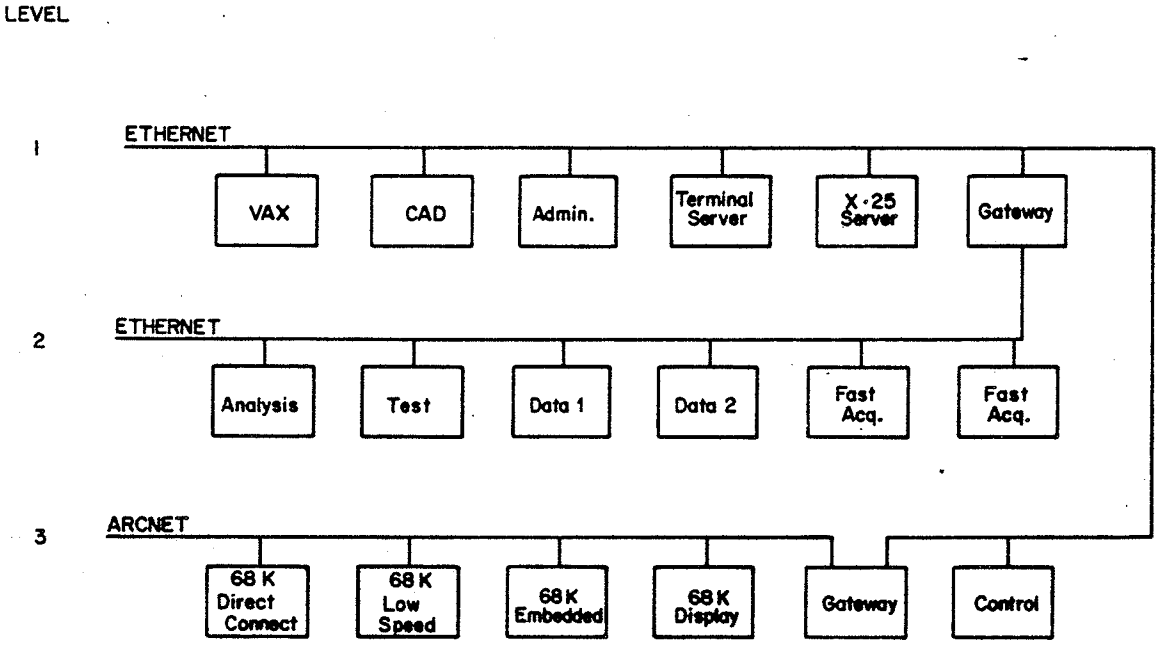
ITEM	QUAN.	DESCRIPTION	COMPLEX	SET	LOG	MAN	SCA
1	18	500 TRIM COIL P.S.	X	X	X	X	X
2	28	800 TRIM COIL P.S.	X	X	X	X	X
3	2	500 ELECTROSTATIC DEFLECTOR	X	X	X	X	X
4	3	800 ELECTROSTATIS DEFLECTOR	X	X	X	X	X
5	8	500 FOCUS/COMP. BARS WITH CURRENTS		X	X	X	X
6	13	800 FOCUS/COMP. BARS WITH CURRENTS		X	X	X	X
7	1	500 EXTRACTION CHANNEL	X	X	X	X	
8	1	800 EXTRACTION CHANNEL	X	X	X	X	
9	11	R.T. ECR SOURCE P.S.	X	X	X	X	X
10	3	MICRO WAVE P.S.		X	X	X	X
11	11	CRYO ECR SOURCE P.S.	X	X	X	X	X
12	200	500 R.F COMPONENT		X	X	X	
13	200	800 R.F. COMPONENT		X	X	X	
14	60	CRYO QUADS P.S.	X	X	X	X	X
15	12	R.T. DIPOLE P.S.		X	X	X	X
16	12	CRYO DIPOLE P.S.		X	X	X	X
17	12	BEAM DIAGNOSTICS	X	X	X	X	X
18	12	EXPERIMENTAL EQUIP.	X	X	X	X	X
19	2	CRYO EQUIP.			X	X	
20	1	500 MAIN MAGNET P.S.	X	X	X	X	X
21	1	800 MAIN MAGNET P.S.	X	X	X	X	X
33	2	LCW			X		

COL.	USAGE
COMPLEX	DOES THE DEVICE CONTROLLED REQUIRE A TRANSFER FUNCTION THAT NOT ONE TO ONE. EXAMPLES ARE: BUMP THREE SUPPLIES TO GENERATE VECTOR ANGLE AND MAGNITUDE. EXTRACTION CHANNEL MOTIOM. TWO OR THREE QUAD. FOCUSING.
SET	THE ABILITY TO RECAL FROM FILE OLD SETTINGS TO REPRODUCE A GIVEN BEAM.
LOG	THE ABILITY TO SAVE THE PARAMETER VALUE ON FILE TO BE USED LATER FOR ANALYSIS. EXAMPLES ARE: BEAM PROBE TURN STRUCTURE. ECR POWER AND ION PRODUCTION. EXPERIMENTAL SETUPS.
MAN	MANUAL (PEOPLE) FEEDBACK CONTROL
SCAN	THE ABILITY TO ACQUIRE DATA ON THE FLY TO ENABLE PLOTTING TUNING, AND CORRELATION BETWEEN ONE PARAMETER AND ANOTHER. EXAMPLES ARE: FOCUS BARS BEAM CENTERING. BUMP ANGLE EXTRACTION EFFICIENCY DIPOLE FIELD AND ION SELECTION

other thing that happens when one tries to cram too much into one computer is that the update/modification process becomes very cumbersome because it is almost impossible to shut down the machine since everything still must continue to run. So we have gone over to what I consider to be the technology of the 80's, viz the networking approach, where we establish a network design and then on each particular network we establish nodes to handle particular functions appropriate to its operational (expertise) level.

In our current network system, there are two networks: an Ethernet physical system which is the main trunk between all our VAX computers (including the data acquisition and data analysis machines), and a second network called an Arcnet down in the Control Room. The system we expect to have ultimately is sketched in Fig. 1; here some of the load from the first ethernet cable is shown shifted to a new ethernet cable (Level II). This would be an evolutionary process and we would eventually take all the data acquisition and analysis machines off the Level I ethernet and move them to Level II so as to reduce conflicts and chances of vandalism. Of course we would then have to have some sort of gateway between the two ethernets.

The Arcnet network we have in the Control Room constitutes the actual control system and consists of a number of "Fermilab clones", each of which is based on a 68000-microcomputer; the display system is on it too. Currently we have six of the 68000's operating: they control the beam line power supplies, the cyclotron control console, the ECR ion source and the 40/20 power supply. There is another network down below the Arcnet which is a low level network of the 68000's; it is not shown in Fig.1 because I am not sure that it can be called a network: it is a master-slave network running down through the lower level devices.



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NETWORK NOTE #1

THE ASSUMPTION HERE IS THAT THE CURRENT STATE OF NETWORK DEVELOPMENT IS ADVANCED ENOUGHT TO SOLVE ALL THE PROBLEMS IN THE COMPUTER AREA. WITH THIS IN MIND WE ARE ADOPTING THE FOLLOWING:

LEVEL

1 DECNET WILL BE FULLY SUPPORTED BETWEEN ANY AND ALL VAX SYSTEMS. THIS WILL INCLUDE ALL LOCAL SYSTEMS PHYSICALY CONNECTED TO ETHERNET, AND ALL REMOTE SYSTEMS LINKED TO THE NSCL. CURRENTLY ONLY THE CHEMISTRY SYSTEM IS CONNECT VIA A SYSCHRONOUS 19.2KBAUD LINE. WORK IS BEING DONE TO CONNECT THE ELECTRICAL ENGINEERING, AND PHYSICS SYSTEMS IN A LARGER NETWORK. FUTURE CONNECTION TO A NATIONAL X.25 NETWORK WILL PERMIT INTERACTION WITH OTHER REMOTE VAX SYSTEMS.

2 NETWORKS WILL ALSO BE USED FOR DATA ACQUISITION AND ANALYSIS TO REMOVE THE LOCATION RESTRICTIONS ON DATA ACQUISITION. THE COMPATABILITY OF DECNET OPERATION ON THE ETHERNET LINE HAS BEEN TEST WITH DATA RATES OF 150K BYTES/SEC AND NO ERRORS. THE RATE WAS LIMITED BY THE BUFFER COPY TIME IN THE VAX CPU AND NOT THE ETHERNET LINE. ADDITIONAL TESTS WILL BE MADE WITH DEDICATED ETHERNET CONNECTIONS TO FIND THE UPPER BOUND.

3 CONTROL SYSTEM WILL ALSO EMPLOY AN EXPANDED ARCNET NETWORK TO OVERCOME RATE AND SYSCHRONOUS PROBLEMS. THE SYSTEMS WILL USE THE FERMI (OR MODIFIED FERMI) OPERATING SYSTEM. CONNECTION TO THE DECNET (ETHERNET) IS THROUGH A GATEWAY. THE CONFIGURATION OF EACH FERMI SYSTEM IS DICTATED BY THE FUNCTION AS FOLLOWS:

A DIRECT CONNECTION TO VME HARDWARE
B LOWSPEED SERIAL CONNECTION FOR REMOTE 68701
C EMBEDED PROCESSORS WHERE SPEED AND ISOLATION REQUIRED
NOTE: MIXED SYSTEMS POSSIBLE

Fig. 1

Thus we have a pyramid. The functions that are to be performed are distributed over this network in a manner appropriate to their requirements. For example, the control for turning on and off a power supply is put all the way down in the lowest level network and having it, whatever its process is, take care of the idiosyncrasies of turning on and off. If one wants a coordinated turn on and off, one moves the control up one level. To have an experimenter take care of the focussing of his beam, one can move the control up one more level to the data acquisition system; the experimenter can then tune his beam through the inner ties down to the lowest level. One moves the control up one more level if one wants to do beam studies or cyclotron extraction studies; the calculations are then done on the higher network and the results are fed to lower levels. As I said before, in the lower level network we have operating displays which are actually man-machine interfaces to give the user an idea of exactly what is going on.

With this arrangement of disbursing the CPU's, we have the capabilities of high level calculations, high speed data acquistion, and also actual process control down at the lower levels.

Now that I have given an overview of the control system, the following speakers will talk about the individual levels.

Equipment Interface--Jack Jenkins

The 68K microcomputers mentioned by Dick Au are shown near the top of Fig. 2. The Low Level Network is illustrated below the 68K's in this figure. The small boxes are instruments on the Low Level Network which are interfaced to the 68K's by the serial lines of the Low Level Network.

A more detailed look at the Low Level Network is shown in Fig. 3. The Arcnet at the top controls the 68K computer, which has a variable number of boards called Octal 68701's plugged into its VME Bus. (VME is an abbreviation for Versa Module of Europe; it is a high-speed microcomputer bus.) The name "Octal 68701" was chosen because there are 8 single-chip microcomputers of the 68701 type on each board. Each single-chip microcomputer controls one serial line, which can have up to 8 instruments on it. The 68K has no work load from the serial activities going on. It just has a memory in which is found whatever data the single chip micros have collected and put into the memory. The memory is a dual-ported RAM which is on each Octal 68701 card (Fig. 4). The purpose of the Octal 68701 cards is to give an interface for small instruments in such a way that the instruments do not have to be mounted in the VME crate or on the VME ground system.

An instrument which shows the need for the Low Level Network Interface is shown in Fig. 5. It is called a Beam Current Meter. It consists of a variable gain preamplifier which measures currents from 10 picoamps to 300 microamps in 16 different ranges. It has variable filtering of AC characteristics and variable corrections for DC offsets. All of its variable parameters (a considerable number) are controlled by a 68701 micro

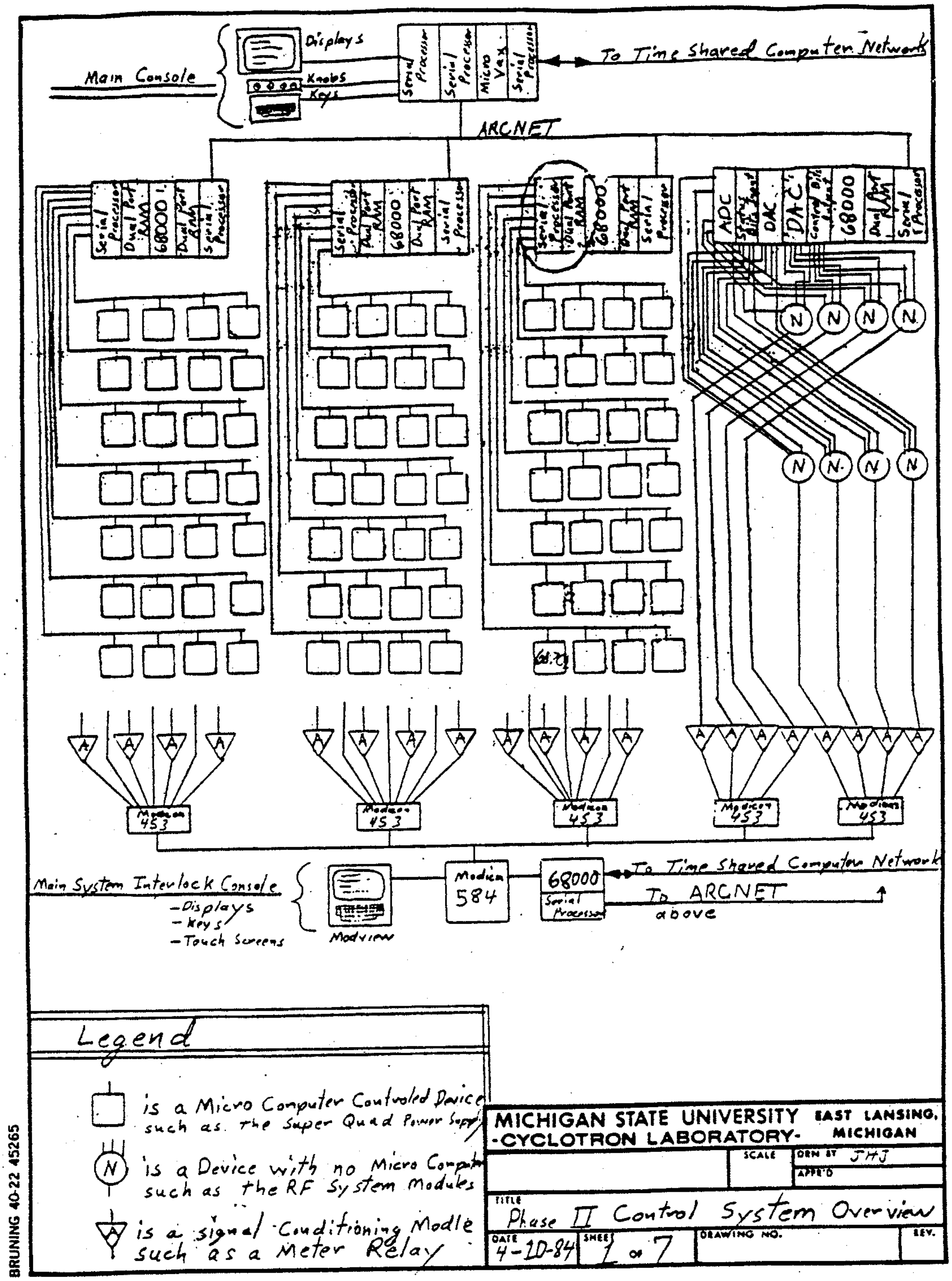
Displays
Knobs
Keys
Main Console
Serial Processor
Serial Processor
Micro Vax
Serial Processor
To Time Shared Computer Network
ARCNET
Serial Processor
Dual Port RAM
68000
Dual Port RAM
Serial Processor
ADC
Status Bits Input
DAC
DAC
Control Bits Output
68000
Dual Port RAM
Serial Processor
N
A
Modicon 453
Main System Interlock Console
-Displays
-Keys
-Touch Screens
Modview
Modicon 584
68000
Serial Processor
To Time Shared Computer Network
To ARCNET above
Legend
is a Micro Computer Controled Device such as the Super Quad Power Supply
is a Device with no Micro Computer such as the RF System modules
is a signal Conditioning Modle such as a Meter Relay
MICHIGAN STATE UNIVERSITY
-CYCLOTRON LABORATORY-
EAST LANSING, MICHIGAN
SCALE
DRN BY JHJ
APP'D
TITLE
Phase II Control System Overview
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Fig. 2

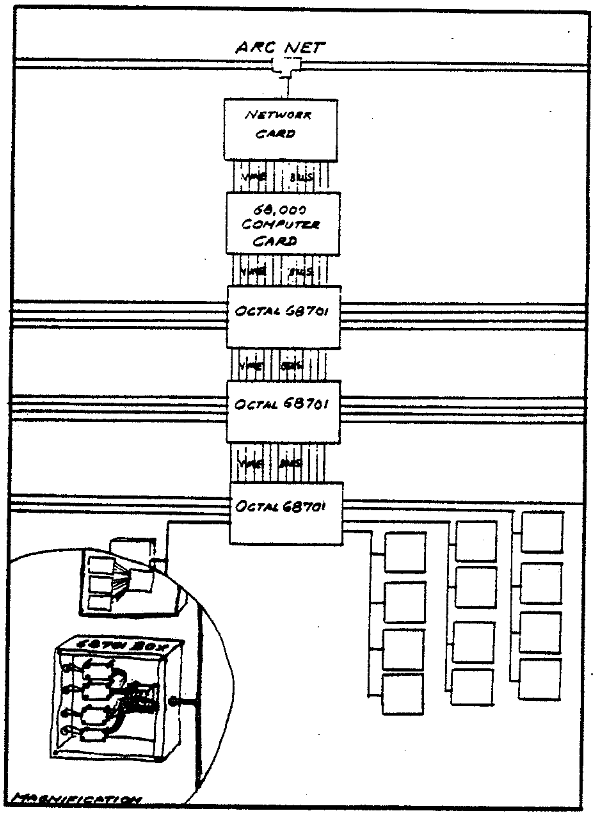


Fig. 3 The Low Level Network

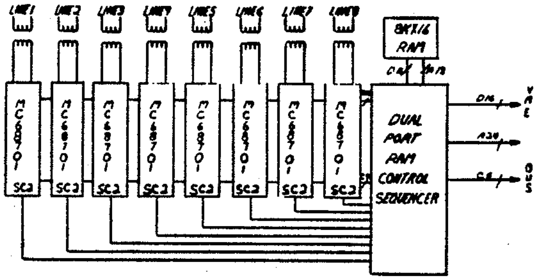


Fig. 4 Octal-68701; 8 line serial interface for the VME computers.

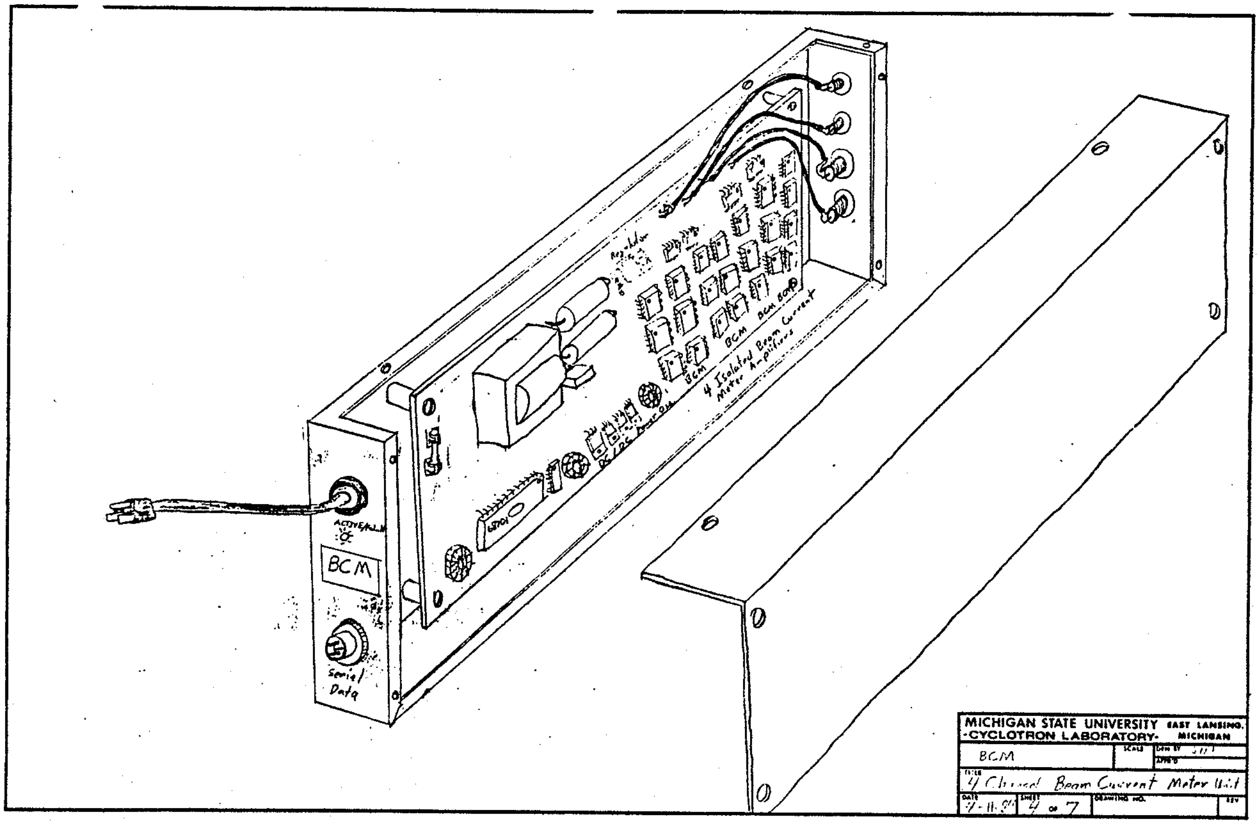


Fig. 5. The beam current meter.

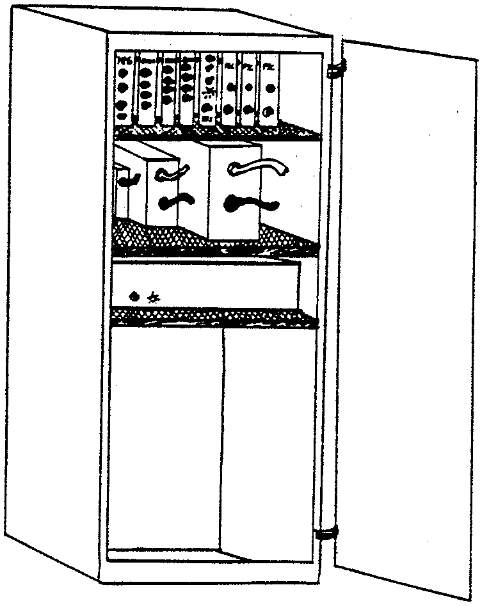


Fig. 6. Box dimensions for Instruments on the LLN are unconstrained.

computer chip on the Beam Current Meter board. The preamplifier output is converted by an ADC which is connected to the on-board 68701. The on-board 68701 circuit is a subassembly which is superimposed by the Computer Aided Design (CAD) system or by photographic means onto the rest of the board which is the unique part of the Beam Current Meter. This superposition gives the designer of the unique part of the circuit (in this case the preamplifier) a standardized microcomputer interface that requires little extra engineering work to add it to the design of the unique part.

The Low Level Network interface provides isolation and lowers the amount of circuitry which must be superimposed on the unique part of each instrument designed in the laboratory to give it a full interface to the control system. The serial data coming and going from the on-board 68701 pass through a small transformer in the 68701 subassembly that isolates the serial data signal so that the instrument has a DC ground system separate from that of the control system. The isolation is completed by the inclusion of a floating, line powered, DC power supply on the superimposed subassembly. It provides logic and analog power to the rest of the instrument. The isolation provides for more accurate instrumentation because it opens the ground loops. It also protects against catastrophic failures that propogate back through the control system. For example, last week when the ECR high voltage arced over, it burned out all the DACs that were controlling the ECR magnets but it did not propogate through the control system and destroy anything further. This was primarily because of the isolation transformers.

Each instrument on the Low Level Network basically comes down to being a box with a serial line and a power cord that can be moved around and placed wherever needed. It may be built inside or outside, it is very flexible and easy to produce. The size of box may be matched to the needs of the instrument that it contains, as shown in Fig. 6.

An additional property of the Low Level Network is that it helped us to decentralize the control system design by using experts in a given field to produce instruments of their own. For example, John Yurkon is a detector expert and he just finished creating a gas pressure regulator for gas detectors that can be produced in quantity inside or outside the Lab, as per his preference.

The documentation of such a detached, modular system works out nicely. We simply have a book called The Device Manual that has an index at the beginning where one can look up the name of a device, such as The Beam Current Meter, and find a chapter containing its theory of operation and a list of all the drawing numbers and computer files that give information on that device. From that one chapter one gets all that one needs to build or repair the device.

There are a few devices that we need which will be manufactured, probably outside, in fairly large quantities. Their designs are more or less finished. For example, we have a large box called a Superquad that is nearly ready for production. It is made to control and power a superconducting quadropole magnet and to protect it in the ways it needs to be protected. The 68701 microcomputer in that particular box takes care of a lot of the peculiarities of running a superconducting magnet. This is similar to what the 68K's do for the main magnet supplies.

POWERS: Are the drawings of the units in the computer itself?

JENKINS: They were intended to be when we got the CAD system but it looks like we will not get it running quite that soon, so they are just in drawing files.

POWERS: What things are on the computer under file names?

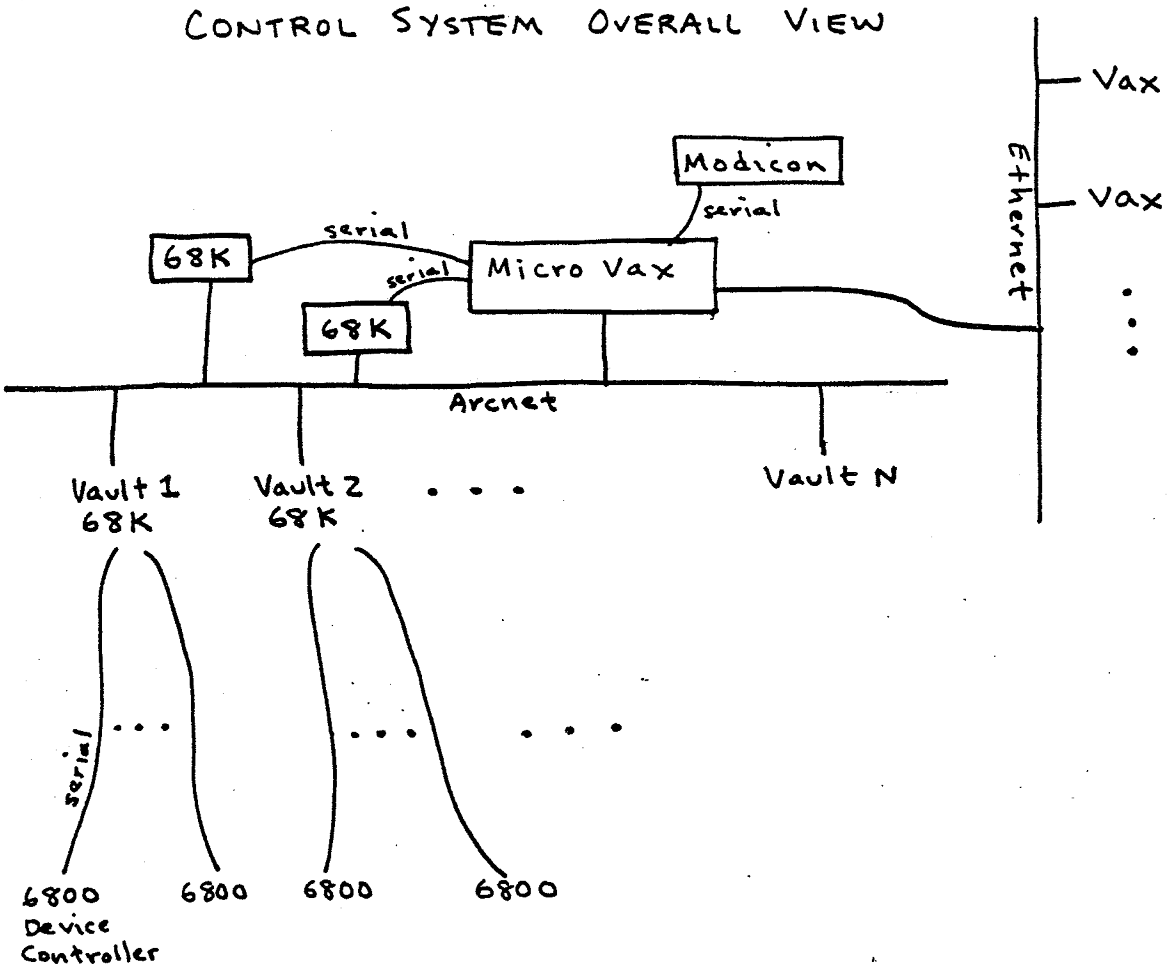
JENKINS: The source programs that run in the 68701's and the parts lists. Some devices have installation instructions that are too lengthy to be in the Device Manual itself but are file referances in the Device Manual. The Device Manual itself is in the computer as a set of files, one for each chapter, which are printed under an index generation utility.

Data Base--Lynn Foth

Figure 7 is a different version of the figure (Fig. 1) shown by Dick Au. It does not take into account breaking the Ethernet into two different networks (which will happen only in the future). I am showing this to indicate the 68K level, which is what I shall be speaking about. The basic idea with this structure is that there are multiple levels of processors. We have distributed intelligence and data base, and distributed control stations so that control is available from many areas of the Lab at once. The processing is done in parallel, expansion and repair are easy, and failure on one computer does not take down everything. The serial network would allow intelligence to be built into equipment where it is needed.

Figure 8 is a crude representation of what one of the middle level VME stations looks like--the rectangle indicates the VME crate and the four computer boards that make up the main system. First, there is a network interface board to the Arcnet which was designed at Fermilab; we now build these boards here. Next is a 68K computer board which we buy and is readily available. Third, there is the non-volatile Random Access Memory (RAM) card (also store bought), which holds the data base so that if the station gets powered down for some reason we do not have to re-download all the data--it just comes right back up running again. Finally, we have the local console card which talks to a specialized little terminal which is shown in Fig. 9. The console card and the terminal it talks to were designed at Fermilab also and we are building them here now.

The program for these computers is in prom, and all of the computers at this level, when we are done developing, will have the same program so as to make the repair and swapping process easy. Part of what allows that to be



- Multiple levels of CPUs
  μVAX , 68K, 6800

- Distributed intelligence and data base
  control avail. from many areas of lab
  much processing done in parallel
  expansion / repair easy

- Serial Network
  allows smarts to be built into device

Fig. 7

LOCAL STATIONS

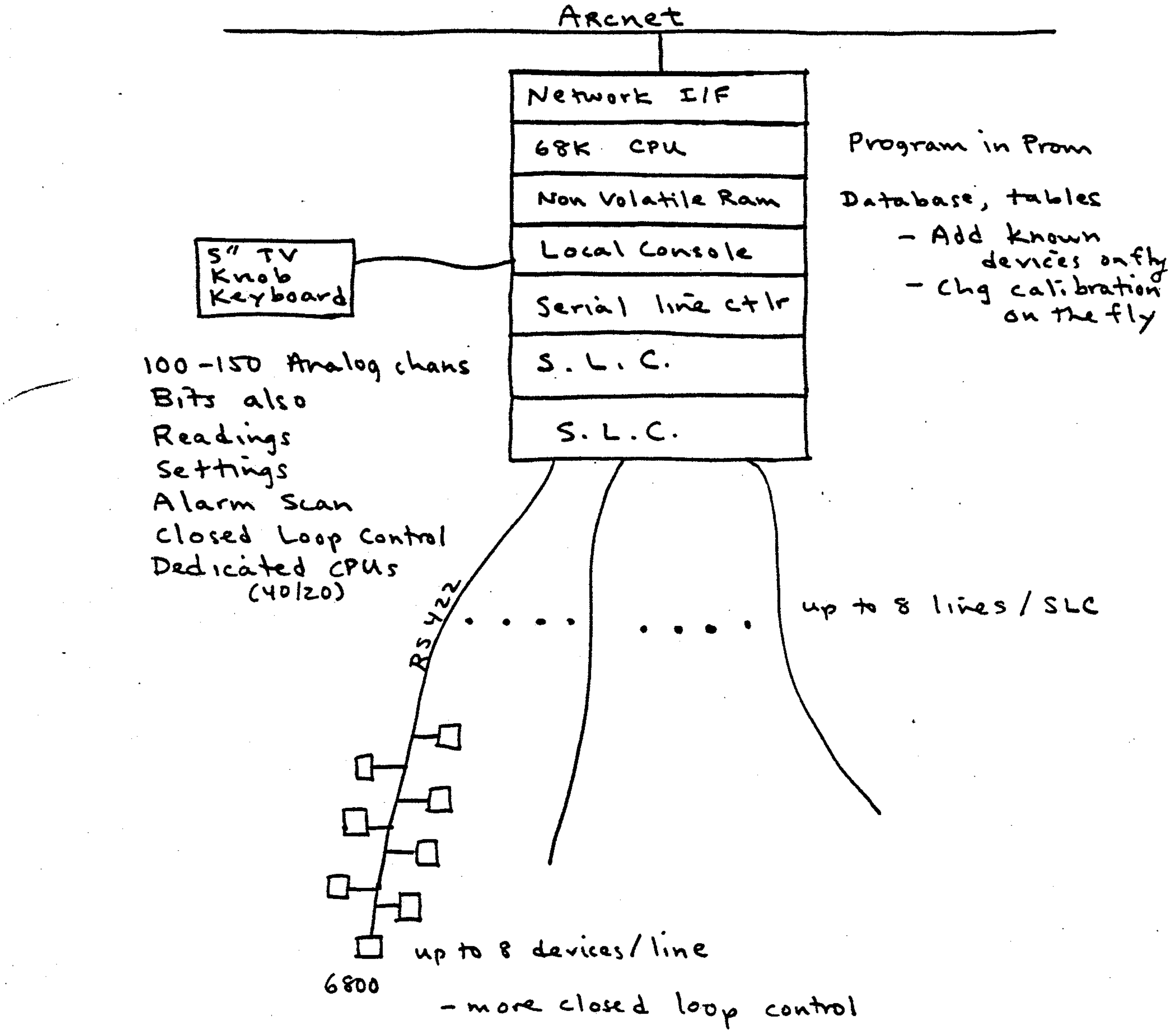


Fig. 8

possible, even though they are controlling different devices, is that all of the data base consists of tables. The software uses a table-driven system which allows us to add calibrations and known device types on the fly. Once we have one device of type A installed, we then can install any number of devices of the same type, without taking the system down and changing files or anything like that. Each of these data bases holds about 100-150 analog channels that have reading and setting information and calibrations, and 100-150 binary channels. These stations read all of the devices that are attached to a local station, and then do an alarm scan on whatever channels we specify. If there are conditions worth reporting, they send out messages over the Arcnet to a station that accepts all those messages and logs them. A closed loop control function can also be done. We can either have that kind of control done by these low level devices at the other end of the serial line from the crate (as discussed by Jack Jenkins), or we can put parallel interface DAC and ADC boards in the VME crates themselves and then write code that gets executed in this system. Right now we actually have both in use. The Perkin power supply is handled with closed loop code and the 68000 computer. We can also add other CPU boards in the VME crate to do special jobs. The 40/20 station has a second 68000 to handle the regulation of that power supply. That is the basic function of the middle level station.

From this station we can monitor or control any device anywhere in the Lab. What we use to do that is a little terminal that is about 7"x19"x13", shown in Fig. 9. It has got a keyboard, a 5" TV tube, a knob, and some push button switches. Programs, written in Pascal, provide the operator interface to display things on the screen and interpret the operator's input. With this little station we can make relative control

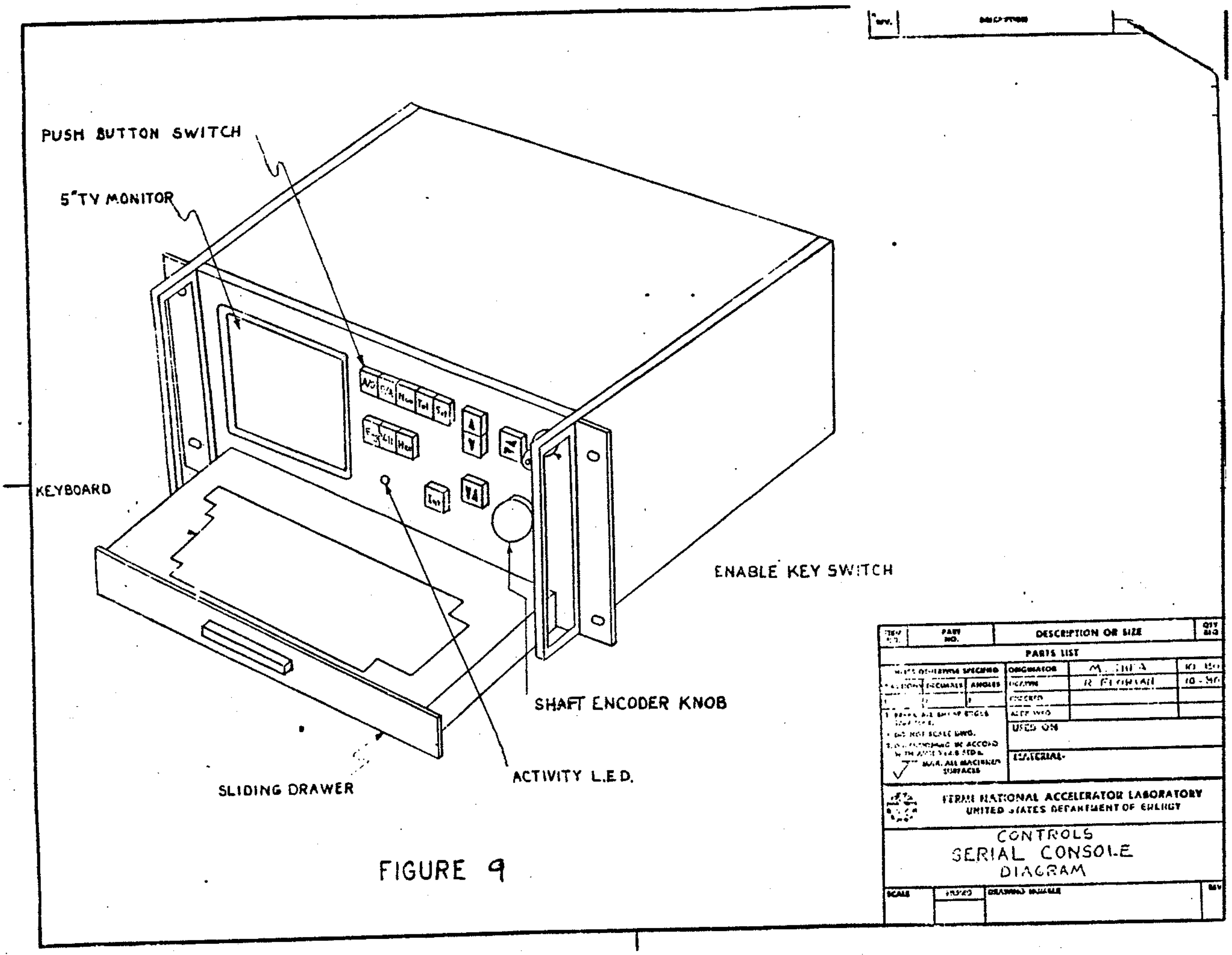


FIGURE 9

Fig. 9

settings either with the knob or with some up and down arrows that perform the same operation faster. The keyboard can be used for making absolute control settings. For stepping motors, we can tell them either to go to a certain position or to go a specified number of steps in either direction.

The idea is to have 10 or 12 of these little consoles in VME crates stationed in various places around the Lab. From them we can spy on and control anything in the control system, provided the device is simple enough that it can be controlled with one knob. On the other hand, if the control requires a lot of different pieces of equipment to be ganged together and multiple knobs to be turned at the same time, then it must be done on the main console. Skip VanderMolen will talk about that.

BLOSSER: Are loops really regulating the Perkin power supply?

FOTH: No, the regulation is done in the Perkin itself. What the little control consoles do are two functions: 1) constantly, every 15th of a second, reasserting the settings in order to avoid the problem of cross talk between the different Perkin outputs which we used to have; (when we changed one output, others used to drift); 2) handling polarity changes in 3 steps, e.g. go from a positive current to +0 amps, wait 1 second, go to -0 amps, wait 1 second, then go to the requested negative current.

Operator Interface--Skip VanderMolen

Near the end of her talk, Lynn Foth indicated the need for a more complicated control system, with a natural user interface and more sophisticated functions, than the little terminal shown in Fig. 9. The idea we came up with was to take one of the 68K crates and add a color graphics screen with four knobs and four analog meters. The aim is to allow the operator to see more than one device and to control multiple devices, either with one knob per device or one knob for several devices. As an example, on the beam line, if we wished to gang several magnets together to control at the same rate, this system would allow us to do that. What the operator interface system consists of is a 512x512 graphics screen with a touch screen on the front. We have at this time up to 24 devices that can be displayed or controlled at one time on a single screen.

Currently, two of these modules have been implemented. One is on the beam line, where it is currently being used, and the other is being set up for the ECR source. Also coupled with this is an auxiliary function that lets us do graphics on one of these screens. (So we can display functionality right on the screen.)

Because the system is on the Arcnet, any device can be controlled from any of the modules. With the graphics we hope to be able to change scales if necessary, display the status and the actual readings, and give a more meaningful interaction with the user. Coupled with this on the Arcnet, we are going to have a MicroVax, which will be used to store a large amount of data in a data base. The problem at present is that, if an error message coming from the device is to be displayed on the display screen, it would have to be a rather cryptic message. What we would like to be able to do is add a screen, exactly where I do not know, which would display a meaningful English message. The difficulty is to have the operator address the problem directly without having to look up a table or code.

In addition, there will be certain configurations and settings that are made while running and it would be nice to be able to log that information so that if that particular beam or setup is required again, one does not have to set everything up manually again. This information would be stored in the MicroVax and subsequently downloaded to the 68K, so that one can simply dial up a particular beam from the information stored on the data base in the Microvax. We are in some ways doing that now in that we do load the 68K's with the MicroVax, as shown in Fig. 7.

One final functionality is that we want the average user to get information off this network without being hooked directly to it. As stated already, one can control any device from anywhere; so if somebody who does not know what he is doing gets in there, he can cause trouble. We hope to be able to allow the user to, for instance, log and plot a magnet curve off the MicroVax by setting up appropriate software to bring the information up, without allowing him to directly access it and thereby endanger the whole operational system.

Coming to specifics, the idea for the control system is to have a main console made up of four of these modules (i.e. four screens with a total of 16 knobs, as well as the analog meters) and three additional screens which will show the status, the selection menu and the high resolution graphics. The menu screen will allow the operator to select various menus and configurations that will be displayed on the screen. For the high resolution graphics, we are considering a large, 1024x1024, screen. All these units would have to fit in a cabinet or box and be within easy reach of the user.

In addition, we are thinking about putting one of the 4-knob modules in each of the Data U's to allow experimenters to control their own devices without having to run to the main console in the Control Room. That will also allow them to record, for instance, parameters such as magnet settings on their data tape, which they can analyze later on, determine whether the parameters drifted during the measurement, and renormalize the data as required.

In summary, then, we shall have a clean user interface for gaining information, storing information, logging information, and clear status messages, with ability to recall old settings quickly and easily, with high resolution graphics for displaying information, and with low resolution graphics and a variable monitoring capability as well. As presently envisaged, all these operations will run off the Arcnet.

Cryosystem Control Requirements--Helmut Laumer

None of the controls on the cryogenic system at present is computer controlled. They are all mostly pneumatic and I shall address them later in the day when I discuss the refrigeration system. Right now I am going to discuss what I think could be our future needs for computer control of the cryogenic system.

One of the items which we will have to control one way or another and which is amenable to control by computer is the liquid level in the coils. We are going to have two cyclotrons with coil volumes of 500 and 800 liters, respectively; also there will be the ECR source and many beam line magnets with cryostats of the order of 50 liters each that have to be either filled at intervals or be maintained at a certain level.

There are at least three ways to control liquid level in a coil: (i) control the feed pressure; (ii) control the flow rate with a feed valve or possibly dewar pressure; (iii) control the pressure at which the coil sits, thereby reducing its response to changes in suction pressure caused by operating other equipment. Presently we control only indirectly the pressure at which the coil sits, by keeping the suction pressure at the inlet of the compressor constant. A bad feature of this is that when an operation is performed that involves the coil of one of the cyclotrons (e.g. increasing the K800 flow), since both feed streams go into suction, the coil pressure in the other cyclotron (the K500) will automatically change. And when the pressure of a coil drops, helium flashes, and the level may drop below what is safe for operation.

Some operations for which we would like computer control are: liquid helium feed to the K500 coil, liquid helium feed to the K500 cryopanels, the same for the K800 coil and cryopanels, and liquid helium feed to the ECR ion source. These devices require continuous liquid flow and hence flow control valves. Further, in order to remove the potential for interaction among the different operations, they should be isolated from each other by having pressure control valves on the exit gas for the K500 and the K800 coils and probably also for the ECR. Computer control would also be desirable for the magnets on the beam line: they are designed to be batch-filled and we would like to fill them under computer control by monitoring the helium level and initiating a filling cycle when the level is low.

The vent helium gas returns to suction. As suction pressure increases, the compressors have to be loaded. Another option is to always run the compressor at a level where it kicks back gas to storage and then the suction-makeup gas would perform that function; of course, that would imply that the compressors operate at a higher power level than actually needed. It is more economical to control by loading and unloading the compressor.

Let me next describe how we presently respond to a sudden increase in vent gas. We usually operate in a break-even mode where just as much liquid is made as used up. The compressor suction pressure is monitored. If this exceeds a preset bound, as would be the case if a heat load is suddenly added, gas is automatically kicked back to the storage tank. The imbalance in liquid production is made up by drawing on reserves in the storage dewar.

Another operation that can be done by computer that we have not attempted at all is logging of data on the cryogenic system. We have many pressure sensors and temperature sensors and it would be nice if one could look at a 24-hour history for four or five functions and see how they interact. At present we do not do that at all. For example, to check for water in the helium stream, at present one needs to pump for about 24 hours on the hygrometer sensor (the aluminum oxide sensor tends to get wet) and then one starts the measuring cycle, watches the helium gas for 2 hours, then turns the gas off and pumps on the sensor again. A sequence like that could easily be put on a computer and then it would not be forgotten. Right now, it does not get measured as often as we would like.

It would also be helpful to include more flow sensors on the refrigerator and the distribution system, to see how their performance changes as a function of time. That would make it easier, I suspect, for somebody who is not very familiar with the system to see when something goes wrong and identify what that might be. Right now we have a very limited number of people who are familiar enough with the system to make a change in our operation.

One could also use the computer to keep track of our helium gas inventory, which is presently done by hand. Under computer control, one would only need to read all those pressures and temperatures by computer and then use the same program to keep a continuous log of helium on hand.

Modicon System--Richard Au

In general terms, the Modicon is a programmable device with ladder-like diagrams, i.e. relay closures. It can be used for analog input but then it becomes extremely expensive, so we are using it only as a programmable relay substitute. It sits over totally independent of the control system, and therefore has high reliability. It is a large Modicon, model 584, with centralized control and has three functional subunits. It can operate as a dedicated unit with direct-connected I/O points or it can have remote I/O points. The way we are operating it is as three remote I/O units, each of which has the capability of 256 inputs and outputs. It is generally used for safety devices, such as door interlocks or anything where one would use a relay system.

The difficulty with the current system is that its output to the control unit is of a bastardized nature. Some of the I/O points are currently fed over into some of the controls and one can read such things as RF interlocks, water interlocks, etc. What is shown is that, for example, interlock 146 has fired. The MicroVax that VanderMolen mentioned will be connected by a wire to the Modicon, so that we can interrogate the Modicon and know what its interlocks are. Thus, whenever an interlock fires, we will be able to read out of the Data Base and know what the difficulty is. We will also able on the MicroVax to have the actual ladder list available, display it on a graphics screen and pinpoint the defective unit (e.g. flow switch #3), so that it can be reset appropriately. These are our plans for the future.

Currently the Modicon operates independently, the program to read it into a Vax computer is available, and we do get generated ladder lists out of it, though they are not on-line ladder lists. The only modification we will have to do is to make the ladder list an on-line one so that we can get the English and the Data Base out to the user. Right now we have to go through a procedure where the user has to look up information on a piece of paper.

In summary, the Modicon is fairly reliable, it takes care of all our safety devices, and it operates as an independent system. The water interlocks, the door interlocks, the vacuum interlocks, and the gas monitors are all on the Modicon.

Computer over-temperature alarms have not been put on the Modicon. For computer over-temperatures, we intend to develop a system whereby an alarm will sound in the University Telephone Operators' Room at the MSU Public Safety Building, so that somebody from the Physical Plant Security comes over and physically corrects the problem.

We also have not solved the question of how to implement radiation safety for laboratory personnel via the Modicon, though we have been discussing it. The State of Michigan Radiation Safety Laws specify that the radiation safety system must operate independently of everything else. But how do we independently shut down the accelerator? Considering that all of our shut-down procedures are controlled by the Modicon, are we allowed to tack on the radiation safety feature as an appendage or do we actually have to have a whole separate relay system for radiation safety? The answer is a little bit unclear to us right now, but we think we have to have the latter.

I suppose cryogenics is where we are furthest behind in terms of computer control. Of course, in principle we know how to do everything. In my opinion, our biggest difficulty is with the lower level items. There is a great variability in the devices that are used in the Laboratory and they are generally new, state-of-the-art devices. Knowing ahead of time what instrumentation is needed to monitor these devices would be very desirable, but in the nature of things that is impossible. That is the difficulty. One way to attack this problem of having the right kind of low level interface at the right time is to get a good generic set of interfaces--modular interfaces, ADC's, DAC's, Bits In, Bits Out, etc. Then if someone comes in and asks for a particular device to be interfaced, we would use the appropriate module from the shelf and we would be home free. Getting such a generic set of modules of input and output functions is a big problem, since we have very little capacity to make them in-house. And the idiosyncratic functions demanded by our state-of-the-art devices generally means that we can neither buy the interfaces commercially (as we did for our Ethernet and Arcnet networks) nor get the design from elsewhere (as we did for our "Fermilab clones").

BLOSSER: Will it be feasible for a user to bring in a device with a standard plug on it to be plugged into our control system?

AU: If there were a standard plug, yes! We are trying to get standardized modules so that, if the device has an analog output, it can be plugged directly into one of our modules and read. And if it needs a digital or analog input, we can connect it up. But there are very few industry standards for controls. You can get some instrumentation like the 488 interface bus but that in general is not applicable to our type of environment. It is good for standard devices like digital voltmeters, but large power supplies and counters are quite unique.

One approach we are taking is to use the fact that we know what the access protocol is on the Arcnet. We can therefore use the MicroVax to take care of a large number of one-shot quick-type interfaces. We program in a high level language like Fortran in the MicroVax, or Pascal in the 68000's, and let the user have access to his device through an access protocol. To control his device, the user uses one of the smart 68000's or maybe even a lower level unit like one of the 6800's, and writes an appropriate Fortran program. From there on up, everything is defined and control is achieved easily by making use of the network functions. The problem is at the ADC or DAC level: once we get a digitized input into a machine, everything is easy.

SESSION II. CRYOGENIC SYSTEMS--Seminar Room, 1:15-3:15 pm, Aug. 29

Cyclotron Magnets-- Don Lawton

I shall describe the construction of the two big cyclotron magnets, which are the main users of the cryogenic system. Figures 10 and 11 are vertical cross sections of the K500 and the K800 cyclotron, respectively. The yokes are shown shaded. There are 5 castings and 90 tons of steel in the K500 magnet, 18 castings and 130 tons of steel in the K800. There is an annular vacuum vessel that we call the cryostat and suspended inside it there is the superconducting coil at liquid helium temperature. There are actually four separate coils making up the solenoid. They are wound on a stainless steel bobbin that with covers welded on the outside serves asthe liquid helium vessel. That vessel is surrounded by a liquid nitrogen shield and the whole assembly is suspended inside a vacuum tank (the "vacuum jacket") by means of support links.

I would like to use some photographs of the K800 magnet coil construction (Fig. 12) to give an idea of the steps involved.

(A) shows a coil cavity that has been prepared for the winding. The stainless steel surface is covered with 10 mils of mylar and then fiberglass parts are put in there to form the winding surfaces. The space in between what we call the pickets becomes helium flow channels.

(B) shows the beginning of the windings, done in a spiral fashion. We notice that it is a very open lattice.

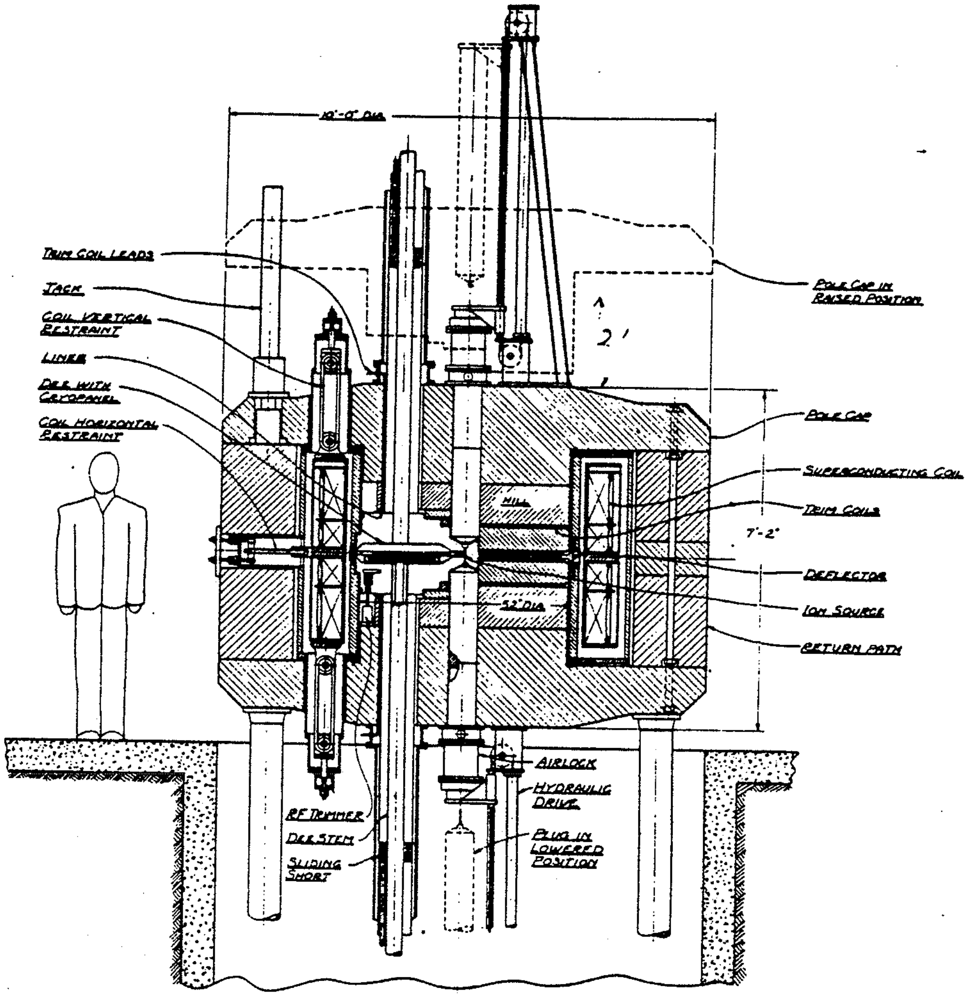


Fig. 10. Vertical section view of
(a) the 500 MeV cyclotron.

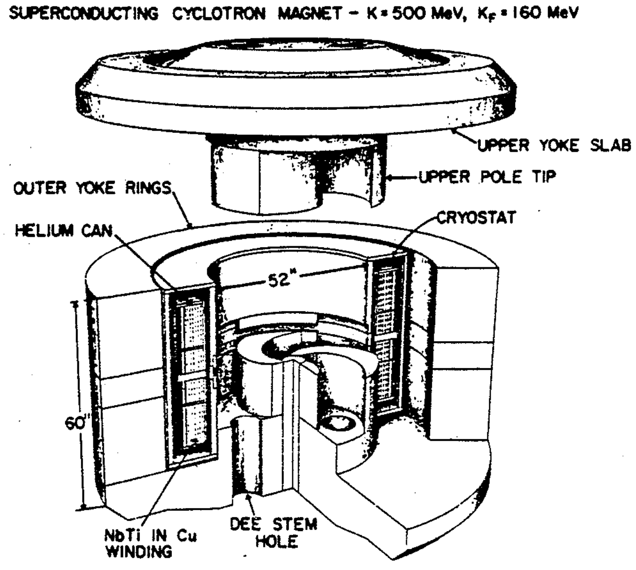

SUPERCONDUCTING CYCLOTRON MAGNET - K = 500 MeV, K_F = 160 MeV

Fig. 10. Perspective view of the magnet
(b) for the 500 MeV cyclotron.

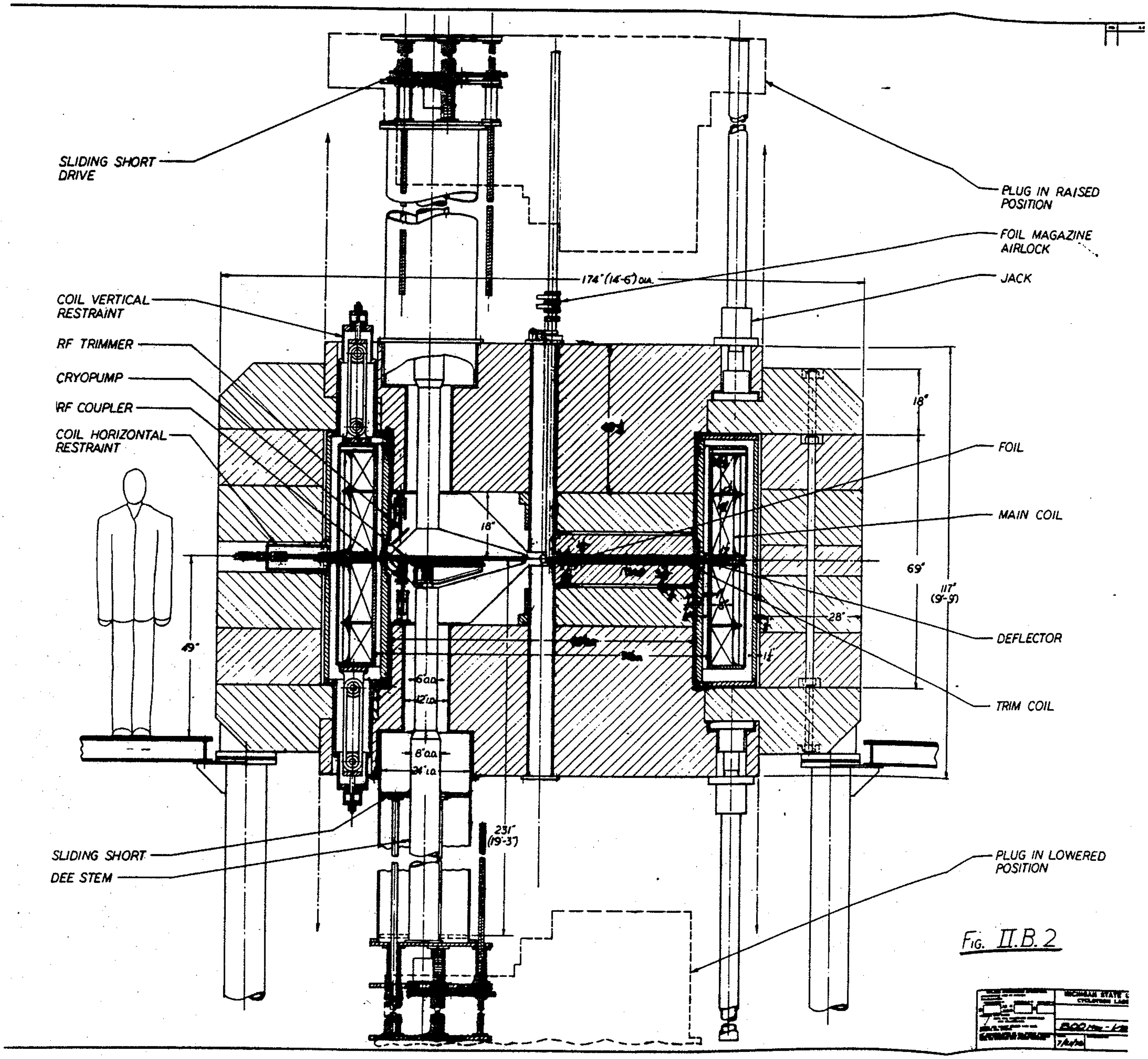
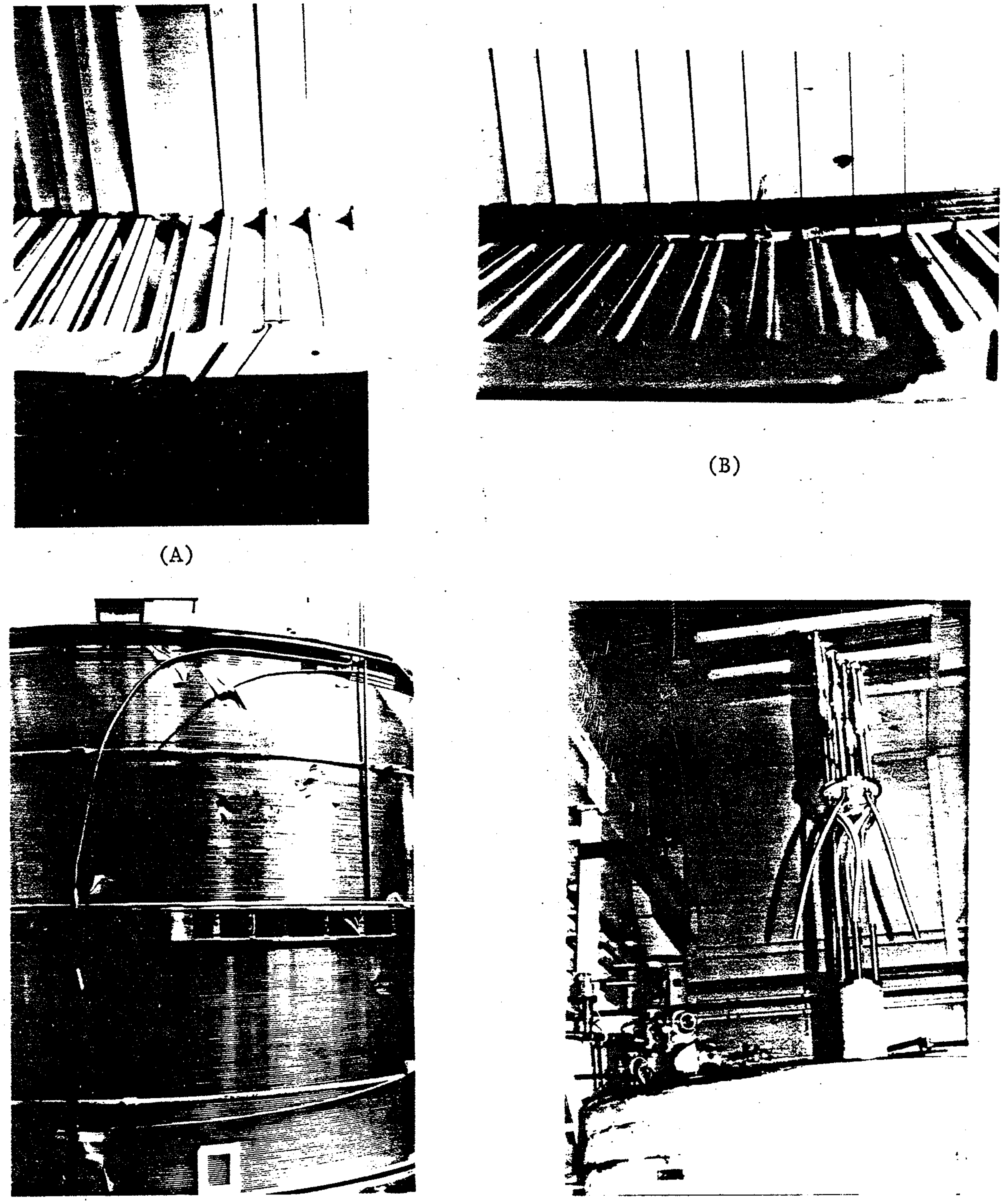


Fig. 11 Vertical section view of the 800 MeV cyclotron



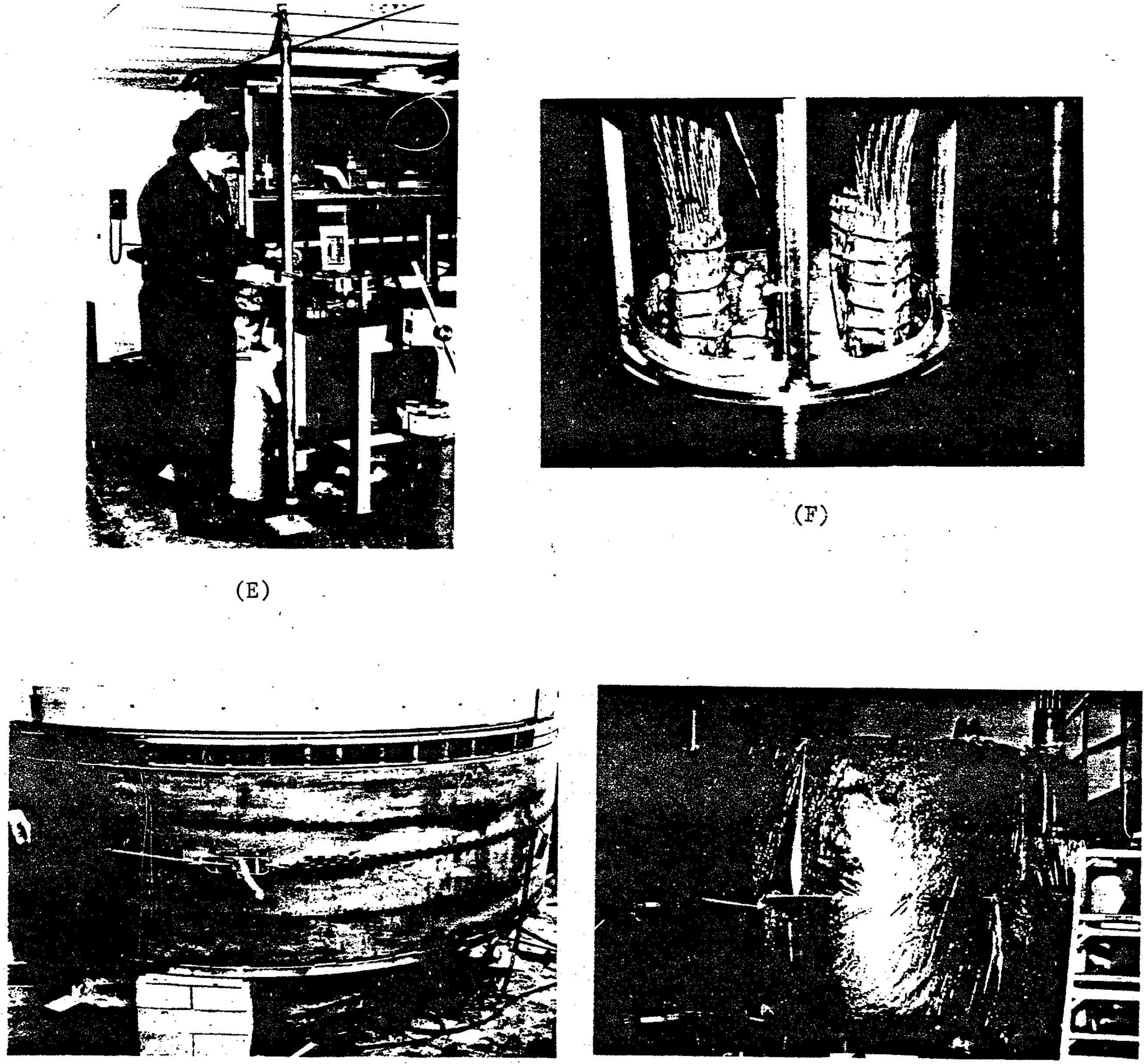
(A)

(B)

(C)

(D)

Fig. 12



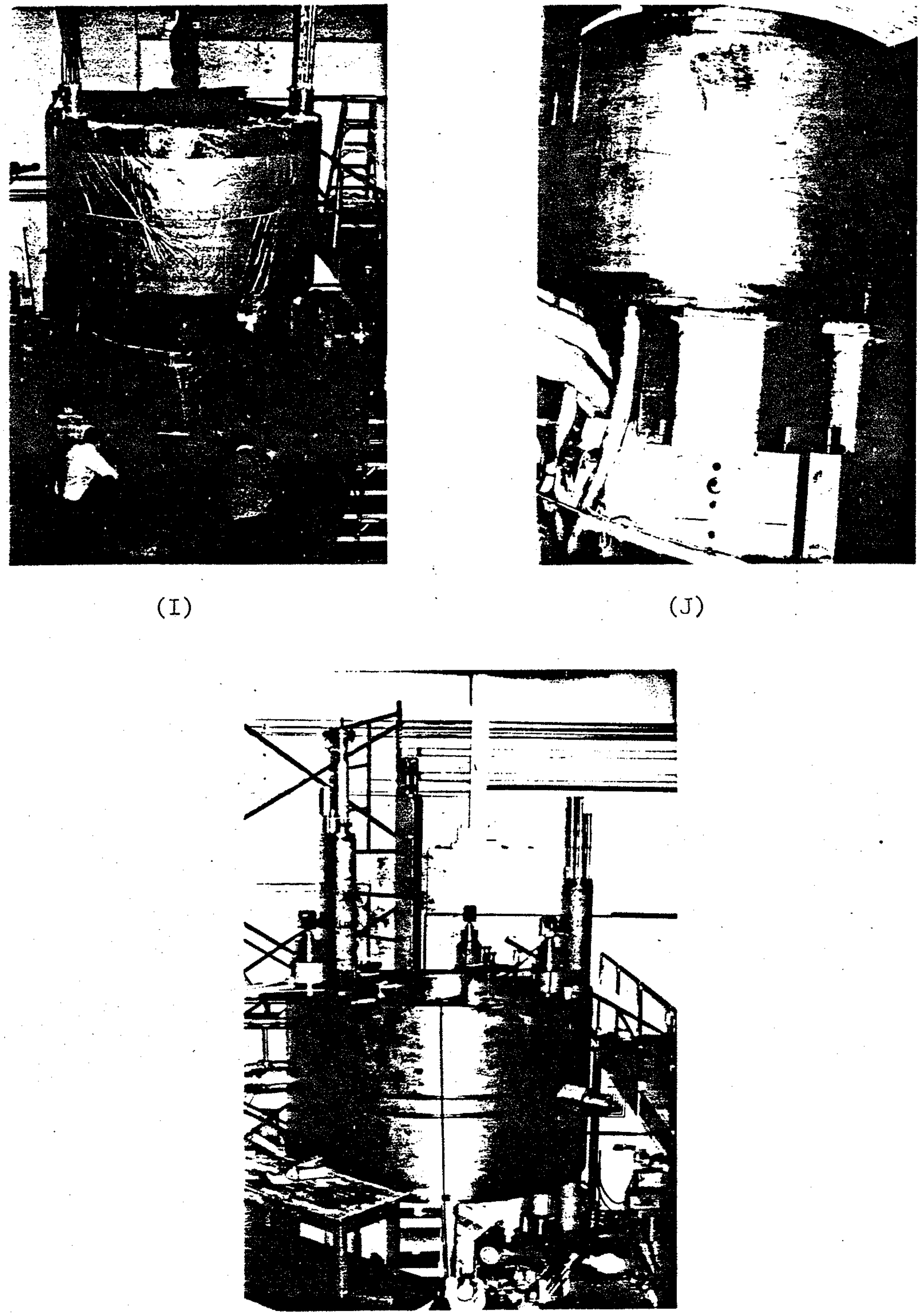
(E)

(F)

(G)

(H)

Fig. 12 (contd)



(I)

(J)

(K)

Fig. 12 (contd)

(C) is a picture of a completed coil with the aluminum banding installed on the outside of the coil in 2-inch wide layers of aluminum wire; the banding is almost of the same cross section as the coil.

(D) is a shot of the construction of the refrigeration port to the coils. The line from the refrigerator comes over at the top and through bayonets, whose female parts appear in the picture, and then through corrugated flexible hose in between the bayonets and the vacuum wall of the coil. This is a temporary measure for the K800, designed to avoid having to saw and reweld the refrigeration line every time we go through a sequence of taking the magnet apart and putting it back together. The K500 also started out that way, but now it is hardlined to the refrigeration system, with no bayonets.

(E) is a picture of the fabrication of the electrical leads. They are 7-feet long and vapor cooled. They were fabricated in-house for the K800; for the K500, they were purchased.

(F) is a shot of how the coil end is attached to the leads: it is wired and soldered. The support links for the coil (which are not shown here but are shown in (K)) are a combination of titanium and fiberglass. The buckets which provide the cooling for the nitrogen shield surround the support link assemblies. We have measured the temperature of that heat station in operation; it is around 100° K.

(G) is a shot of the covers going on the outside of the helium vessel. The median plane of the helium vessel is a series of bars which are able to carry the coil load but allow us to bring the injection/extraction channels out through the coil. After the coil was welded up and leak checked, we covered it with insulation (standard building insulation) and filled it full of liquid nitrogen to cold-shock the welds.

(H) is a shot of the superinsulated coil, showing aluminized mylar on the outside. We put that on layer by layer, not using blankets. Outside that would be put the nitrogen shield, then the vacuum jacket. There are 20 bright layers between the helium vessel and the nitrogen shield, and 30 between the nitrogen shield and the room temperature jacket.

In (I), you can see the superinsulated coil being lowered into what is actually the lower half of the liquid nitrogen shield. Between the lower and upper halves, there is an opening at the median plane so that penetrations could go through. Potentially, even a tiny gap in the insulation can cause problems, but we have had none. The insulation ended up bulging out of the crack between the inner cryostat wall and the upper flanges, and we just scissored it off.

POWERS: Is the edge of the cut exposed at a different temperature? For if so, there would be the danger of a side shine into the paper which would then become a glow all the way down through the layers.

LAUMER: It did not look like that. There was always plenty of insulation in there, so that we did not see the wall of the cryostat.

(J) is a picture of one of the liquid nitrogen buckets that surround the support links and provide the cooling for the liquid nitrogen shield. The bucket is of all stainless steel construction, penetrated by a copper bar which in turn is bolted to the top or bottom flange of the shield. The copper bar is there to provide good heat conduction.

(K) is the last picture I have, and shows the more or less completed coil and vacuum vessel. We can see two of the three median-plane horizontal support links, all three of the upper vertical support links, and one of the three vertical links at the bottom. The three big vertical structures on the top are, from right to left, the refrigeration port with bayonets, the electrical leads, and the safety port with a 4-inch diameter, 30 psi rupture disk (for the K800 helium vessel; the K500 has a 3" rupture disk).

POWERS: Are there other relief valves in the system below 30 psi?

LAWTON: There is a pop-off disk on the vacuum vessel. And there are lots of other pop-offs in the cryogenic system itself.

POWERS: Only one vacuum vessel relief? If the helium vessel goes, it probably pops into the vacuum--and you would depend on one pop-off disk to relieve the pressure?

LAUMER: An additional problem is that the O-ring bonding leads to relatively high relief pressures.

POWERS: But neither the helium vessel nor the vacuum vessel is code stamped? I realize the vacuum vessel does not have to be, because it pops at 10 lbs, i.e. below one atmosphere. (N.B.: Only vessels that have to withstand pressures of 1 atmosphere or more need to be code stamped. In case of a quench, a pressure of up to 3 atmospheres can develop in the dewar.)

BLOSSER: Well, at the time we built these things, code stamping for cryogenic vessels was not a matter of legal importance. Actually, the medical cyclotron is the only device for which we really talked very much about the possibility of code stamping and even there decided that we did not need to do it.

POWERS: I guess this could be called a U.S. government laboratory, and so is outside the bounds, so to speak, of Michigan regulatory coverage. What is the design pressure for the helium vessel? Anyway, the whole pressure vessel aspect of the cryostat is sort of mute, and it seeems to work all right.

BLOSSER: The stored energy is sufficiently high that one does not intentionally let the liquid helium level go down enough to quench the coil. On one occasion the K500 accidentally quenched due to low helium level and things went as designed: the rupture disk ruptured and the helium vessel was safe. Also, our large coils have not shown any training behavior: we look for conductor motion as we turn the coils on for the first time, and we have not seen any.

POWERS: Do you have a quench protection system?

BLOSSER: Yes, there is a dump resistor. When we quenched the K500 coil, quite a big chunk of the energy did end up in the dump resistor. It is in a water bath and we see how hot the water temperature gets. Let me add that the cryostats are always surrounded by great chunks of iron, and so are surely safe.

POWERS: I should explain to everybody that I am at Fermilab a great deal. I was asked by Fermilab to qualify literally thousands of pressure vessels around the laboratory because I happen to be a professional engineer. One of the things I am sensitive to is creep. Do the links work pretty well? You have obviously had good luck with them, do you notice any creep?

LAWTON: Not that I know of. The operations people did not mention anything about that.

BLOSSER: All these links do have strain gauges.

POWERS: Are they heavily loaded?

LAWTON: The K500 upper links are at 10,000 lbs. Their breaking strength is around 40,000 to 50,000 lbs.

POWERS: The breaks occur at the nitrogen station, right?

BLOSSER: The one link we tested to destruction broke at the end bearing.

POWERS: Any data on creeping? We did a lot of work on creep, again back at Fermilab. Our system had 36,000 adjustment screws. They were in compression and were heavily loaded (to about 85% of the breaking point) in the direction normal to the fabric. Neiman and Gonczy at Fermilab have creep data now, I think, for the whole range of temperatures. They also have a U.S. patent on a design for the links.

NOLEN: In the K800 links, the fiberglass only exists below nitrogen temperature, with titanium above nitrogen temperature.

POWERS: Actually, these things have to work at room temperature for a period of time before they reach the cooling down stage, so you need tests. After it goes through the freezing phase, the fiberglass is pretty solid and there is very little creep.

Beam Line Magnets--Jon DeKamp

We plan on using about 70 quads and 15 dipoles of assorted configurations for the beam transport system during Phase II operation. Most of the quads will be packaged as doublets. Probably, half the dipoles will generically be of the same type, viz ±16° benders, with the other half being one-way benders. In all of these the field will be shaped by the iron. The quads will all be cold iron magnets and the dipoles will all be warm iron magnets. The big difference between the quads and the dipoles will be in the amount of current run. The quads are designed for low current and have a large number of turns, while the dipoles are run on a higher current. This has some ramifications for the current lead design and operation.

I have got some pictures of the quad while it was being constructed and assembled. Figure 13 shows one of the quad coils (the scale is in inches). The coils are made of 3600 turns of 0.3 mm diameter wire and are wet-wound with epoxy in a random wind around the winding fixture and oven-cured. A coil can be wound in about 5 hours. The fact that the quad is iron-dominated (i.e., the field is shaped by the iron) allows for random-type winds, as wire placement has very little effect on field shape. The end forms on the coils are made out of the same epoxy as the coil is wound from and are molded separately and bolted onto the form.

Figure 14 is a picture of the yoke and pole tips assembled together, prior to the installation of the coils. The pole-tip shape is hyperbolic.

Figure 15 is an end view of the assembled magnet. A G-10 splice ring is bolted to the yoke iron and into a groove in that ring is epoxied the

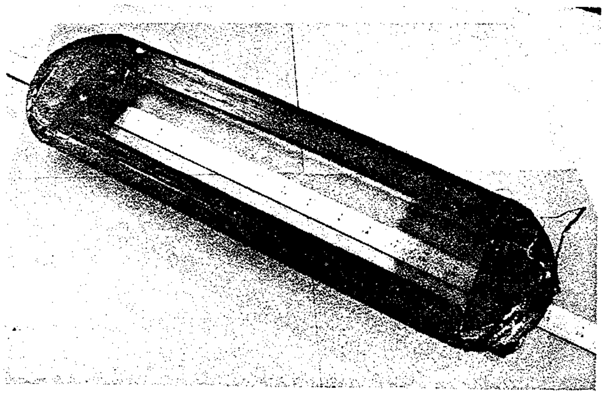


Fig.13. Photograph of the superconducting coil. The scale is in inches.

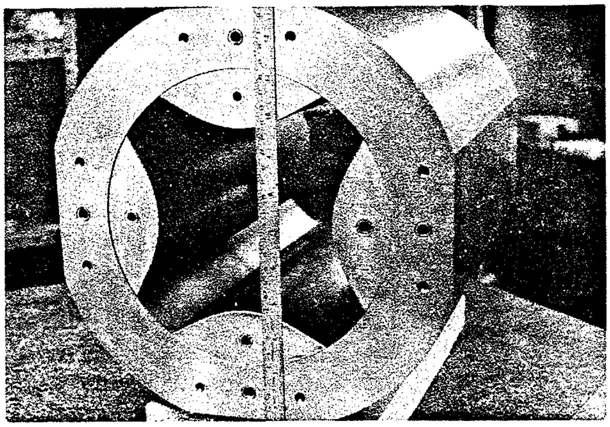


Fig.14. Photograph of the steel yoke and pole tips.

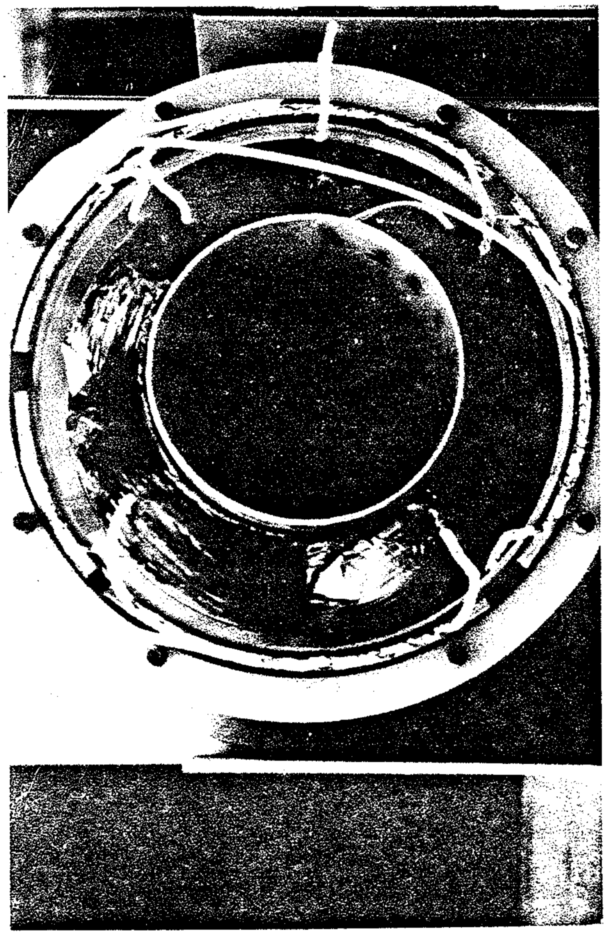


Fig.15. Photograph of the coils assembled around the pole tips.

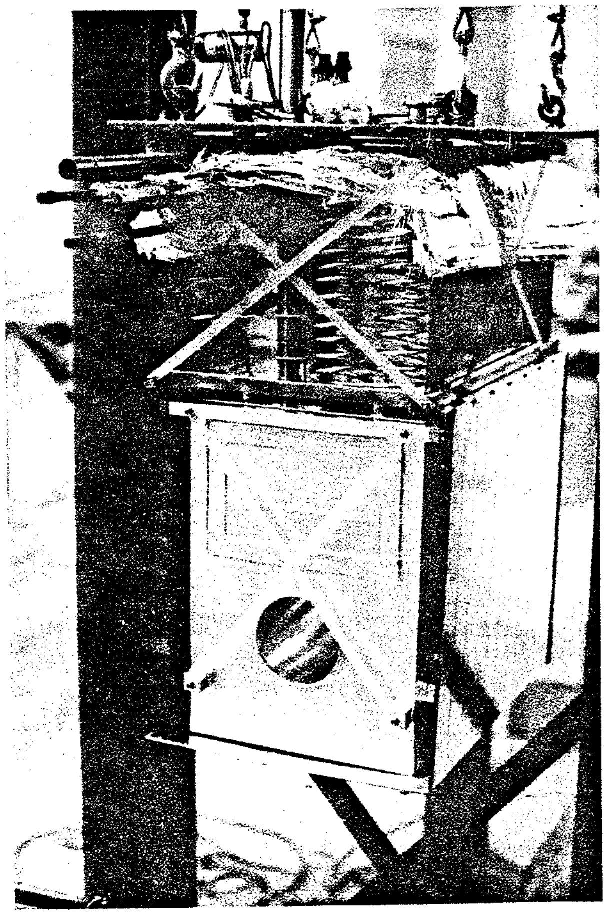


Fig.16. Photograph of the quad.

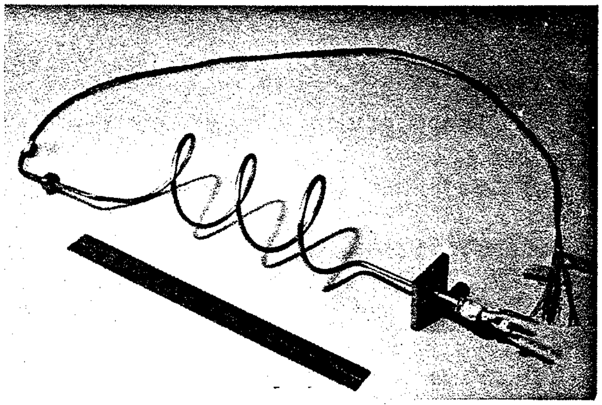


Fig. 17. Photograph of the current leads.

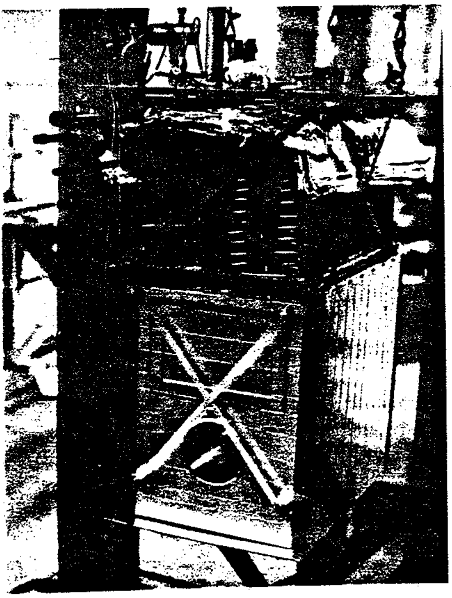


Fig. 18 The magnet prior to final adjustment of the support links and installation of the superinsulation blanket on the nitrogen surfaces. The only insulation between 77 and 4.2K is the aluminized tape. The coiled feed lines are also visible, as well as the leads.

superconducting bus bar (made of the K800 conductor material) where the coil connections will be made. The (cold) bore tube appears as the inner annular ring in the figure.

After inserting the magnet into the helium vessel, the vessel was welded shut, except for a window giving access to the leads, rupture disk assembly, and cryogen inlets. Both the helium vessel and the nitrogen dewar have capacities of 25 liters, with expected usages of about 0.1 ℓ/hr for both liquid helium and liquid nitrogen. Thus we expect the nitrogen and helium containers to run on a weekly batch-fill schedule. To keep the conductive heat load on the helium as low as possible, the helium vessel is suspended from the nitrogen dewar by G-10 supports, thereby insuring the supports are properly anchored at 77 K. The nitrogen dewar is likewise suspended from the room temperature surface by adjustable links, necessary since the warm bore is mechanically floating with respect to the magnetic center. The suspension system is shown in Fig. 16, prior to assembly of the nitrogen dewar, with the nitrogen shield partially in place. The crosses are the support links: the upper crosses connect 300 K to 77 K, and the lower set 77 K to 4.2 K. The nitrogen container is up on top and the helium container down on the bottom, where the magnet is. Note the crook in the upper link to accommodate the cryogen transfer lines.

Figure 17 shows the current leads prior to installation. In a 3/16" diameter, .005"-thick wall stainless steel tube, there are 29 strands of insulated superconducting wire: two sets of 9 for the current leads and 11 for instrumentation. They are mostly sealed with epoxy to stop helium from leaking. The leads are vapor-cooled and they do not place any additional heat load on the system. This is confirmed by noting that the boil-off rate does not increase when there is current in the leads. So the leads are pretty efficient. The magnet is capable of returning all its boil-off gas through the vapor-cooled leads themselves, and there is very little frost on the top.

To reduce the large heat leak associated with the liquid helium feed valves when they are closed between the weekly fillings, spiralled thin (.010") walled, 0.25" diameter tubing 100 inches long connects them to the helium dewar. The heat leak associated with the valves is then reduced to 0.01 ℓ/hr between fillings. Again in order to reduce the heat load, the rupture disk and assembly are attached via a thin-walled bellows-type vent pipe, constrained with G10 supports: the convolutions in the bellows imply a long effective length, which helps to reduce the heat load.

In the final assembly, the 4.2 K and 77 K surfaces are coated with aluminized tape. Following a technique reported in the literature for reducing heat transfer between 77 K and 4.2 K, no superinsulation is used between the 4.2 K and 77 K surfaces. The helium bore floats around the nitrogen bore with no contact and no spacers in between. This is an unusual feature of our design. Superinsulation is used between 77 K and 300 K, however. Figure 18 shows the assembly before the nitrogen shield is completely attached and before the final superinsulation blanket has been applied. The coiled feedlines are visible, as are the current leads.

The arrangements I have described will be followed for all our beamline magnets, except possibly for a couple of large dipoles. They will all have their own cryogen containers, sized for operation on a weekly fill basis.

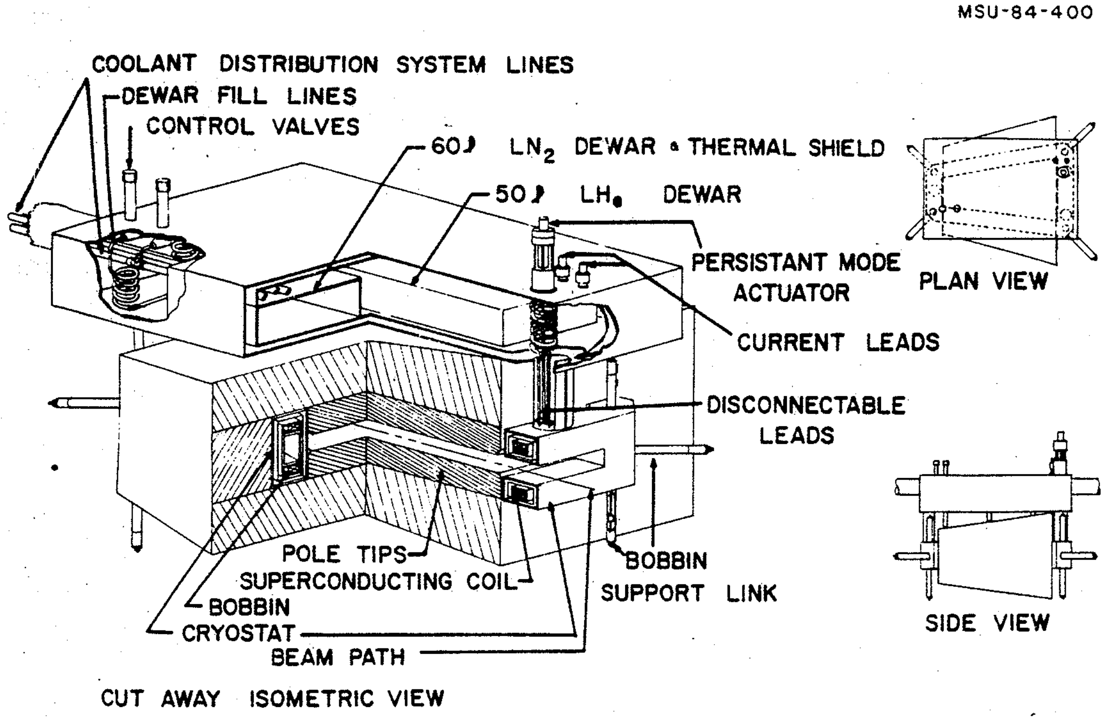
POWERS: Have you measured the amount of heat leak?

DEKAMP: Yes. In the initial measurement, we obtained a boil-off rate of 0.15 liters an hour, which is to be compared with the design rate of about 0.1. We noticed that the bore tube of the nitrogen shield was 40° K hotter than it should have been, which would have put a considerable radiation heat load. Since then, I have made the contact more uniform over the whole diameter of the bore tube by clamping more carefully; that has improved things considerably, for at present I get about 90° K for the bore tube temperature.

Let me now briefly describe our dipole magnets. Figure 19 is a schematic drawing of a ± 16° bending dipole magnet that is under construction. They are designed to be operated at the nominal maximum current of 100 Amp ("warm" design). In order to keep the liquid helium consumption low (consistent with a weekly batch-fill operation) despite the high current, we plan on operating the magnet in persistent mode so that we do not have high heat load for the vapor-cooled leads. (Of course, there will be a heat load during charging, but it will be for only a short period of time.) Because of the "warm" design, the arrangement of the magnet area gets considerably more complicated than for the quads; there is very little clearance between the nitrogen shield, cryostat wall and bobbin, and the support links are a little bit more sophisticated so as to support the bobbin, because the axial forces are unbalanced. The rest of the construction is basically the same as for the quads, except that the helium and nitrogen dewars sit side by side instead of piggy-back. The shields are similar up on the top, all our shields on the quads and dipoles are conduction cooled.

POWERS: Have you tested the persistent switch?

DEKAMP: Yes. We tested it in the test stand with a small mockup of the coils that we plan on using here; they were the same cross-section but in a smaller wind. We had no trouble making the switch work, we would make contact and disconnect several times. It is of commercial manufacture, with disconnectable leads, mechanically operated.



SUPERCONDUCTING ± 16° BENDING MAGNET

FIG. 19

Spectrographs--Al Zeller

The S800 is the major spectrograph we are building. Many of you have been out there to see the pit with those two big pieces of iron. Figure 20 is the cryogenic sketch of how we want to operate it. Of course, the cryogenic design follows the layout of the magnet itself, which will be supported upright; there will be two quads up in front that are not shown on the sketch. All this will probably sit on top of the support that holds up the magnet. We presently envision a batch-filled mode for this device. Because the magnet has large stored energy, we would have to run a cryostable coil. At 500 amps, it requires a reasonable amount of liquid helium to run the leads, so we need to have 1000 liter dewars. The other possible option would be to move the 1400 refrigerator down to that end of the building.

Basically, the liquid helium connection for the S800 will be done in the same way as for our beamline magnets, as described by Jon DeKamp. We will have a cryogen distribution system and there will be a major point that branches off that to fill the dewars for the spectrograph plus the other magnets. (There are a number of magnets that bring the beam into the pit, and they all have to have liquid helium supply.)

In a magnet with a compact design, such as the medical cyclotron being built for the hospital in Detroit, any quench that occurs will propagate rapidly from layer to layer, so a non-cryostable coil can (and will) be used. But in the S800 spectrograph, the path length around the coil--and therefore the propogation time along the conductor--is very long. This usually results in high temperature hot spots. One could pot the coils and thereby get faster quench propagation, but because the coil is so long, and

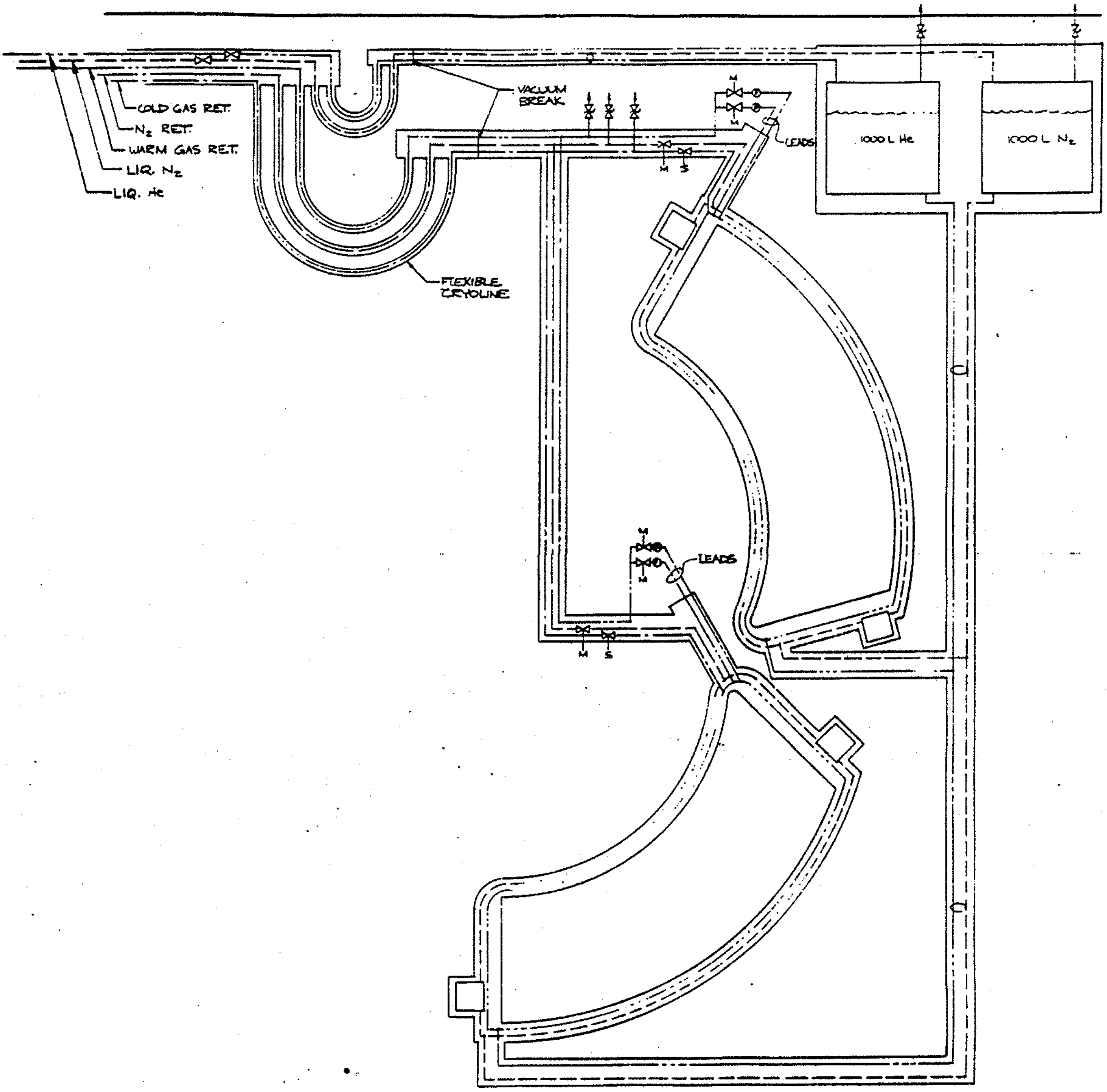


Fig. 20 Proposed cryogenic distribution system for the S800 spectrograph.

the consequent temperature rise so large, one still has to have some sort of dump resistor. It is possible to build a non-cryostable coil but that would require a redesign of the coil structure. Instead, we have opted to have a cryostable coil and no potting. That is basically the cryogenic aspect of the S800 design.

The other major problem that we have looked at is the structure of the magnet itself. The coil, of course, has to follow the sagitta of the beam which means we have a negative curvature on one side of the dipoles. So we plan on having a microscopic winding. The coil will be wound with very little tension, held in place turn by turn with clamps, and finally kept under external pressure by steel springs. The coil will have 364 turns per each half of each of the two dipoles. We envisage that as an open structure where we wind up. We have 13 G10 spacers with machined grooves, we will just lay the conductor right in and then bring it out, then fill up the space with steel springs.

POWERS: It will be a short spring, all at one temperature, so there will be no problem. If one end was hot and the other cold, then it would probably break--but if you cool the whole thing, it probably will not break unless you impact it.

ZELLER: Since we do anticipate that there might be a quench during the lifetime of the device, we have paid great attention to the design of the coils. We will have a set of clamps and a big table; it is a kind of hinged arrangement that swings out of the way. We will clamp one turn, then wind up the next turn in the usual way, and thus proceed layer by layer. We will not be able to wind from the inside because of the negative curvature, so we will just walk our way around for a total of 1456 turns for the two dipole. We will manually pull the wire along and put a clamp on it every time we move a couple of feet. For the next layer, we will come around removing the clamps in front. It will be feasible to finish this in a couple of months. Do you know of anybody who has built a superconducting magnet this way?

POWERS: I know some people who tried at MCA; the device did not come up to the expected level of performance.

NOLEN: Requirements on this coil are minimal in terms of what a cryostable conductor can do at 2 Tesla (e.g. it will operate at only about 50% of the short-sample limit). What we really wanted to do was to have a magnet with the general shape sketched in Fig. 20, but also having a saddle coil at each end, for that would have been more efficient magnetically. But we finally decided that we did not want to tackle both the the negative curvature and the saddle the first time around.

ECR Sources--Tim Antaya

This week we are in the process of turning on a room-temperature Electron Cyclotron Resonance (ECR) source that will be coupled to the K500 cyclotron. It is presently the largest operating ECR source.

We may also build a second, more advanced source which will have basically the same vertical design but will use superconducting coils. It is this advanced source that I want to talk about. Compared with the room-temperature source, it will be larger by about 60% in linear dimensions (thereby having a much larger minimum B structure), and will likely have a higher magnetic field. Actually, design studies occurred first for this advanced source, though we shall soon reconsider whether to modify the design in the light of our experience with the room-temperature source.

The superconducting ECR source is a D.C. device and its design is shown in Fig. 21. It involves a large superconducting magnet consisting of a set of six epoxy-impregnated superconducting solenoid coils and a hexapole ("sextupole" in American usage) coil that runs the whole length of the source. The peak axial field for 6.4 GHz operation is around 5 kilogauss; the field at the winding is 10-12 KG. The reason for using, despite these low magnetic fields, superconducting coils is mainly the magnetic efficiency; power consumption for room-temperature magnets becomes prohibitively high for large-diameter coils.

The iron return yoke that surrounds the device is shown shaded in Fig. 21 and is similar to the yokes in our superconducting cyclotrons. Both the hexapole coil and the circular (solenoidal) coils are in a common liquid helium chamber. The maximum current density in the hexapole coil is about 20,000 amps/cm^2 and in the circular coils are about 8,000 amps/cm^2. The

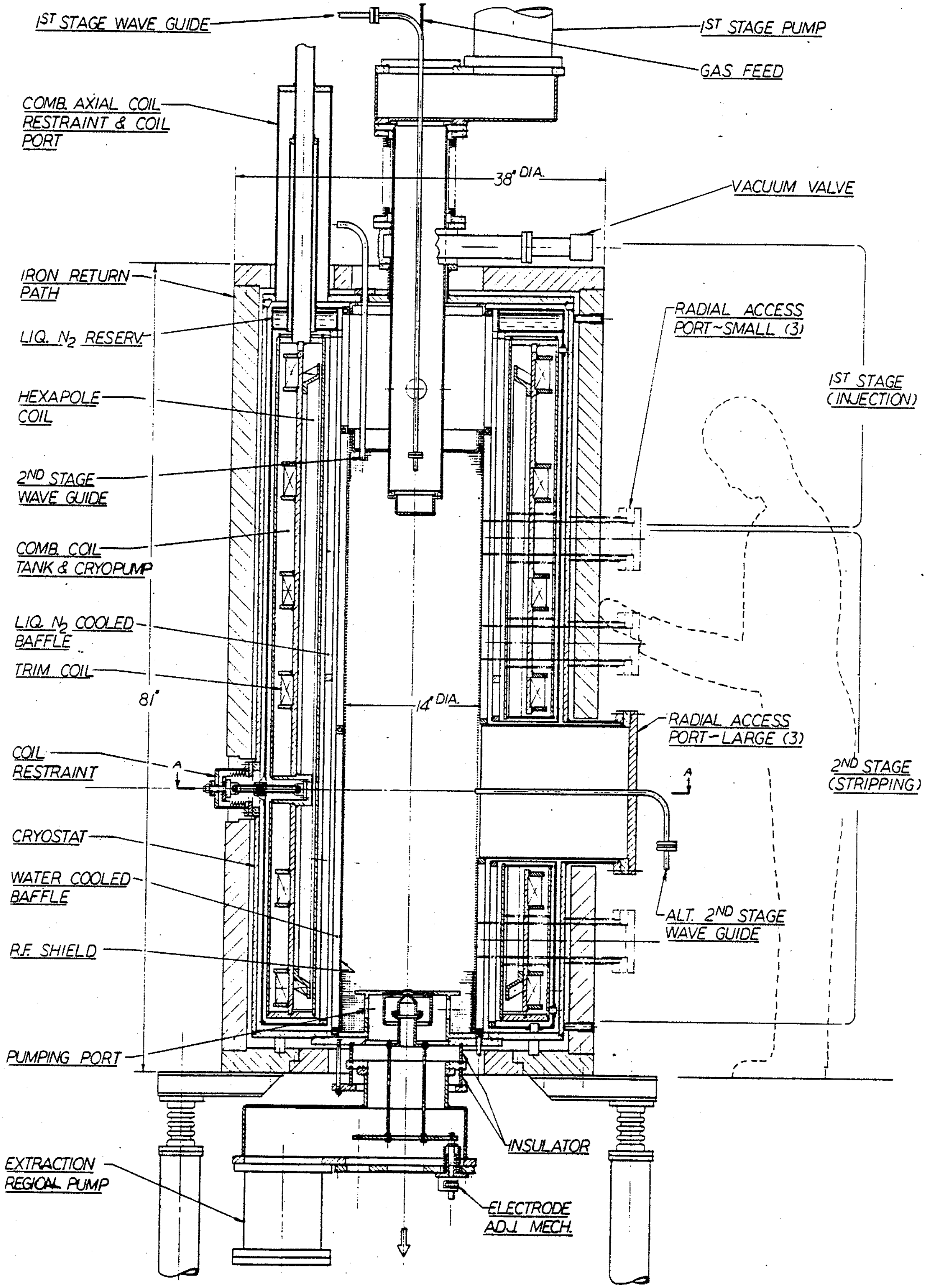


Figure 21. A drawing showing the updated design of a vertical superconducting ECR ion source with a return yoke and second stage cryopumping off the coil vessel surface. To ease modification, the entire first stage is retractable through a vacuum lock. Both radial and axial access to the second stage will be possible.

coils are not cryostable but I believe that they will be self-protecting. They have to be, because a quench in one coil induces quench in all the others, since all are in one helium vessel. We think this is an advantage, in that it allows the self energy to spread throughout the whole coil system in case of a quench. But we are unable to model the quench effect properly, because the coupling geometry (i.e. the interaction between the hexapole and circular coils) is complicated.

Another important feature of our design is to use cryopumping off the 4° K surface of the coil vessel to produce the vacuum in the plasma chamber. Have you ever come across such a design?

POWERS: Yes, the proposed superconducting supercollider design plans to use the cryopumping effects of the helium vessel for evacuation of the chamber. It is an energy-saving idea--all the valves on the chamber can be closed and it runs all the time; there will be portable repumping stations that are brought to it when there is a leak. The major problem with such an arrangement is that, if the liquid helium goes sub-lambda so that the helium gets into the insulating vacuum, it cannot be pumped out because obviously the vapor pressure of helium at liquid nitrogen temperature is one atmosphere. One can probably oversome that by putting in some kind of a bonded sieve getter or something like that. But it is a remote contingency which will not happen unless helium gets into the vacuum jacket.

BLOSSER: We do not want to use superinsulation in this device both because the design is tight as regards space and because we want a clean vacuum in the source. Instead, we will put tape on the helium vessel. The nitrogen load is an issue here and we might want to go with a double shield.

POWERS: Vapor pressure of organic material is very low at 4.2° K, so you will have a clean vacuum even if you use superinsulation. I wrote a paper on a type of insulating system using aluminized mylar for the 1985 Cryogenics Conference held at MIT. Alternatively, it is possible to put on a bakable superinsulation that has no organic material: in fact, that is the stuff that was originally used for superinsulation. It consists of a random matte fiberglass, with a polyester binder, and an aluminum foil for the bright reflector. You wrap it around like a tape and then bake it out in a high vacuum processing system to drive the polyester away, leaving only the glass. It is a well known material and has been used for years. The data on that type of superinsulation, including the K factors, are well known. If you want me to talk about it, I will be glad to. You can use that and aluminum foil, as opposed to aluminized mylar, and have no organic material left. Otherwise, you can do nothing and take the heat load.

NOLEN: We are also worried about other effects, like the interaction between the plasma and the cryopumping.

ANTAYA: Yes, the plasma gets heated with a lot of microwave power and leaks in all directions--in both the axial and transverse planes. That introduces a load, which may get past the baffles. The order of the baffles is: a microwave screen, a water-cooled chevron, a nitrogen-cooled chevron, and then the helium vessel. The chevrons will be made of copper, so as to conduct the heat away.

POWERS: Are they blackened?

ANTAYA: No, nothing yet. You mean, blacken the copper?

POWERS: Yes. I am thinking that you do not want the chevrons to be bright and reflect back the plasma energy. You should try to stop the energy from making it to the helium vessel wall, by picking it up at the two chevrons. What is the pressure of this plasma ?

ANTAYA: 10^{-6} Torr.

POWERS: That is in the free molecular flow regime, so you can pick the energy up with the chevrons before it reaches the helium. You should do a Monte Carlo calculation to see that that is really what happens.

ANTAYA: It is a complicated interaction inside the plasma, with all the hot electrons following the field lines.

POWERS: I suppose it is not easy to make those chevron shields. If you get around to doing it, let me know, I used to make cryopump chevrons. We make chevrons all the time.

ANTAYA: We have got other chevrons to make, as well. I have talked with Tom Henderson of Berkeley; he makes big chevrons.

Cryopumps--Jerry Nolen

There are two types of cryopumps that fit in the category of beamline cryopumps. One type, which will be small in size and will essentially replace the ion pumps that are on our present beamlines, will use only liquid helium. It will not use liquid nitrogen, because we want to be able to let it up to air and pump down again quickly. (Nitrogen is hard to get rid of, while helium can be easily removed by letting in air.) It will be operated in batch-filled mode, using the same distribution lines that will bring liquid helium and nitrogen to our superconducting quadrupoles. We worked on its design about a year ago but have not pursued it since then; the design still needs to be detailed. We did not want to put superinsulation in the beam vacuum, so we were going to use a helium container surrounded by two copper sheet metal chevron shields cooled by the boil-off gas from the helium. One shield would be at 100 or 130 K, and the other at something like 40 K. But it occurred to me, listening to your account of bakable inorganic superinsulation a few minutes ago, that it might help us out a lot--a few layers of it around the second shield might make a tremendous improvement. There would also be charcoal, not in direct view of the chevrons but on the backside.

POWERS: You should put the charcoal at 4.2 K.

NOLEN: Right.

POWERS: You know, the adsorption isotherms show that a cryopump does not work very well (i.e. does not reach really low pressures) at temperatures above 8 K, when there are gases like hydrogen, helium and neon around. Commercial cryopumps such as the ones you have in the Lab, which are refrigerated pumps, do not generally get down to 8 K. So, although they work fine, they will not be able to use molecular-sieves--they cannot pump helium with any great facility. But a liquid helium cryopump, which reaches temperatures well below 8 K, can use bonded molecular sieves very effectively.

NOLEN: Also, considering that we put ion pump or small turbopump appendages along the system every 50 feet or so, helium pumping is not critical.

Let me now turn to the second type of cryopumps we want to make. It will be larger than the first type, will use both liquid helium and liquid nitrogen, and will have a 20" gate valve. The plan is to use two of these on a big scattering chamber we shall have (8' diameter, 10' long). If there are leaking gas counters inside the chamber, there could be a really large load on the pumps. One advantage of having liquid-helium cryopumps on such a system is that we can open the system to the cryopumps at something like 2 Torr and just condense out all the air; it will cost us only 3 liters of helium to do that, and it is the fastest known way to get to high vacuum--normally the region between 2 Torr and high vacuum dominates the pump-down time. This is also the region where one would get backstreaming if mechanical pumps were used.

POWERS: Your estimate of 3 liters of helium is based on calculation of the thermomolecular condensing effect. But you must remember that when you let the cryopump up to 2 Torr, you break the insulating vacuum, and the heat load goes up. So you need another kind of insulation which works better at higher pressures (like 2 Torr). There are ways to achieve this, and we can talk about them. Of course, beyond a certain stage the superinsulation will not recover.

NOLEN: We also use cryopumps on the K500 cyclotron and are in the process of extending them to the K800. They have a problem, in that they do not reach either helium temperature or nitrogen temperature: the helium vessel is usually at 7 K, the nitrogen vessel at 100 or 110 K. That is mostly because we lack enough space to build proper reservoirs and sufficiently thick material to conduct the heat away. In the K500, cryogens are first brought down 20' below floor level to the bottom of the resonators and then up through the RF dee-stems. There are no reservoirs other than a volume of about 15 cc for the nitrogen. So we keep the liquid helium and nitrogen flow rates quite high, in order to have a large heat transfer coefficient. Actually, because the cryopump is right in the valley of the cyclotron, the geometry is really good for getting high vacuum in the beam chamber, provided this space limitation is absent.

Sometimes, we run ion sources that put neon in there, which is hard to pump. That causes vacuum excursions every once in a while, and we have to stop operation till the system recovers. We have ideas of using a getter like Al-Zr strips to improve the cyclotron vacuum. It would be a long strip and one could pass a current through it to reactivate it.

POWERS: You are talking of a getter pump. We have got one for the antiproton source at Fermilab. Some of these getters can be sputtered onto walls, for others you open up cans. I have always had good luck with bonded molecular sieves. Whereas the getters have limited capacity and finite lifetime (which must be calculated beforehand), the molecular sieves can be reactivated very quickly by baking.

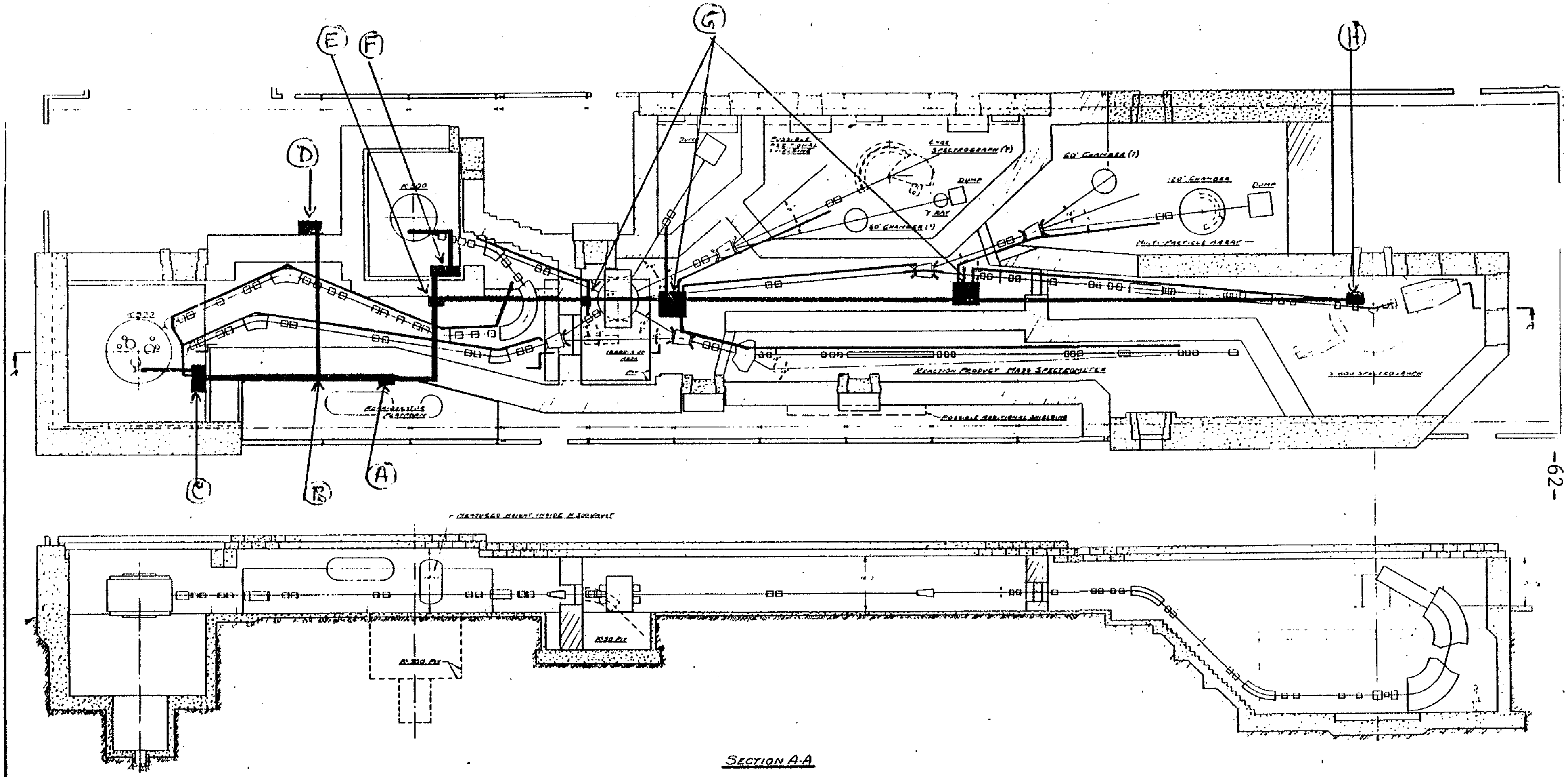
Cryogenic Distribution System--Al Gavalya

The original Phase I cryogenic distribution system is based on the CTI-1400 refrigerator. It is coupled to a distribution box, which feeds through the K500 Vault shielding to a main distribution box inside. That box distributes cryogens into the cryogenic port of the K500 (for the coils and shield) and down into another box 20' below floor level (for distribution to the K500 cryopanels, as mentioned by Jerry Nolen). This is a stand-alone distribution system at present.

The distribution system for Phase 1.5 is partially in place. What will be the main cryodistribution box for the Lab in Phase II operation is located on the balcony of the Blue (800-watt) refrigerator. It is coupled to the Blue refrigerator and to liquid helium dewars through bayonets. We can also couple that box to the K500 distribution system, or run temporary lines (with removable bayonets) to the K800 magnet. We can valve off the CTI-1400 and decontaminate it, while running the K500 with the Blue refrigerator.

The distribution system for Phase II is shown in Fig. 22. The first task will be to connect the existing main distribution box (A) to a junction box (B) which will allow us to tie in to the superconducting ECR source (when that comes on-line) and to send supplies to a distribution box (C) for the K800 coils, K800 cryopanels and some of the beamline magnets. There will be several more junction and distribution boxes, as shown. (We define a junction box to be a box with no valves; all the valves are in the distribution boxes, which therefore are generally more expensive).

In the main distribution line, we have the (subcooled) liquid helium supply line, the cold gas supply and return lines, and G-10 cards that act



A = Main distribution box
B = K800/ECR junction box
C = K800/Beamline distribution box
D = ECR distribution box

E = K500/East High Bay junction box
F = K500 distribution box
G = Beamline junction boxes
H = S800 distribution box

Fig. 22 Proposed Phase II cryogenic distribution system.

as spacers. Each line has 20 layers of superinsulation. Then comes the liquid nitrogen shield, which has its own supply, is conduction cooled by a copper line that is soldered at one corner, and has 20 layers of superinsulation. The whole assembly fits into a cradle formed of G-10 cards that are held in place by aluminum spacer blocks, which are tack-welded to an aluminum pallet that slides inside a steel rectangular tube serving as the vacuum jacket. Because of limited space, the nitrogen supply line is outside the shielding; the nitrogen return line is at 300 K, mainly because we think it will not radiate into the (superinsulated) box.

BLOSSER: Why do you bother to superinsulate each line separately?

LAUMER: In the case of nitrogen, it is because we want to take the cold gas back and use it for something else.

POWERS: Do you design your own bayonets?

GAVALYA: No, we buy them from Frank Meyer of MTM Cryo-Tech Lab at Oak Lawn, near Chicago. Their heat load is 0.88 watt a pair.

The main distribution box has 7 valves. One of them takes care of the nitrogen supply to the floating shield in the box. A second one handles the return gas; there is no valve on the supply side. Another sends supplies down the distribution line shield to the K800 distribution box, where that line ends in a phase separater vessel. The lines of the distribution box feed through vacuum extension tubes of small cross section, so that the length of the heat transfer path to the outside world is increased. Our temperature sensing devices are: for helium, two carbon resistors in a cover block, indium-soldered to the tubing; and for nitrogen, a thermocouple. All the tubing in the box is INVAR; since it has 1/10th the contraction rate of stainless steel, we do not have to worry about fully restraining the tubing. Actually, the original thought was to use it in the long distribution lines in place of bellows.

POWERS: You have had no problems with INVAR, such as corrosion?

NOLEN: No, but there has not been much time for corrosion to set in, either. Brookhaven uses it pretty extensively in power transmission lines. Its use greatly simplified the layout of our box. We had one defect in a tube, where we welded it on one of the temporary 60'-long transfer lines from the dewar to the K800 cyclotron. When it was taken apart, we found a bad weld. It did not leak when it was originally leak checked. (We did not do a detailed leak checking of the whole weld, for we had never found a defect like that in our other tubings). The question is, why did it leak when it did, other than just normal cycling?

POWERS: How much are you spending on the INVAR?

GAVALYA: We have spent a total of about $20,000 so far. We certainly would not need more than twice that much in all. I think the place where we really save is in the construction. Once we get past learning how to make good welds so that it comes out right the first time it is leak checked, then the fabrication costs will get much smaller. Part of our problem is that we have to fit things in small spaces.

Let me now discuss the expenses involved in making the junction boxes and the distribution boxes. The Phase II cryogenic distribution system will require about 8 of these boxes, with the boxes getting less complicated (and less expensive) the farther away they are from the two cyclotrons. As a very rough guess, each box may cost about $50,000. One of the issues is how to go about getting them made.

POWERS: A big expense in designing such complicated boxes is in ensuring that all the parts fit together properly. This can be done by making enough engineering drawings, but that takes a lot of time. Often, a better way, especially if the device is to be fabricated in large numbers, is to make a model of it with wood, PVC tubes, etc. Such a model would readily show up possible problems.

GAVALYA: The Computer Aided Design (CAD) system which we have recently purchased lets us, in essence, do the modeling right on the drawing board. In many ways, a subassembly made by CAD is like a model; you can put it in the CAD system, rotate it to check clearances, etc.

The CAD becomes a very powerful tool when designing something that will be fabricated in large numbers. Even though the details of the assembly might be different from one box to the next, they will all be made up of the same components. Once the whole model is on the CAD system, it is trivial to project out the subassemblies (the system does that by itself). The components can be saved in the computer library. They can then be pulled out as needed for the next assembly.

The first two boxes we designed at this level of complexity were done by hand; it took me about a week to do each view, and the entire design took about two months. But the most recent box was designed with the CAD system. That took me about three months, since I had no prior CAD experience and had to learn the process along the way. Once I had the completed drawing, it took me no more than two days to produce the isometric and balloon the drawing.

NOLEN: We want to explore the possibility of working out an arrangement with some nearby company that does not have any experience in building these boxes and yet is willing to do it under our supervision. What do you think of that scheme? Do you know of any company that will be willing to accept such a job? And how should we work out the details of a contract?

POWERS: I agree that you are better off training a local machine shop than you are going to some shop that already knows what it is doing! The trouble with the latter approach is that, if you find a shop with a good fabrication capability, it will want to accept the design responsibility as well. For otherwise, in case the product turns out to be unsatisfactory, there will be the question of whether it was the design or the fabrication that failed. But the way you are proposing, you bypass that question: you control the performance and accept the liability. You would have access to inspect the job as it progresses. You should be able to get the shop to do the work on a fixed-price basis. Of course, in your cost estimate, you should take account of your overhead associated with training and monitoring the shop. If the shop has difficulty procuring some material, you can supply it; and if it gets damaged, the shop should supply the replacement. I would be glad to help you work out the details of such a contract.

In regard to possible companies willing to accept such a job, I know that Frank Meyer has made cold boxes and things like that. His firm is near Chicago and so is not strictly local. For making the valve boxes-that you want, the only firm I know that used to do it is Vacuum Barrier Corporation of Massachusetts. And I do not think they will do it any more. I used to work for them and we did a big valve box job for some company. I do not know who else would do; maybe Minnesota Valley, they are located in New Prague, Minnesota.

NOLEN: Our other option is to expand our in-house staff, since presently we do not have the capability to make all that we want. The trouble with that is, what do we do with the increased staff once the job is finished?

Refrigeration Plant and Problem Areas--Helmut Laumer

We have two liquid helium refrigerators: a CTI-1400 refrigerator and an 800 watt unit which we call the Blue refrigerator. The CTI-1400 is specified to yield 34 ℓ/hr (liters/hour) of liquid helium or 95 watts of refrigeration when 3 compressors are operated. The performance specifications for the Blue refrigerator are 400 watts of refrigeration at 4.5 K and simultaneously 100 ℓ/hr rate of rise of liquid level in the dewar. It should be able to provide 200 ℓ/hr of liquid or about 800 watts of refrigeration. A sketch of the Blue refrigerator system is given in Fig. 23.

Table 2 shows a history of the performance of the Blue refrigerator system as hardware changes have been made. The first run was carried out late in 1982. A number of improvements to the equipment have been made since then. Peak production up to the present was 187 ℓ/hr of liquid helium or 510 watts. One of the original problems was that, although the design calls for 62 g/s (grams/sec) of helium gas, the oil-flooded screw compressors can only deliver 55 g/s. In the mean time, we have bought a compressor which can deliver an additional 30 g/s. In a recent test using this compressor we found that at a supply pressure of 240 psig the flow to the cold box was limited to 60 g/s. The net production at this time was below the peak value noted above, which had been achieved by supplementing the original Sullair compressors with the three CTI-1400 compressors, which nominally added 12 g/s to the 55 g/s, and with the supply pressure to the cold box at 250 psig.

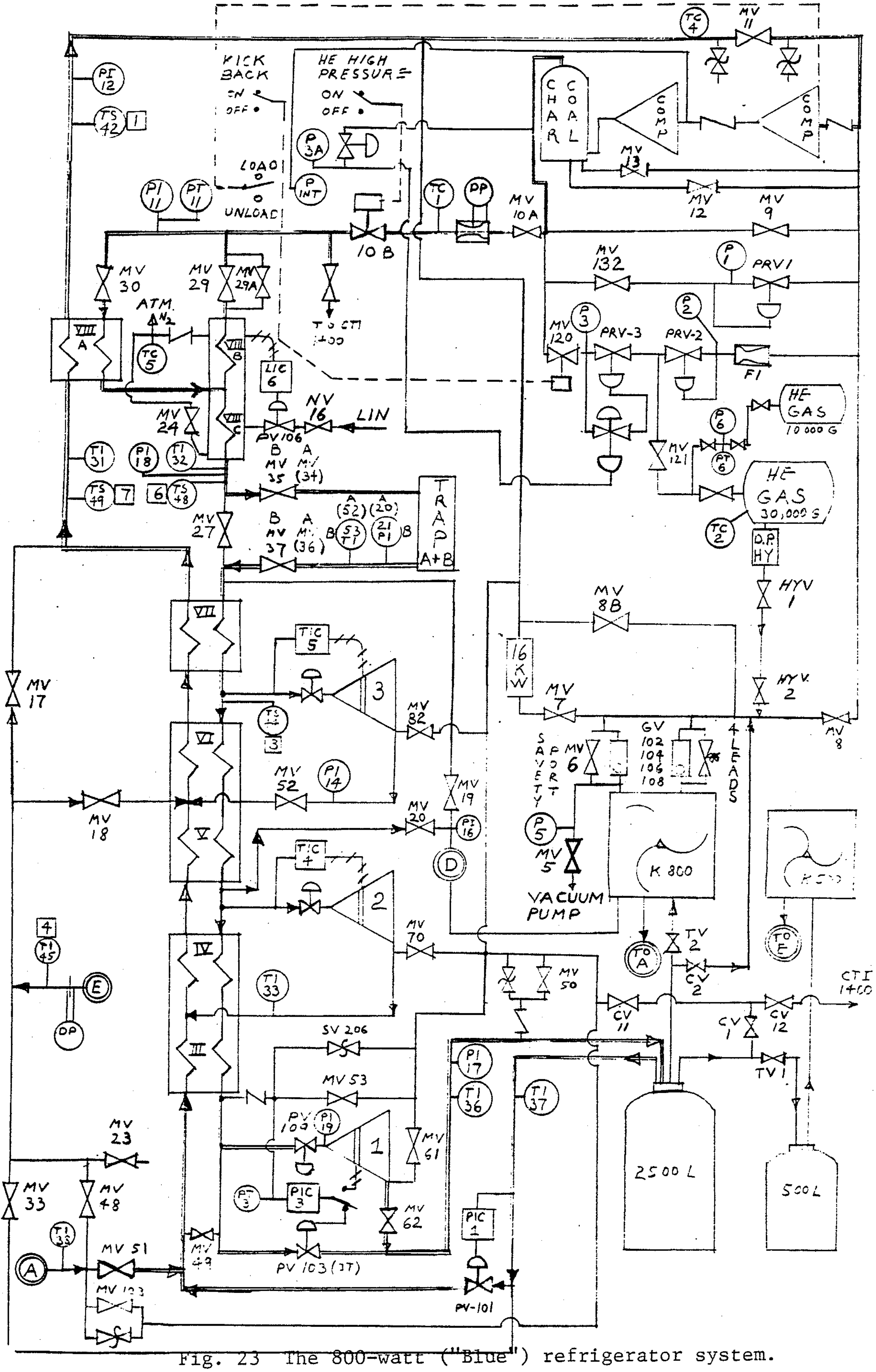


Fig. 23 The 800-watt ("Blue") refrigerator system.

Table 2. Performance history of the 800-watt refrigerator

Date	Liquifaction (g/s)	Heater Power (watt)	Trial Length (hrs)	Comments
12/ 8/82	4.3 -0.2	0	1.78	
12/10/82	1.3 -0.1	200	1.85	
12/10/82	0.0 -0.3	250	0.95	
12/21/82	0.3 -0.2	380	1.35	1
12/21/82	0.6 -0.4	450	0.67	1
12/21/82	4.2 -0.2	0	1.53	1
1/11/83	4.4 -0.1	0	1.83	2
1/14/83	1.1 -0.1	300	4.32	
3/23/83	4.6 -0.3	0	0.85	
3/31/83	4.2 -0.2	0	1.30	
4/21/83	4.6 -0.2	0	1.43	
6/ 8/83	4.1 -0.2	0	1.27	
7/26/83	4.7 -0.4	0	0.58	
7/26/83	5.4 -0.2	0	1.17	3
7/27/83	1.8 -0.1	400	2.07	3
8/16/83	6.2 -0.1	0	1.13	3
8/16/83	0.3 -0.1	510	1.72	3
8/17/83	4.12-0.03	0	2.68	
Acceptance Specs.	2.79	400		

1. A temporary 1 ft tube extension was fitted to the delivery line of the transfer line during this run.
2. The transfer line was lengthened by 1ft to get dewar gas return inlet out of the bayonet sheath.
3. The three CTI-1400 compressors adding a nominal total of 13 g/s where operated in parallel with the Sullair compressors.

BLOSSER: Why did you use 240 psig instead of 250 psig in the recent test?

LAUMER: Arbitrarily. I did not know that I had operated at 250 psig before. The recent test was with the wet engine running. The other difference was that the other engines were running at a lower speed. There is some chance that the difference is due to the installation of close tolerance pistons, and apparently we may not be able to run these as fast as before. I did not play enough with the speed controls; these engines are controlled by an oil break and there are at least two valves we can adjust for minimum speed and maximum speed. So there is some chance that we will get the same performance that we got before.

However, there is a serious oil contamination problem that we discovered in 1983. It so happened that the CTI-1400 compressors failed for various reasons and we simply switched to a mode in which we supplied helium to the CTI-1400 refrigerator from the Sullair compressors. As soon as we did that, within less than a week, the CTI-1400 refrigerator plugged up. We found that we could clear the blockages by blowing warm (20° C) helium gas through the refrigerator. A trap located in the return stream from the refrigerator collected oil. It was at that point that we discovered that the oil removal system for the Sullair compressors was inadequate. We have changed some of the hardware and the system operates much better at present. The helium stream from the Sullair compressors carries oil at typically 180 parts per million (PPM). After passing through a set of Balston condensers of type DX, this is reduced to 45 PPM. A second stage of BX elements reduces the oil content to the 1 PPM range. The helium gas then traverses a charcoal bed and 0.3 μ final filter. A PPM INC. aerosol monitor indicates contaminants that are in the 0.01 to 0.03 PPM range at this point. However, the heavy oil contamination from the past has left both refrigerators fouled with oil, which we propose to clean out with solvent as time permits.

Recently, a more puzzling contamination problem has surfaced. What we experienced is the following: after operating the K500 system for 3 to 12 hours or so, the helium liquid level in the coil begins to drop. If valve HCV1 is closed for 30 seconds and then is reopened, the plug usually clears and it takes another 3 to 12 hours for the plug to form again. We have the option of automating this process but would of course like to eliminate plug formation in the liquid helium distribution piping.

Let me now talk about some other problem areas. When we warm the refrigerator up, we do know there is a noticeable increase in the water content of the helium gas. Remember that the unit that we have for external nitrogen trap is designed to take the flow of only one CTI-1400 compressor. In the interest of getting the refrigerator back on the air we usually cut short the period that we run the gas through the external absorber. We have also found oil in the engines of the two refigerators, and of course poor refrigerator performance is the result. This is a problem we will have to solve. What we would like to be able to do is to run the K500 system with the CTI-1400 refrigerator and then we would be free to initiate the clean-up of the Blue refrigerator. As regards where we are now--yesterday we got the CTI-1400 to work at a liquefaction rate of 30 ℓ/hr. Refrigeration capacity was better than 55 watts and worse than 85 watts. So there is a chance that we can run the system in a mode where we operate two or three days and then make liquid for a day until we have cleaned up the Blue refrigerator.

BLOSSER: What was the supply pressure to the CTI-1400 during the capacity measurement above?

LAUMER: It was pretty close to 245 psig at the pressure gauge PI-33. The flow can be measured by the Venturi flowmeter which is in the gas stream of all the helium, with branches to the CTI-1400 and to the new refrigrator. Closing the valve to the CTI-1400 caused a drop of about 9 g/s in the total helium flow. This can be compared to the flow expected from the three CTI-1400 compressors which should add to 12-13 g/s.

BLOSSER: That indicates there is a plug in the cold box, since 245 psig should be full compressors.

LAUMER: Right, the manufacturer does not list production capacity for four compressors with nitrogen precooling, so I suspect that the limit of what the refrigerator can take is when the supply pressure is at 240 psig. There was a question about check valves in liquid helium supply lines. I think we could probably leave some out. The reason for putting check valves in the cryopanels originally was that if things go wrong in the cryopanel, for example, if they are warmed up accidentally, the raised pressure in the cryopanel could possibly push hot gas into the coil and then lower the liquid level there. Whether that would really happen I do not know.

Refrigerator Capacity Measurements

I shall start out with the CTI-1400. In the reliquefier mode it delivers at least 80 watts at 4.7 K; it operates the K500 system in this mode. To identify the contributions to this heat a number of measurements can be made. One of the easiest measurements made is the heat load due to the K500 coil. We do this by taking a boil-off curve. Figure 24 shows such a curve for the K800; the one for the K500 is pretty much the same. S is when the supply valve is turned off, A (B) is when the level falls between the large and small coils in the upper (lower) half of the magnet, and C is when the level is at the median plane. Knowing the volume of the system and the rate at which the level drops (as monitored by a level sensor), one can calculate the heat load. The observed boil-off rate of 28 ℓ/hr for the K500 represents 19 watts. The heat load of valves and bayonets is 25 watts. Cryopanels add another 10 watts. We are then not far from accounting for the heat load supported by the CTI-1400.

BLOSSER: But I had the sense that the K500 boil-off rates were smaller than those of the K800.

LAUMER: The best we had on the K800 was a little bit less than the K500. Table 3 shows the history of the boil-off curves for the K800. It includes a wide range of conditions. The lowest heat load was observed with the radial forces balanced.

BLOSSER: So the K500 boil-off rate at an earlier time was lower.

LAUMER: Yes, the K500 rate before we did the median plane penetrations ranged near 22 ℓ/hr. When we put in the penetration, it rose to 28ℓ/hr. Accounting for the heat load represented by the K800 system is more

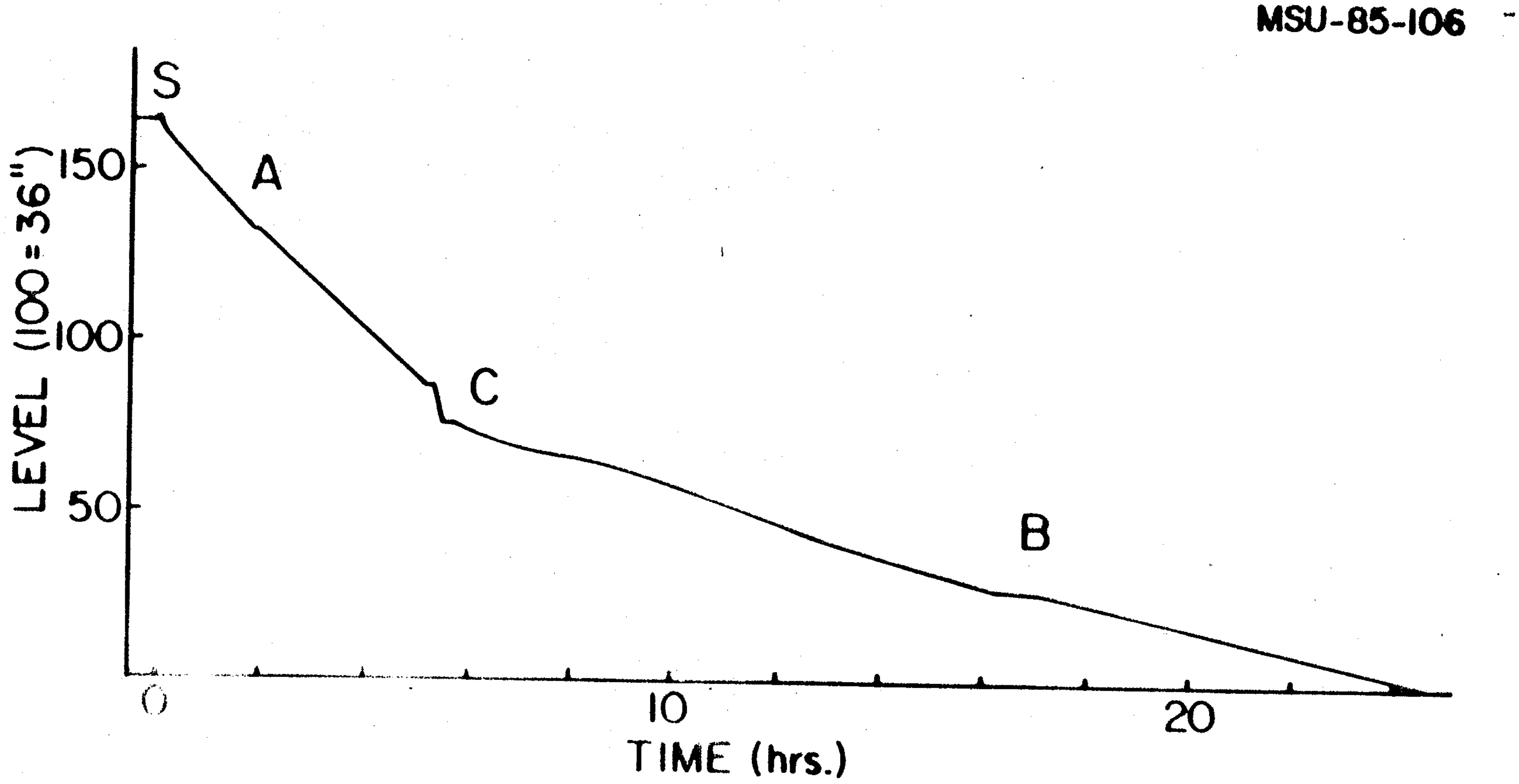


Fig. 24. A boil-off curve for the K800 coils.

Table 3. History of the boil-off curves for the K800 coils.

Boil Off Rates for a Number of Cryostat configurations.
boil off rates are given in % of level sensor per hr. Rough convertion factors are 5 liters per % or 3.3 watt per %/hr
ranges are :
60% to 30.5% on upper level sensor represents small upper coil.
27.5% to -1% on upper level is a portion of the large upper coil
96.9% to 83.6% on lower level sensor is a portion of large upper coil just above the median plane.
72.5% to -1% on the lower level sensor represents the coils below the median plane.

	boiloff modes								
level sensor range	1	2	3	4	5	6	7	8	9
upper 60% to 30.5%	44.0	16.7	11.9	13.0	14.7	14.8	19.7	5.59	7.96
upper 27.5% to -1%	37.0	13.6	9.03			12.7	15.6		5.40
lower 96.9% to 83.6%	37.6	13.0	9.05			12.0	12.3		5.44
lower 72.5% to _1%	8.35	3.85	3.30				4.76		3.23

1	liquid nitrogen feed off; shield and link temperatures near 200 K.
2	liquid nitrogen on.
3	LIN on ; coil moved.
4	LIN on
5	LIN on, coil moved up tree flats then down three flats.
6	LIN on; pump median plane penetrations.
7	LIN on; lead gas off.
8	LIN on; radial forces low and equal; lead gas flow 8 to 10 SCFH before and 5 SCFH during boiloff.
9	LIN on; lead gas flow on; 4/9/85 to 4/11/85 boiloff.

difficult. Based on the boil-off curve, the coil represents a heat load of about 20 watt.

NOLEN: What is the heat load from the leads?

LAUMER: I do not know, I assumed it is included in the observed 20 watt initial boil-off rate. The disquieting observation is that to keep the K800 coil filled, the Blue refrigerator operates very close to its capacity. The maximum refrigeration capacity at 4.7 K measured was near 500 watts. We know it is not presently operating at that level, since the compressor power is lower than it was for that measurement. However, analyzing a coil cool down curve and considering the total mass for the K800 coils (1.07^{7}x10^{7} g of copper plus 7.8x10^{6} g of stainless steel) yields a refrigeration power of 300 watt at 30 K. We also performed an experiment where the refrigerator was turned off and the coil was kept filled from the dewar. The level drop of the dewar indicated a liquid consumption rate of 200-280 watt.

The only other sources of heat load, apart from the 20 watts of the coil, are two transfer lines, each about 60' long.

BLOSSER: The line that takes the gas back is involved?

LAUMER: Yes, it is involved in trying to explain the numbers measured. What should 60' of average transfer line cost you? If it is a pretty good transfer line it should not cost you much, certainly not more than 10 watts each, and so the only obvious way I can simulate a lot of heat load is if a lot of the liquid is returned in the return stream. You can see that you can use up liquid that way. It would be used at a rather high rate but would not represent an actual heat load. I guess the only other option is that the transfer line actually is a high heat load.

POWERS: What's the tolerance of the bayonets, i.e. the clearance between male and female?

LAUMER: I do not know. The manufacturer gives 0.44 watts heat load per pair of bayonets.

SESSION III. Operating Procedures/Safety/Hazards--Seminar Room, 9:00-11:00 am, Aug. 30

Accident and Injury Statistics--Lawrence Tharp

My assignment this morning is to discuss Laboratory accident and injury statistics. I want to start off by saying that, strictly speaking, we do not have them. We keep records only on accidents and injuries that require treatment. I think that is a very important distinction. The records we do possess have come about from the fact that anybody who requires treatment for a work-related injury has to fill out a piece of paperwork in order to get treatment at the campus facility. I think we can confidently say that we know about all accidents which cause injuries and require treatment. If there is an accident or injury which does not require treatment, we do not necessarily know about it. If it is an extremely serious accident--life threatening--I am sure the word gets around. But there is no formal reporting procedure.

While it might be a good idea to keep records on all accidents, not just those requiring treatment, I see two problems in doing so. One is defining what an accident is. If someone is working with electrical equipment, is uncertain about the danger, is wearing electrical gloves to cope with the flash and a severe flash occurs, there is no injury because it was prepared for--is that an accident? I do not know. Was it an accident only if he was not prepared for it and got burned? Secondly, there is the question of how to get a reporting system that will operate effectively. It is easy to see how our current system operates for accidents requiring treatment but, given the Lab's bias towards getting work done rather than

August 28, 1985

Table 4. LABORATORY INJURIES REQUIRING TREATMENT

May 1983 - Present

Summary

Injury	Occurances	Days Lost
Back/knee strain	4	6
Cuts on hand, leg, face	6	0
Object in eye	4	0
Burn - electrical flash	3	29
Burn - soldering	2	0
Foot injury	2	0
Chemical splash	1	0
Allergic reaction	1	0
Falls	2	0
Other bumps & bruises	3	0
TOTAL	28	35

1983	Name	Injury	Days Lost
5/1	Capelli	Back strain	0
7/29	Tucker	Cut finger	0
8/26	Fighter	Dust in eye	0
10/25	Berning	Burn-torch	0
10/26	Welton	Tool slipped, cut thumb	0
10/31	Wilson	Stepped on nail	0
11/29	Wilkinson	Cut finger	0
12/20	Magistro	Alkali splash	0
1984			
1/25	Nurnberger	Cut finger	0
3/12	Lawrence	Cut leg	0
4/28	Fighter	Plate fell on heel	0
5/3	Niemeyer	WD-40 in eye	0
8/7	Miller	Bumped head	0
8/20	Cole	Smashed finger	0
10/30	Harris	Back strain	4
11/7	Gallagher	Back strain	2
11/15	Kranz	Dust in eye	0
12/14	Fighter	Cut cheek	0
12/17	Vacek	Strained knee	0
1985			
1/10	Sawyer	Bruised-fell on ice	0
2/28	Waddell	Object in eye	0
3/6	Mooney	Allergic rash	0
5/23	Easley	Electrical flash burns	1
	Young	" " "	2
	Gonzales	" " "	26
6/11	Zarobinski	Burn - soldering	0
7/9	Taylor	Bruised - fell	0
7/25	Young	Finger - pinched & cut	0

doing paperwork, what would be the incentive for people to report accidents that did not require treatment? Those are two unanswered questions in regards to compiling complete statistics.

Let us look at Table 4, which shows the statistics gathered over the last 28 months. If we wanted more details of the past we would have to go to individual personnel files. It is easy to find out what accidents an individual has had--you just look in his or her personal file. Only over the last 28 months have we kept a separate file on accidents requiring treatment, so that we can see what injuries have occured in the Lab during that time. We have had 28 people injured--about one a month. Most of the accidents were minor--they were not life threatening or potentially dangerous. (A piece of dust in the eye, superficial cuts, a slipped razor blade, things like that.) But there are two kinds of accident that have caused lost days: (i) two separate incidents of back injuries having to do with lifting, and (ii) the electical accident we had this summer. A total of five people have been absent from work because of these accidents: two in the back incidents, three in the electrical accident. These are the areas where I think perhaps we should do some work in helping people to understand potential dangers. We already are doing a lot on teaching electrical safety.

We have 225 people on our staff, half of them are part-time, and on the average they work half-time, so we have 170 full-time equivalent staff. Our reportable injury rate of one per month therefore translates to one injury every 14 man years (30,000 work hours). I am curious to know how that compares to data from other similar organizations, to find out if our injury rate is high or low.

Let me come back to the issue I was previously raising. There are no reported minor incidents leading up to the serious electrical accident we had. Minor accidents did happen, but were not reported. There were several cases of flash burns and other cases where people did not get flash burns because they were wearing gloves. Dan Magistro, for instance, had told me he had several burns, but none requiring treatment. Harold Hilbert described to me an incident where he used gloves and did not get a burn. The question then arises: If we have a better reporting procedure of events that do not cause injury, can we see a pattern developing and prevent it before it happens? That is a question rather than a statement about whether we can do it, but a question worth looking into.

BLOSSER: Lawrence, how would you go about turning better statistics into safer work?

THARP: We would try to identify patterns. For instance, at one time before we started keeping these statistics, I was noticing a pattern that Dan Magistro's group had 3/4th of the accidents in the Laboratory over a 6-month period. So we took it to the Safety Committee, which pointed out the pattern to Dan. But when I look for patterns among the incidents listed in Table 4, I do not see any. If we had better statistics, we might have seen a pattern coming in regards to the electrical accident.

POWERS: You said that there is no policy about what is reported and what is not. Is it an individual decision on the part of the person who has been in the mishap?

HILBERT: I think it is also the decision of the supervisor, since he is usually aware of the accidents.

POWERS: If there is any significant number of accidents, the supervisor might tell his people to not report anything unless it is unavoidable. So there are two risks: the first risk is that the accident is not reported, and the second risk is that it is covered up.

THARP: I do not mean to imply that information on minor accidents does not spread around in an informal fashion. I am sure much of it does--much of it is known.

Operating Patterns for Running Experiments--N. Anantaraman

I wish to give you an overview of how we operate the K500 cyclotron for experiments. Let me begin by pointing out that operation of the K500 for experiments is one of the two main missions of the Laboratory; the other is the construction of the K800 cyclotron. Experiments began with the K500 in September 1982. Since March 1984, we have changed to a pattern of running 7 days a week around the clock. Unlike high-energy laboratories like Fermilab, we run only one experiment at a time. A typical experiment runs for 4 days, the range being from 2 to 8 days. There might be 6-10 experimenters, consisting of a mixture of faculty members, postdoctoral fellows and graduate students. About half the experiments involve purely in-house users and the other half a mixture of in-house and outside users. There are very few experiments involving purely outside users. The pool of outside users has stabilized over the last two years but we expect that pool to increase significantly in 1986 with the availability of higher energy beams from the ECR source. About four to five days per month is scheduled maintenance, corresponding to about 15% of the total time. Another 25% of the total time is taken up by overhead (changing beam energies, developing new beams) and breakdowns.

One practice that has been very helpful is the Operations Meeting every morning starting at 8 AM and lasting about 10 minutes. This meeting is attended by about 20 people, representing the Operations group (which is involved with running the K500), the Repairs group (which is involved during maintenance and breakdown), and the Lab management.

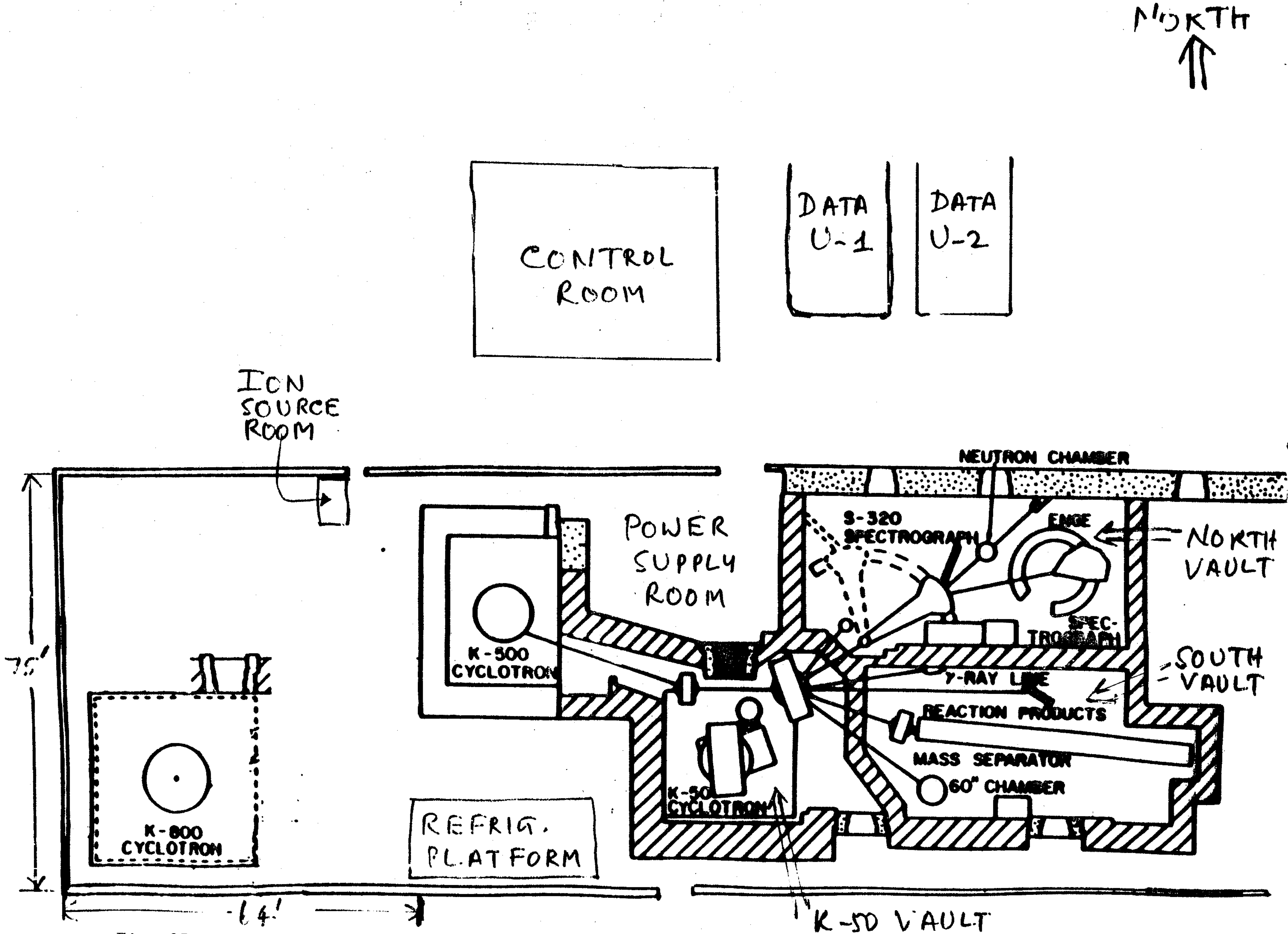


Fig. 25. Layout of Lab, showing the two cyclotrons, experimental vaults, Control Room, etc.

Experiments are done in one of three vaults; most are done in the North Vault or the South Vault, some in the K50 Vault. These vaults are shown in Fig. 25, which also shows the locations of some other areas I shall be referring to in this talk: the Control Room, the data collection areas U-1 and U-2, the Power Supplies Room, the Ion Source Room, etc.

I now turn to the three subtopics I have been asked to cover.

(A) Staff Who Are Here Vs. Time Of Day:

The Lab staff can be divided into three groups:

(i) Staff not directly involved in K500 operation: They constitute by far the biggest group, comprising of all except about 20 of the Lab personnel. Their number is about 160 staff plus 44 undergraduates. (The total Lab strength is about 225.)

(ii) The group directly involved in running the K500 for experiments consists of 8 operators (100%), 3 beam physicists (30-50%), and 1 RF engineer (25%), in addition to 6-10 experimenters (100%). The numbers in brackets are the time-averaged percentages of the total work hours which the various personnel devote to K500 operation.

(iii) In addition to group (ii), another group comes into action during maintenance and breakdown. It consists of 2 people from the cryogenics group (15-25%), 3 from the assembly group (10%), 2 from the electronics group (15%) and 1 from the engineering group (50%). Of course, the resources of the entire Lab are available for major repairs, but normally it is this subset of people who do most of the routine repair work.

As regards the time of day during which personnel are present at the Lab: almost all staff members are present from 8 AM to 5 PM; from 5 PM to midnight, there will be 1 or 2 operators, 1 or 2 experimenters (on shift duty for the ongoing experiment), occasionally 1 beam physicist, perhaps 6 to 10 students, postdoctoral fellows and faculty (not connected with running the K500), and 2 janitors. From midnight to 8 Am, there will again be 1 or 2 experimenters, 1 operator, and perhaps 2 students.

(B): Typical Things They Would Be Doing/Locations: I shall describe the activities of group (ii) only, since this is the group involved in K500 operation.

Operators: Their main job is to start the K500 cyclotron and keep it running. They also log information of various kinds, e.g. on the liquid helium level, the currents in the power supplies, etc. This they do for the most part from the Control Room (shown in Fig. 1). Another of their duties is to build spare ion sources for later use in the machine; this is done in the Ion Source Room. Usually, the cyclotron runs unattended when the operators are building sources. During maintenance and breakdowns, they take apart and put together parts of the K500 as needed (in the K500 Vault), do leak checking of parts (in the High Bay area), etc.

Some potential dangers during these operations are the following:

(1) The main danger is their working alone in the K500 Vault. About 5% of the total running time, it has happened that an operator on the midnight shift has been the only person in the whole building. (This does not happen when experiments are running smoothly, since then there will at least be the experimenter on shift duty in the Data-U area; but it does happen during maintenance and breakdowns.)

(2) Exposure to low-level radiation when working with ion sources. Protective devices like gloves, aprons, and a containment box are used to minimize exposure.

(3) Climbing tall ladders.

(4) Going to the K500 cyclotron pit, with the possibility of oxygen deficiency in the air there. For protection, an oxygen monitor has been installed in the pit; a portable monitor is also available.

(5) Working with the high voltages on the deflectors. The danger has been minimized by building a cage around the deflector area.

Beam Physicists: Their main responsibilities are to tune the beam from the cyclotron exit to the target in the experimental area in one of the three vaults that are used for experiments, and to keep in good operating condition the beam line equipment (vacuum pumps, scintillators, gate valves, etc.). The areas that they work in are the Control Room, the Power Supplies Room and the experimental vaults. A possible danger in their activities is that they have to deal with several high voltage power supplies.

R.F. Engineer: He is responsible for changing the RF (radio frequency) during energy changes; in the last 6 months, however, many of the K500 operators have learned to do RF changes themselves. The RF engineer is also responsible for fixing RF problems, which have been the most common cause of K500 breakdowns. He has to work with very high voltage amplifiers and power supplies. As a safety precaution, when such work is being done, there are always two people, each observing the other; grounding hooks are also used.

Experimenters: They work in one of the experimental vaults before and at the start of their experiment, and in one of the two Data U's during the experiment. They are mostly involved in harmless activities, collecting data. One possible danger is that they do operate quite often detectors containing explosive gases in the experimental vaults. But there are gas monitors and alarms that sound in the Control Room when there is a dangerous level of explosive gas in the vaults. Procedures for dealing with such emergencies have been developed, and the K500 operators are familiar with them.

(C) Building Security Vs. Time Of Day: The main point to make here is that there is no guard or patrol in the building, and that our security measures are predicated on voluntary compliance. In the daytime hours, 8 AM to 5 PM, three doors in the building are open--the front door, the door in the receiving area and a door in the machine shop area. On the average we have 20 to 30 outsiders coming in each day, mostly students wanting to meet their professors and salesmen wanting to meet potential customers. There are also tour groups, perhaps 3 or 4 groups totalling 100 people per month. All these people are supposed to stay in the front lobby until met there by the person they have come to see (who is called to the lobby by the receptionist). In the period from 5 PM to 8 AM, all doors to the building are locked, and the only way for an outsider (viz. one not having a key) to enter is by being let in by someone in the building. An unofficial patrol is provided by our building janitors, who work from 5 PM to midnight and are familiar with the staff members who are normally present in the Lab during the evening hours. Also, the campus police check the outside doors occassionally.

Our safety procedures are based on the expectation of voluntary compliance with the rules posted prominently at appropriate places. All high-level radiation areas are clearly marked. Every employee is issued a film badge and a radiation safety manual, as well as a Lab Handbook which summarizes all Lab safety procedures. Nevertheless, it is possible for an uninformed novice to wander into a dangerous area; the danger might be from radiation, from high voltage or from several other sources.

Electrical Problems--Bill Nurnberger

There is not really a great deal to talk about because we have had only one electrical accident, on May 23, 1985. This is primarily a report on that accident, in which three people got fairly severe burns. But there were no electrical shocks. The accident upset enough people in the Laboratory so that a fairly detailed report was made on it, an analysis was done regarding how it could have been prevented, and recommendations were made to get rid of some of the problems that were turned up by the analysis.

The report pointed out that the accident could have been prevented if the power had been turned off to the supply in the panel that it happened in. It could also, most probably, have been prevented if the people who were working had taken a closer look, noticed that there were exposed conductors, and taken pains to cover them.

The following are the recommendations made in the report:

1. The Laboratory's electrical work procedures should be reviewed to insure that electrical work is done in conformance to code.
2. Employees involved in electrical work for a large portion of their time should be encouraged to obtain a state electrician's license.
3. All electrical panels should be labeled regarding location of disconnects. The disconnects should be labeled indicating the panels they are powering.
4. Consult with Physical Plant to have lock-outs installed on the feeds to individual distribution panels.
5. Review procedure for control of keys to Electrical Room.

6. Discuss with Physical Plant the advisability of having an emergency key under glass at the Electrical Room.
7. Train selected staff in emergency electrical procedures.
8. Install safety lights in Seminar Room, hallways leading to Electrical Room and in other locations as necessary.
9. Arrange to have access available to experimental vaults during a power failure.
10. After responding to an accident, non-essential Laboratory staff should not congregate at the scene of the accident, as this may impede rescue operations.
11. Establish procedures for reporting accidents not causing personal injury. (Currently, only accidents causing personal injury are reported.)
12. The Laboratory should schedule discussions of safety issues.

Let me now discuss the background to these recommendations and the follow-up actions taken. It is felt by many people in the Lab that much of the work that has been done in the Lab has not been in conformance with the National Electrical Code and other codes. At the time of the accident, our reliable electrician was off with medical problems and there was no legally responsible electrical supervisor for all the work that was being done. That is the basis for recommendations #1 and #2. In actual fact, at the time of the accident, one of the people involved in it was about to take the test for the Michigan Electrician's License and has since passed it. The policy could be made stronger by requiring people to have the license (offering them paid time off to take the course)--in which case we would have more people better trained to do electrical work.

The basis for #3 is that, when the accident occurred there was a lot of running around with people trying to find out where to turn the panel off. It became obvious very quickly that nobody knew where the switch was. Since then, labels have been put on essentially all the disconnects and panels in the building, indicating what switch supplies what panel and where it is located. There is also a dump button for turning power off to the entire building.

Regarding the implementation of #4, the question came up as to whether or not we could do it with the equipment we have. It turns out that it is possible. Padlocks have now been put in place.

In regard to #5 and #6, Dan Magistro used to have a key to the Electrical Room, but at the time of the accident he was on disability leave and Henry Blosser had that key. But a lot of people did not know that. It was recommended that the people who did electrical work should be made aware of where the keys are. We now have a key under glass at the entrance to the Electrical Room and it can be taken out in an emergency situation by breaking the glass.

Regarding #7, training classes have been conducted. I think that #8 has also been implemented. I do not know the status of #9. I suppose that once the power goes off, there is no hydraulic power to open the vault doors, though there is a battery-operated back-up system. #11 was discussed by Lawrence Tharp earlier today.

So that is the outcome of the electrical accident. It opened our eyes to the need to pay more attention to the safety aspects of our work here.

I was also asked to discuss other hazards in the Laboratory, which are mainly the result of 20 years of being unaware of how seriously people can get hurt quickly. We have got many, many quick fixes that have never been made into right fixes after the immediate need was over. Examples include improperly supported cables, conduits that dangle, and switch gear cabinets that have modifications in them so that their doors cannot be closed anymore. We should spend time fixing them properly.

There is a Safety Committee responsible for monitoring safety issues. It is fairly active, but it is not external to the Lab, it is internal. I feel that sometimes an awful lot of effort is needed to convince the Committee that there is a problem. When I have brought up a problem, I have been asked to prove that there really is a problem. I think it should not be up to the employees to prove that; a more appropriate response would be for the Committee to say: "We will look into it and either fix it or satisfy ourselves that it is not really a problem". That would seem a better way to encourage people to be more safety conscious.

We also have a University group physically inspect the Lab for safety once a year, and we are required to make improvements as per its suggestions. But it only monitors superficial issues like a solvent bottle in the wrong place or too much paper in somebody's office. It does not really monitor electrical procedures, radiation safety, important things like that, because it does not fully understand such matters.

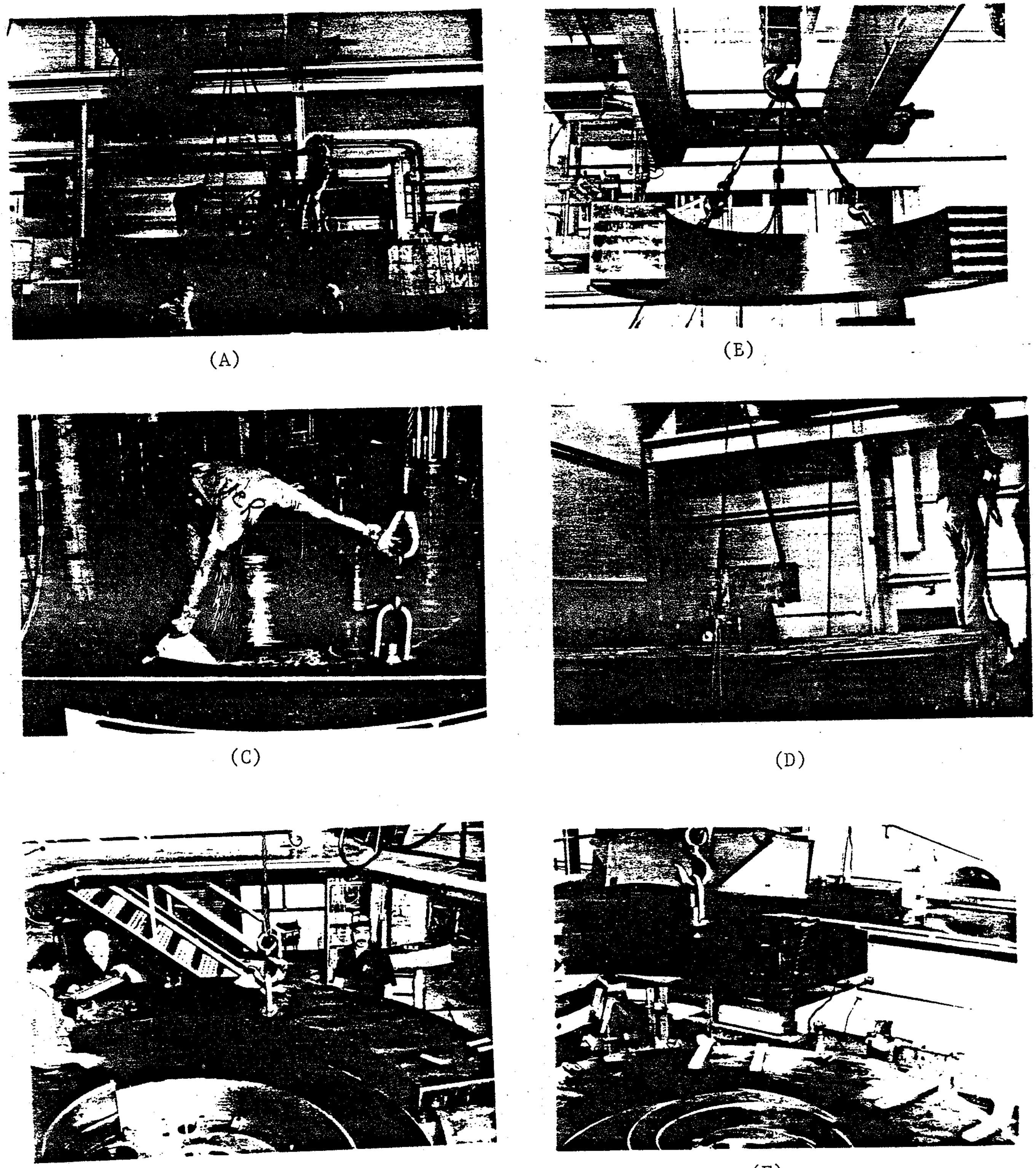
(Editor's note: Radiation safety is monitored by the University's Office of Chemical, Biological and Radiation Safety. An employee of that Office is stationed in the Laboratory on a full-time basis. Reg Ronningen will mention this in his presentation.)

Rigging--Harold Hilbert

I shall use a set of photographs (Fig. 26) to illustrate this talk. I classify the rigging in the Cyclotron Lab as being of two different types: the type that has been designed into new fixtures, and the type that is used to unload trucks coming into the building. The first type has the lifting gear design already built into the fixture--a good example would be the rigging for the large magnets--and are therefore relatively easy to handle (photograph A). The other type is shown in (B). Items we have unloaded from trucks in the past have consisted of large pieces of metal, electrical supplies, power supplies, and machine tools and equipment.

For the design-type rigging, what is most often used is an eye-bolt or hoist ring. It is essential to use hoist rings when moving heavy pieces of equipment. For instance, a magnet section could comprise a load of 30 tons, and the hoist rings used in (C) are good for 20 ton loads each. The type of rigging used is also dependent on the cabling: if the piece being hoisted will be raised above equipment such that the height from the load to the crane is limited, we will be forced to use a short chain or cable arrangement; but if we are simply moving the piece across the floor, we might use longer nylon slings and chains to change the angle to lower the load on each of the cables (D).

The magnet pieces were all designed with lifting holes built right into them, so that each individual "C" section can be lifted up and pulled apart. Although it is not apparent from the picture, the centerline of the crane will not allow us to pick that particular piece straight up with the 40-ton crane. (I believe that ours is the only nuclear physics laboratory in this country that has a 40-ton crane.) In this case, a counterbalancing method



(A)

(B)

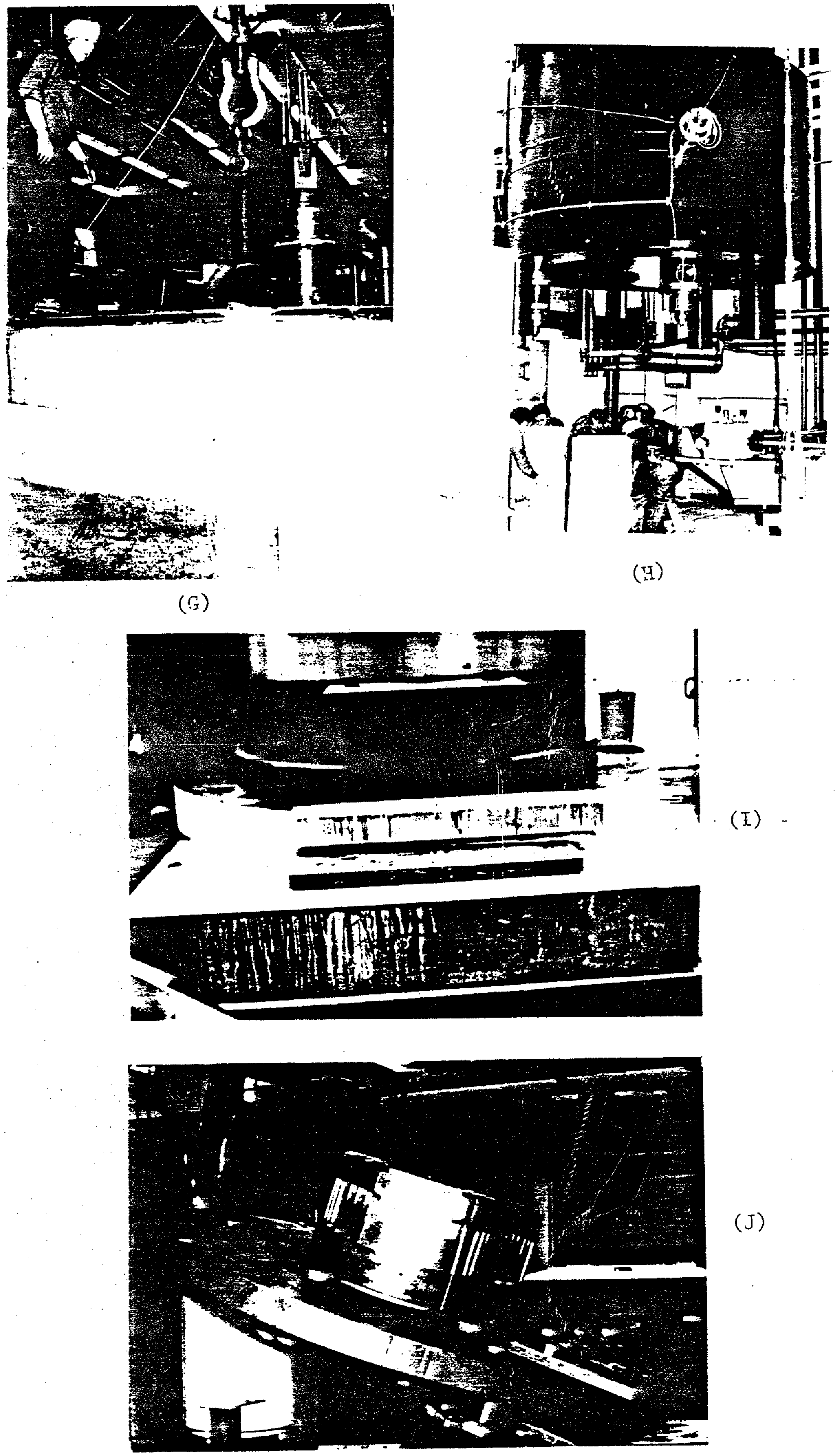
(C)

(D)

(E)

(F)

Fig. 26



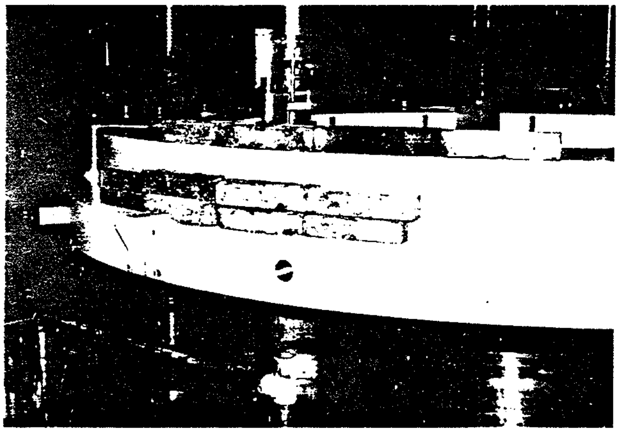
(G)

(H)

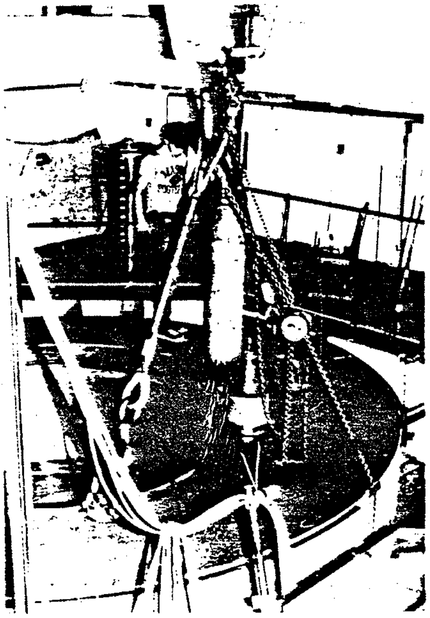
(I)

(J)

Fig. 26 (contd)



(K)



(L)

(M)

Fig. 26 (contd)

must be used. That involves lifting the piece up with a 5-ton unit on the end of the crane and using the 40-ton crane as a counterbalance, by suspending it from a similar large piece (E and F). There are only a few pieces on the back side of the K800 magnet which are that difficult to access.

(G) is another example of rigging fixture that has been designed and built in the Lab. It is what we use to lift the K800 cryostat and bobbin. We use the concrete blocks ordinarily used for shielding, and readily available in the Lab, to establish a place for the bobbin (H). We have also designed lifting fixtures into the concrete blocks that are the plugs for the hydraulically-operated vault doors (I). They are used for positioning or flipping the various pieces. In (J)< they have been used to rotate the piece around a point. A couple of plates were bolted onto the cap of the magnet, the magnet rests on a steel plate (at the bottom right corner of (J)), and the steel plate rests on the concrete (not shown). The crane is on a 40-ton hook.

The speed of the small hooks is 7 feet/minute, and the big one is multiple, with a very slow down and up. We do our own hand-rigging to counterbalance (K) or level (L) the loads. We only purchase cables which we believe have been tested. The nylon slings are adequate for 6000 pounds in a straight pull. The particular piece of equipment shown in (M) is secured in place with dowel pins, and the nylon rope is allowed to stretch as the load goes down. It is considerably over-rated for the load--here it is only 1800 pounds per unit.

Most of the hooks and all of the slings are marked for what their capacity is, although there are a couple of 50-ton eye-bolts and shackles with no markings on them. The big pieces we move usually have write-ups in close proximity so that there is no doubt as to their weight, but we might improve on that by indicating on the pieces themselves their exact weights, by either scribing or stencilling.

The biggest problem we run into when moving heavy pieces is the problem of breaking eye-bolts. The angles get pulled and there is danger of dropping the piece. We make sure that the proper people are present to oversee the operation, and there is a list of the people in the building who are allowed to use the crane.

Radiation Safety--Reg Ronningen

The first part of this talk is on operating procedures. First, I will present you with the Radiation Safety Manual, produced by Ed Kashy, Lawrence Tharp and Rich Lassin (report No. MSUCP-38, dated 6/27/84). The manual outlines procedures, safety techniques, dose limits and responsiblities of radiation safety workers; it also describes our safety systems. It is given to everybody who works here: staff, students and outside users. Those people who work here must sign a form stating that they have read it. This is an important part of their radiation safety and our adhering to University requirements. People are also given badges when they start working here.

The implementation of radiation safety in the Lab is under the auspices of the Safety Committee chaired by Ed Kashy. There is also a subcommittee on radiation safety. I act as Radiation Safety Officer. The other members of the subcommittee are Rich Lassin, a trained health physicist employed by the University's Department of Radiation Safety to work here, and Peter Miller of Operations. The cyclotron operators are also trained in radiation safety and tested once a year on radiation safety as it relates to operations. The operators are then quite useful for day-to-day, hour-to-hour radiation safety monitoring. In fact, one of our operators has worked with radiation in a hospital environment. Another one was in the navy's nuclear program and he has been very useful--I view him as an unofficial member of the radiation safety subcommittee.

I shall next discuss radiation hazards in the Laboratory. I break these up into primary and secondary sources of radiation. Table 5 is a list of primary sources, the type, magnitudes, and procedures. The magnitudes

Table 5. Primary Sources of Radiation

Source	Type	Magnitude	Procedure
K500	X,γ,n,β direct beam	5 R/hr neutrons <100 watts	(1) Secure vaults: door * neutron shutters * chains * RF interlock (2) measure neutron flux outside of shielding
RF	RF	leakage (very small)	warning sign
	X-rays	100 mR/hr	(collimated source)
Deflector Test Stand; Electrostatic Test Stand; RPMS	X-rays	1-10 R/hr	warning signs, lights, local shielding, close vault (RPMS)
ECR	X-rays microwave	10-1000 mR/hr no leakage	local shield (highly collimated)
Sources	γ,β,α,n	$<10^{-6}$ Ci → 0.5 Ci neutrons	-MSU approved purchases -inventory system -check-out procedure -storage is shielded -some in locked room -some in locked containers

are the maximum we have observed in most situations, and often they are measurements "on contact". The personnel dose would then be lower because the best shielding is "one over r-squared."

The first source is the K500 cyclotron itself, with all types of radiation: X-rays, gamma rays, betas, neutrons, and the direct beam. The magnitude for neutrons is typically about 5 R/hr. The standard procedure in running the K500 is to secure the Vault. Involved in this, there are shielding doors and neutron monitors. There is a monitor for each vault as well as some that ring the shielding walls on the outside. There are also chain interlocks which must be secured after checking each area in a specified sequence. These are all interlocked to the cylotron RF. There are thus many points in the security system, the failure of any one of which shuts off the RF, so that the cyclotron goes down. The external neutron monitors in unsecured areas will also shut off the RF if the neutron flux is too high.

Another source is the RF system, with RF leakage (measured to be very small) and X-rays as the possible dangers. The X-rays are from electron bombardment inside the machine. I should point out that the K500 is an excellent shield itself with its great mass of iron, so that there are just a couple of viewing ports where X-rays can come out and be a problem; they are highly collimated. The operators can be in the K500 Vault with the the RF system on (but the source interlocked off). Usually, if they are at a port it is to calibrate the dee voltages and they would have a detector in front of the port. There is also a warning sign there. X-rays are also produced at the deflector test stand, the electrostatic test stand, and the RPMS (a nuclear physics device), but are again fairly well collimated, so we put up local shielding, signs, and in the case of the RPMS, if the level is high, we close the door of the vault it is in. The ECR source is a potential source of microwaves (negligible) and X-rays (highly collimated). When the source is operating full blast we expect doserates of up to 1 R/hr. The device provides its own local shielding but perhaps we will need more shielding as we get more experience with the source operating on-line. We have check-sources in the lab for detector calibration purposes. The radioactivities here range from less than a micro-Curie to a 0.5 Curie neutron source. The source storage area for low-level sources has local shielding and the more hazardous ones are kept in a locked room. The most hazardous ones are kept in locked containers. To purchase a source we must have University approval. We have an inventory system and a checkout procedure for sources.

Let me mention some numbers to give you an idea of how the doserates in the Lab compare with very hazardous levels: 100 R is needed for biological effects to first appear (they are repairable) and about 500 R for 50% probability of death within 30 days in a given human population.

I turn now to secondary sources (Table 6). A major secondary source is when the K500 is open for repair and then possibly the worst-case whole body dose can be around 250 mR/hr. These radiations are very well localized to specific parts of the machine, in the region of the electrostatic deflectors. When possible, the internal repairs are done during a planned maintanance period after the K500 has been turned off for a day or so. Along the beamlines we have beamstops, slits, and beamdumps. Two of the dumps are unshielded Faraday cups, and we have measured up to 200 mR/hr doserates for high intensity beams. Typically, along the beamlines at the slits and stops the levels are around 5 mr/hr. We do have radiation from the various cyclotron parts, such as deflectors, couplers, ion source parts,

Table 6. Secondary Sources of Radiation

Source	Type	Magnitude	Procedure
K500 open for repair	β,γ	<3 R γ <7 R β worst case whole body dose 250 mR/hr	-Open after a day or so of shut-down -use disposable coveralls, gloves, hats, boots, glasses
Beamlines Beam Stops, Slits Beam Dumps	γ,β	<200 mR/hr at unshielded dumps ≲ 5 mR/hr at stops (fast decaying) ~1 wk	-warning signs -surveys
Parts: deflectors, couplers, ion sources, used components	γ,β	~10-20 mR/hr γ 40-50 mR/hr β (ion sources) ~1-5 R/hr β+γ (deflectors)	-store until cooler if possible -repair using gloves, glasses, lucite window box
Targets	γ,β	few to hundreds of mR/hr	procedure for storage, Store in Pb pig if >20 mR/hr

Radioactive parts are checked and labelled before being reworked by shop, welders etc. This is done by Operations staff. The Health Physicist or Radiation Safety Officer advises on safety.

and beamline components. These can be activated directly by the beam or by secondary reactions such as neutron activation. Parts can range from 10-50 mR/hr up to 5 R/hr for deflectors. Deflectors if at all possible are stored until "cooler" before repair; this is generally possible because we have spares. Targets can be typically a few to hundreds of mR/hr depending on how long they have been bombarded. The usual procedure is to keep them in lead pigs until the reading through a glass storage beaker is less than 20 mR/hr.

The operators are responsible for checking and labeling parts before they are sent to the shop for repairs. They or the shop personnel check with the health physicist or me on safety concerns.

Now for some statistics. For the year 1984, 135 workers were monitored. Out of them, 12 received measurable doses, with an average of 25 mR whole body dose for the year and a maximum of 60 mR. The allowed limits are: 100 mr per week, 1250 mr per quarter, and 5000 mR per year. Thus we have had no problems in terms of radiation exposure.

We have had some accounting problems, however. There was a lost finger badge that was missing for several months. When it was found and read out, the dose was about 45 R--this is reportable to the State in writing. We checked the person's whole body exposure for the period and that showed nothing. He was an operator and none of the other operators received high doses for that period. We checked the possible scenarios empirically and found that the ring would have had to lie in the K500 Vault for 3 months to get that dose. We did have to tighten our badge turn-in policy so that badges are checked off as they are turned in. We now have about 95% compliance for turn-in.

The welders were concerned about internal contamination when repairing radioactive couplers, so we sampled the air during an actual repair. We actually had two air samplers: one near the mask to monitor the breathing zone, and a more powerful one nearer the working area. We then analyzed the filters with a high resolution gamma detector to determine the radioactive species and internal hazards.

We have had some problems with neutron leakthroughs and skyshine. We had to put some extra shielding in one vault to reduce leakage into another. The skyshine results from the K500 having an open path above the K500 Vault. So we have put an "igloo" concrete block structure around that area and that has cut down the problem. Also, we purchased a more reliable portable neutron detector for surveys, because the old one was sensitive to thermal neutrons for which the tolerances are higher.

Our interlock system is checked about three times a year. We check the operation of the doors, scram buttons, and neutron monitors. We are trying to make this system better: for example, about once a year the neutron monitor high voltage system tends to shut itself off. This can also happen when there is a power failure. We installed a HV sensor interlock to shut off the RF when this happens. We are in the process of building better neutron monitors--better detectors and a stop-light system display with lights flashing to convey doserates.

POWERS: Are there personal monitors?

RONNINGEN: Yes, we do have GM counters in the hallways. We put up area monitors for neutrons. Our whole body badges are sensitive to fast neutrons (Neutrak 144, see Fig. 27) but we do put up Neutrak-ER (see Fig. 28) badges as area monitors. We also put up some standard gamma film badge area monitors. We also have an array of pocket dosimeters and newer, portable LED dosimeters, as listed in Table 7.

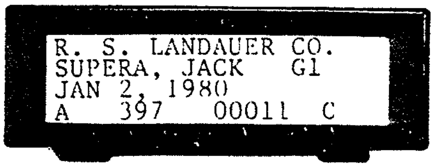
BLOSSER: We do have ahead of us the issue that as the K800 goes into operation the radiation level will go up, because of higher beam energies.

Neutrak™ 144

TECHNICAL DESCRIPTION

A thermally set plastic cast from the monomer allyl diglycol carbonate, trade name CR-39, has been employed as the sensitive component of a new fast neutron dosimeter capable of recording recoil protons. This track-etch type dosimeter consists of a piece of CR-39 placed in contact with a charged particle radiator made of polyethylene. Recoil protons emerging from the radiator penetrate the CR-39 track recorder producing trails of ionization damage which are chemically etched, or enlarged, by processing the CR-39 in an aqueous caustic solution. This treatment results in etched tracks which may be visualized in an ordinary optical microscope.

Actual Size



R. S. LANDAUER CO.
SUPERA, JACK G1
JAN 2, 1980
A 397 00011 C

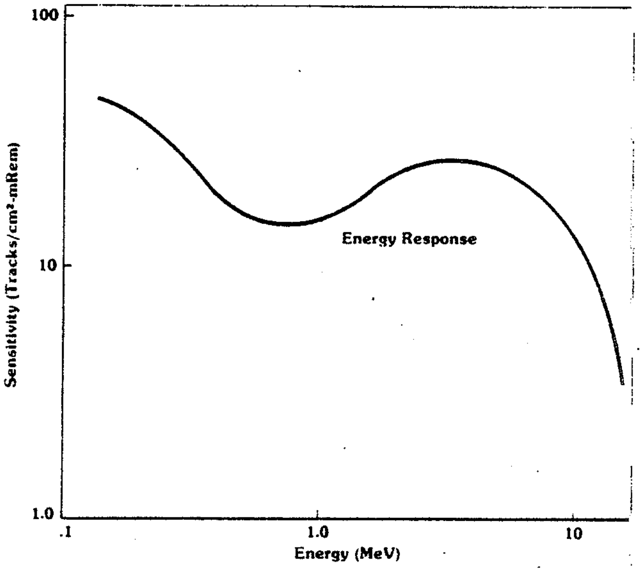
COMPARISON OF **Neutrak 144** RESPONSE
SHIELDED REACTOR SPECTRA

Exposure Set	(1) Reactor Shield	(mRem) (2) Delivered Dose	(mRem) (3) Neutrak-144
1	BARE	140	163
2	BARE	1120	1048
3	12 cm Lucite	533	531
4	12 cm Lucite	202	209
5	20 cm Concrete	695	874
6	20 cm Concrete	154	235

(1) Fifth Personnel Dosimetry Intercomparison Study (PDIS), March, 1979, Health Physics Research Reactor, Oak Ridge National Laboratory.

(2) Delivered Dose subject to adjustment, exposures estimated at +30%, -10% true dose.

(3) Response based on AmBe Neutron Spectrum; not corrected for reactor spectrum.



Landauer

R. S. Landauer, Jr. & Co., Division of Technical Operations, Incorporated

Glenwood Science Park • Glenwood, Illinois 60425 • (312) 755-7000

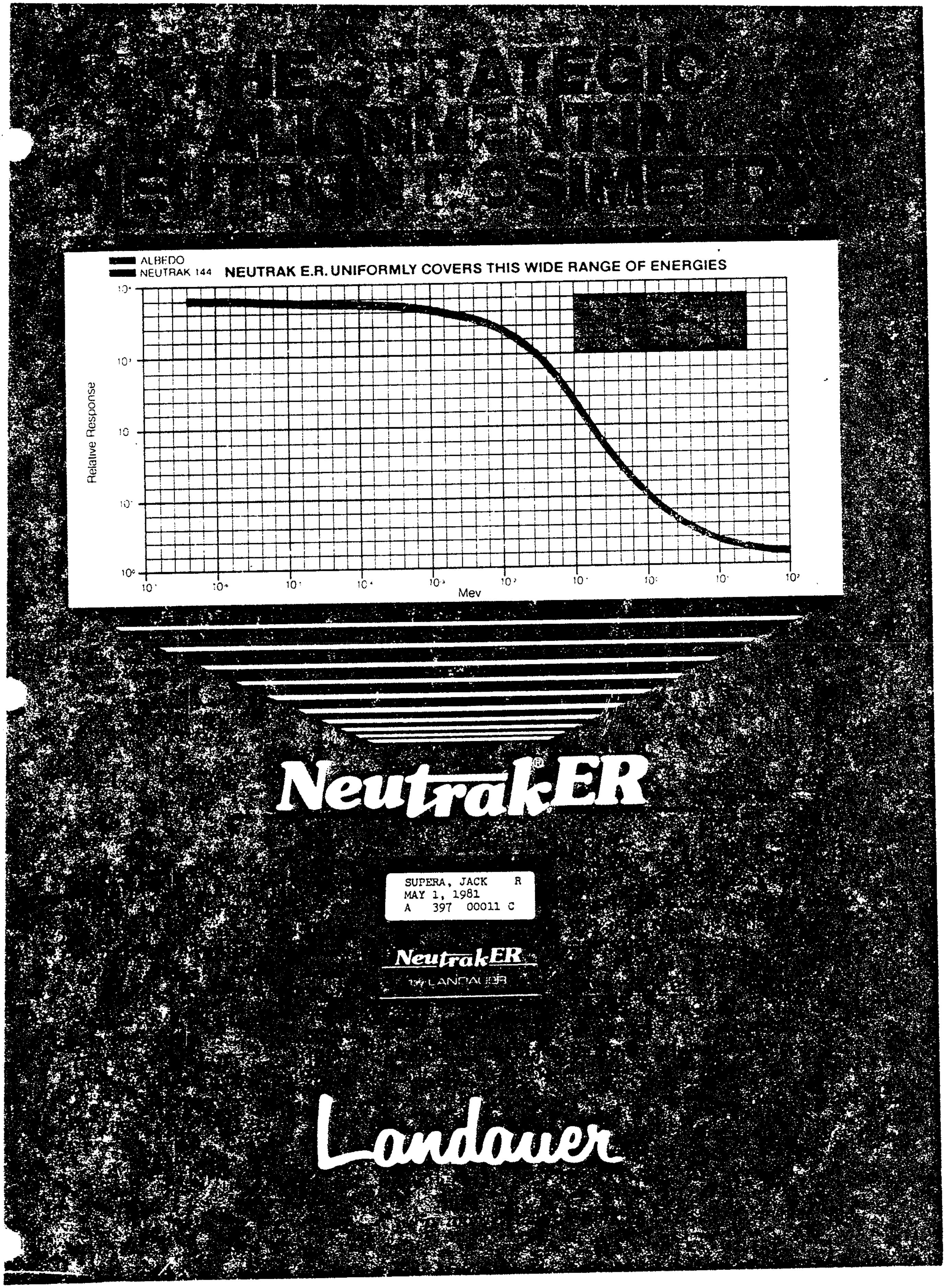
3 New England Executive Park
Suite 218
Burlington, MA 01803
(617) 272-2720

39 Milltown Road
East Brunswick, NJ 08816
(201) 238-6444

999 N. Sepulveda Boulevard
El Segundo, CA 90245
(213) 640-1015

2990 Richmond Avenue
Suite 144
Houston, TX 77098
(713) 521-9430

Fig. 27. Landauer-G badges are issued to all staff except those who risk high neutron levels in their work areas; the latter are issued Landauer-B badges. All badges are changed monthly.



SUPERA, JACK R
MAY 1, 1981
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Fig. 28. Neutrak-ER area monitors.

TABLE 7

RADIATION PROTECTION EQUIPMENT AT NSCL LAB AS OF 7.19.85

TYPE OF MONITOR	QUANTITY	LOCATION	COMMENTS
1. ALPHA DETECTOR	ONE	DET. LAB	ZNS TYPE. LUDLEM MODEL 43-5
2. G-M AREA MONITORS (WALL MOUNTED)	THREE	HIGH BAY AREA	LUDLUM 177 W/ 44-7 OR 44-9 GM
3. PORT. G-M	THREE	EQUIP. SHELF	LUDLUM 3 W/ 44-9 GM PROBE
4. PORT. NaI SCINT.	ONE	EQUIP. SHELF	LUDLUM 3 W/ 44-10 PROBE (2"X2")
5. ION CHAMBERS	FOUR	EQUIP. SHELF	VICTOREEN MOD. 497,400A,470(2)
6. NEUTRON DET. (PORTABLE)	THREE	EQUIP. SHELF & SOUTH VAULT AREA	*EBERLINE REM METER, BONNER SPHERE, BF3
NEUTRON DET. (WALL MOUNTED)	SEVEN	VAULTS AND HIGH BAY AREAS	BF3 WITH MODERATION
7. POCKET DOSIMETER (CHIRPERS)	TWO	EQUIP. SHELF	1 CHIRP=.025MR
POCKET DOSIMETER (QTZ. FIBER)	SEVEN	EQUIP. SHELF	NO CALIBRATOR
POCKET DOSIMETER (THERMAL NEUTRON)	ONE	EQUIP. SHELF	
9. AIR MONITOR (& PUMP)	ONE	RF BALCONY	EBERLINE G-M AMS-3
10. FILM BADGES (FINGER RINGS)	31		LANDAUER U TYPE
(WHOLE BODY)	328		LANDAUER B & G TYPE
(AREA MONITORS)	SIX	HIGH BAY AREA	LANDAUER I & G TYPE
11. SHOP VACUUM	ONE	WELDING LAB	ARCO WET-DRY VAC W/ HEPA FILTER

Gas Counters--John Yurkon

We use several types of combustible gases in the Lab. Primarily we use isobutane, P-10 (which is 10% methane and 90% argon), a 75% hydrogen-25% nitrogen mixture (in a hydrogen furnace), and a 50%-50% argon-ethane mixture. These are used in proportional and avalanche detectors, located in areas that are typically very well sealed off: the North Vault, the South Vault and the Detector Lab. There are several possible sources for leaks, as shown in Fig. 29: the gas bottles and the gas handling systems in the Vaults. These are temporary setups that are constantly changing, so there is always the possibility of a leak in a connection or gas line. We have vent lines under negative pressure to take the gas from the roughing pumps out of the Vaults.

To detect the presence of combustible gases, we have a gas sensor in each of the two Vaults. The sensor is connected to an alarm which is also connected to an electromagnetic solenoid valve on the gas bottle upstream of the regulator; that valve will shut off once it senses the presence of gas at the 20% level of the Lower Explosive Limit (Fig. 30). We have one sensor at each station and it is calibrated for the gas that is in use at that time. If there is a leak, an audible alarm sounds outside the Vault. There is a line to the Control Room that sounds an audible voice alert and prints a message on a terminal, as sketched in Fig. 31. There is a list of instructions posted in the Control Room that explains what to do in case of an alarm. On each gas handling system there is posted a set of operating instructions so that even if the experimenter is not there the operator could figure out what to do.

POSSIBLE SOURCES OF LEAKS

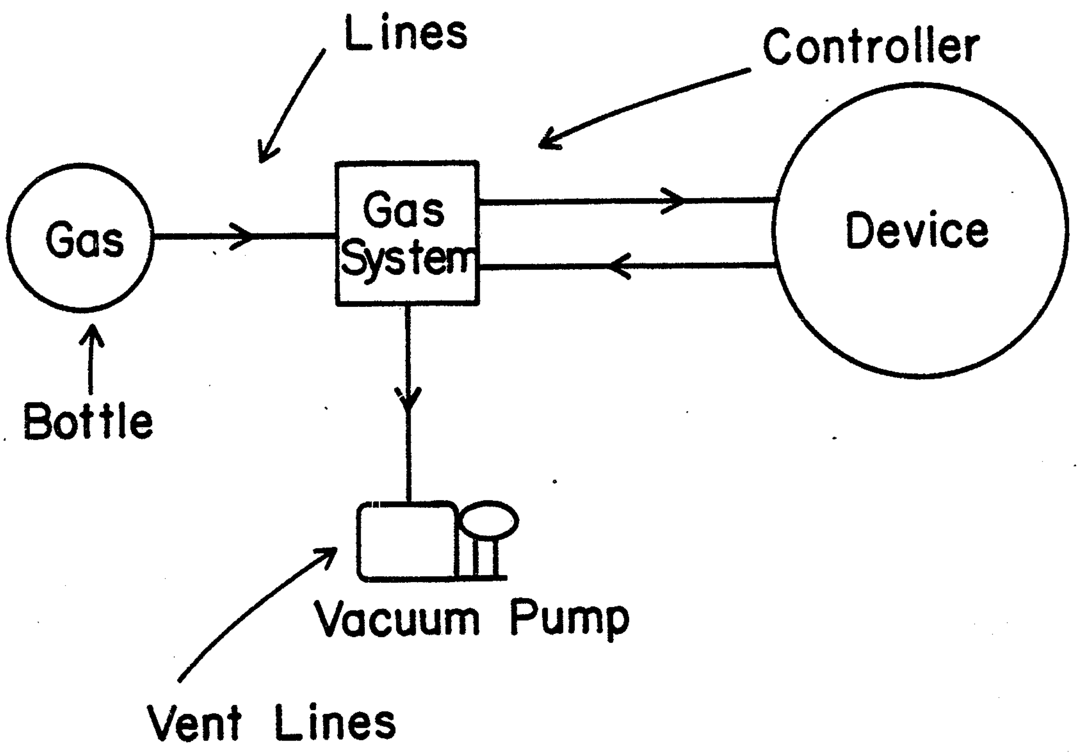

Fig. 29

MSU-85-572

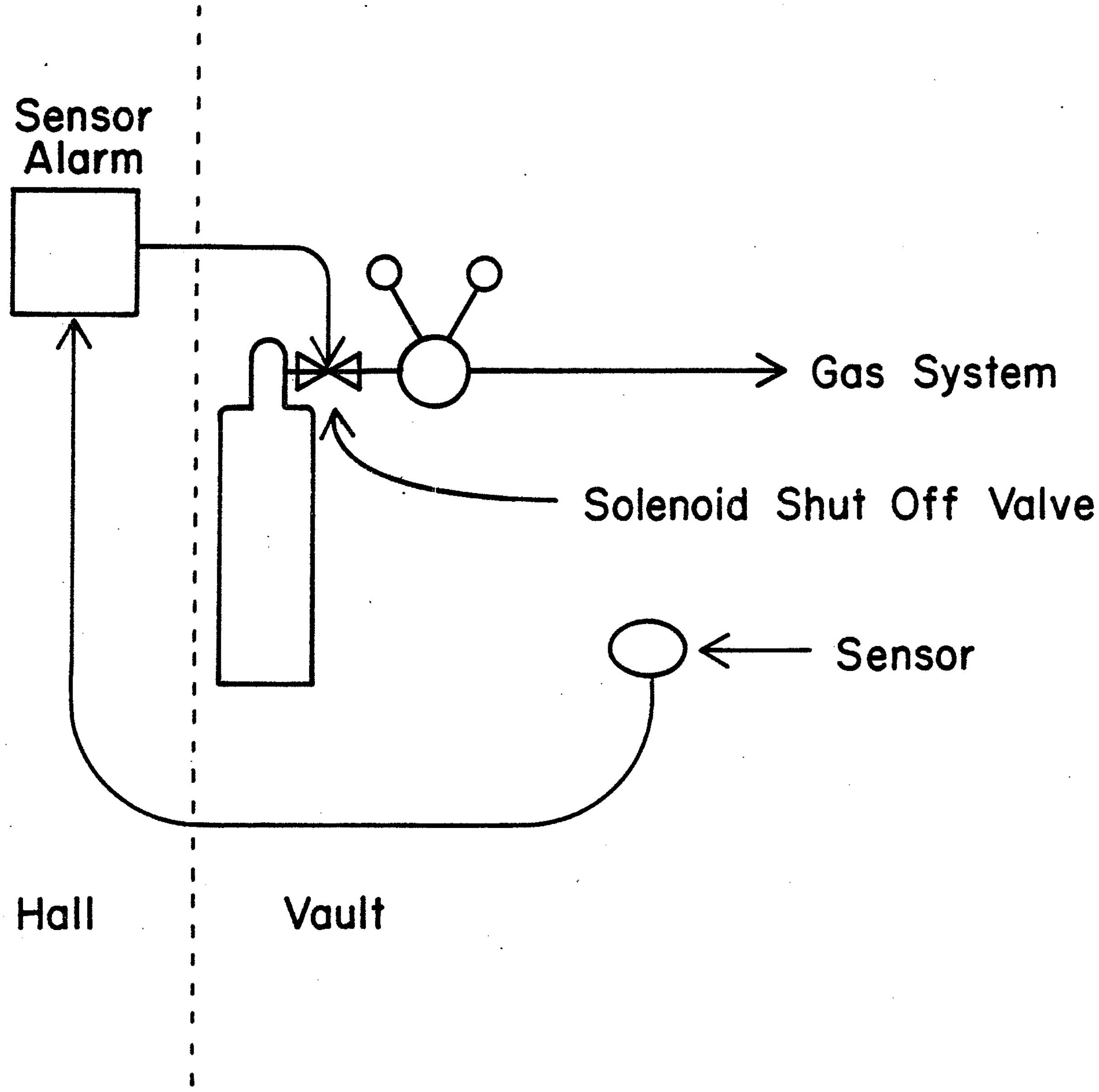

Fig. 30

ALARM SYSTEMS

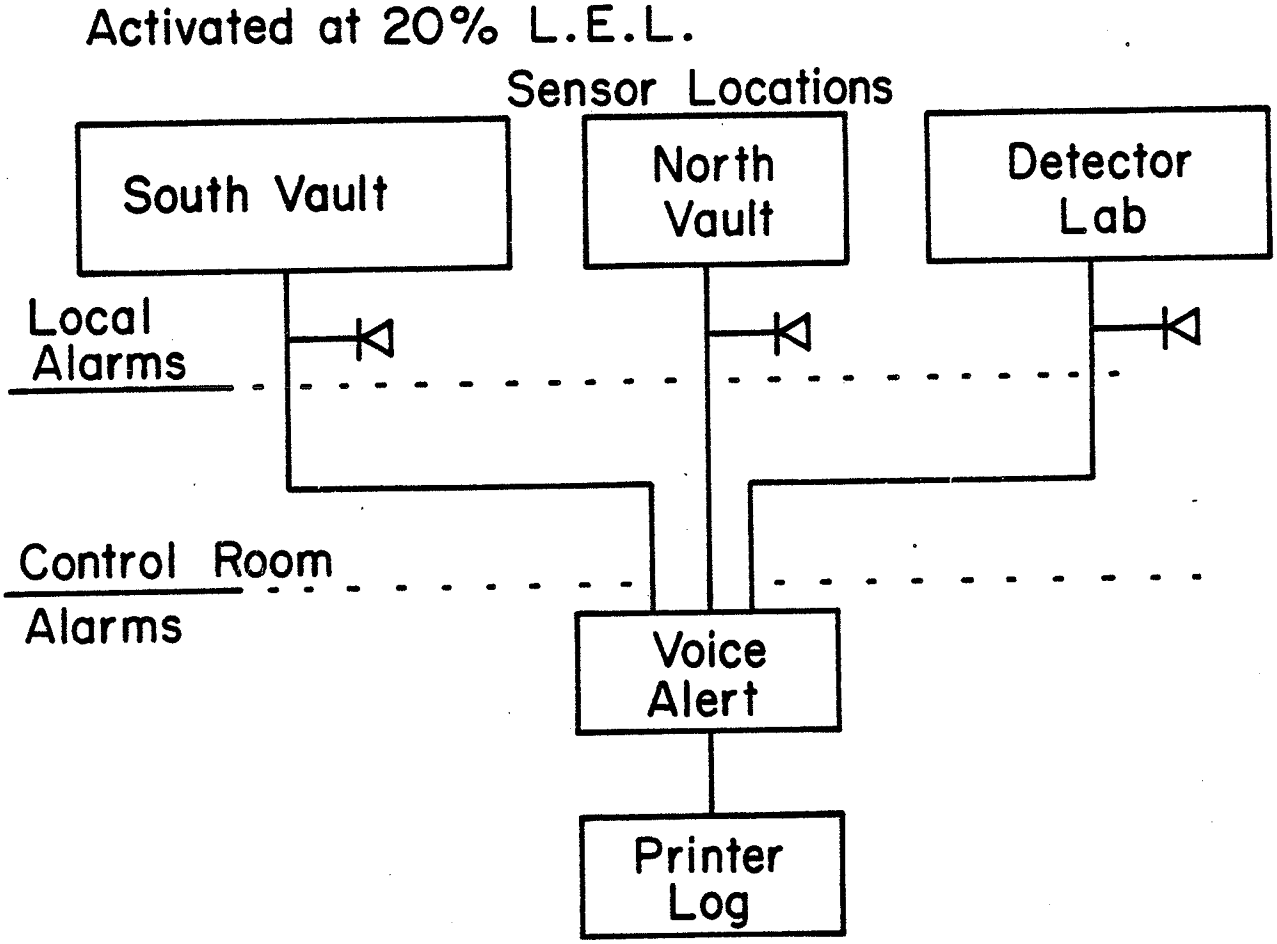

Fig. 31

Another possible danger is that, in case of a power failure, the roughing pump would stop and let air leak back into the detector with the combustible gas, thereby forming an explosive mixture. To solve this problem, safety solenoind valves have been installed that will isolate the gas system and vent the roughing pumps in case of electrical failure. When power is restored, they will not open again until a safe vacuum has been attained in the roughing pump foreline.

We have had one alarm in the South Vault that indicated a level of explosive gas. Upon investigation, a leak was found in the regulator on the isobutane bottle. When the Vault was sealed up again, the alarm went off again. We could not find any other sources of gas; we kept venting the Vault and sealing it up again. The level gradually decreased. We were not sure whether gas was trapped in the Vault and was taking a long time to purge or whether there was a leak that could not be found. We did find some combustible gas beneath the Vault door which remained there for a period of a week. Vent lines were installed under the doors to prevent this from occurring again. We are not sure that the alarm was responding to this gas, for later on we found that an alcohol cooler had evaporated in the Vault a gallon or more of methanol--which the sensor is also sensitive to.

On account of possible danger from the liquid nitrogen cooling lines in the K500 Vault, we have installed an oxygen deficiency detector in the K500 pit. There is an alarm in the pit which can also sound an alarm in the Control Room. There is a small oxygen deficiency sensor located outside the K500 Vault which the operators can carry into the Vault. They also have oxygen masks which they can wear in case of need.

There is also a carbon monoxide detector. It is located on the source gas balcony and its sensitivity is set such that the alarm goes off when an equipment with a high exhaust load is run in the High Bay area. People have got accustomed to the alarm going off.

Cryogenic Blowoffs--Helmut Laumer

The helium and the nitrogen systems are possible sources of serious accidents. For the most part, our approach is to design equipment so that it is safe. Accidents we have had which resulted in injury are limited to people getting frost bite on exposed skin. Another potential accident is when we blow rupture disks, for example. We have had vacuum jacket failures on both the K500 and the K800 coils and the disks performed as designed. The only danger I can see is that once it ruptures people congregate around the noise to see if something is wrong and everybody wants to help. Apparently people think we are losing a lot of money during these episodes and their first idea is to install another rupture disk. It is during such an operation that people can experience frost bite. Also potentially dangerous are the compressors and associated pressure vessels. When working on any of that equipment one has to be sure to take the pressure off; we have to pretty much rely on the people working on the equipment that they do follow these procedures. Similarly, with the cold boxes, transfer lines could by mistake be pulled while under pressure. When pulling transfer lines from liquid-filled dewars, the risk of frost bite injuries always exists. We usually try to get the vessel very close to atmospheric pressure, so that once the line is pulled out the helium stream coming out is moderate. We usually wear gloves while performing this task. We do not use face shields much but perhaps we should. We do not use any other protective clothing.

The other weak point that I can see is the way we handle the liquid nitrogen; anybody can access it. The helium storage tanks are other possibly dangerous equipment. They are rated at 300 psig, but the compressors are usually set to compress to 240 psig, though they can be set higher. The compressors themselves have safety devices that should shut them off once the pressure goes above 280 psig; they as well as the storage tanks have blow-off valves that blow at 300 psig. So I think that the chance of overpressurizing the tanks is pretty slim. The tanks are located in a restricted fence area that keeps the public away.

AUSTIN: Should our general policy on using relief valves be to have double protection?

LAUMER: Where we can trap liquid between two valves on the transfer lines, we usually have just one relief valve . For equipment with large storage volume, like the dewars, we have double relief valves. I think the coils also have a pop-off valve that opens before the rupture disk (I am not sure about the K800).

POWERS: What do you put on vacuum jackets?

LAUMER: That may be a weak point. We use a combination pumpout port with blow-off plug. It consists of a stainless steel fitting, O-ring and a plug. If a pressure develops on the vacuum side, we rely on the plug to blow out. There is some danger of being struck by a blowing plug. Secondly, the O-ring may have been sitting there for years so that it forms into the surface, and the pressure at which it then blows out may be pretty high. It is pretty hard to get around this. Even the commercially available pop-off devices usually have elastomers that eventually bond to surfaces.

POWERS: Have you ever ruptured an internal line? I understand that you fabricate those lines.

LAUMER: Yes, we fabricate transfer lines and cold boxes. I do not think that we ever had one of these things blow out. But we have built some that leaked.

SESSION IV. MANAGEMENT AND PLANNING--Seminar Room, 11:00-12 am, Aug. 30

Schedule Planning Procedures--Rex Morin

I wish to talk about some of our planning techniques based on network planning, whose advantages are listed in Fig. 32. I view planning as the first step in a planning-estimating-control process that continues through the life of a project. I am a recent addition to the Laboratory and we are just starting to use network planning techniques. A network is an excellent tool for showing inter-relationships between tasks. That is extremely important in a developmental activity such as we have here at the Laboratory, because inter-relationships show the complexities--and we certainly have a complex job to do here. That is one of the reasons why I am promoting the use of network planning techniques. A second reason is that complicated developments such as ours need any tools they can find in order to get greater visibility into their projects.

I want to spend some time describing network planning techniques in general, even though that may bore people who are already familiar with them. In my view, the power of network planning is due to the fact that engineers and scientists think in terms of pictures and want to be able to see the inter-relationships of tasks and how they connect up to define their work route and solve their problems. This was not possible with the automatic systems of the early days (the 50's), but today network automation is a powerful tool that is here to stay. PERT is the oldest and best known example of a network planning technique, though I am not a proponent of PERT. Another project planning scheme is the Critical Path Method (CPM), which I tend to use.

NSCL PROJECT PLANNING

- PLANNING IS FIRST STEP IN THE PLANNING-ESTIMATING-CONTROL PROCESS.
- NSCL STARTING TO USE NETWORK PLANNING TECHNIQUE.
- NETWORK IS EXCELLENT TOOL FOR SHOWING TASK INTERRELATIONSHIPS.
- COMPLICATED DEVELOPMENTS NEED VISIBILITY TOOL.
- MANIPULATION OF NETWORK DRAMATICALLY INCREASES POWER OF TECHNIQUE.
- EASE OF ALTERATION ESSENTIAL FOR USE DURING PROJECT EXECUTION.
- A HIERARCHY OF NETWORKS CAN PROVIDE ZOOM FEATURE.

Fig. 32

Of course, in any developmental program, the way one is going to do it changes as one is doing it, as one takes account of unforeseen problems that come up. If one knew exactly how to do it, it would not be a development program but a production program. One of the disadvantages of network planning previously was that it was a great deal of work to go back in and try to make changes. But in the last two and a half years, science and technology have given us the ability to actually manipulate (alter) the network. Network planning must have that abilty if it is to be useful in the cycle of planning, estimating, control, plan-estimate, or replan-estimate-control. LISA Project was the first one that came out with that ability. It was followed by MAC Project, which is the one we are using here because I happen to own a MacIntosh computer--and because LISA is not built any more. Both LISA and MAC use the CPM technique.

Another thing which I like to see on any kind of plans is what I call the zoom feature. Depending on what I am interested in, I may want to stand back and get the whole picture without being confused by a lot of details, or I may want to zoom in and get details of a problem area or an area of interest. So in our planning technique, we are incorporating a zoom feature that will let us get the level of detail that is germane to what we want.

In network planning, the first thing one does is to divide a project into individual tasks, which can be further divided into subtasks and so on. If that is done in a formal manner, one will end up with a Work Breakdown Structure (WBS). I hope that we will eventually start creating WBS's that will be relevant to our functioning. But even without a formal WBS, we can go ahead and start to separate things out into different tasks.

In the next step, the plan is laid out in a two dimensional network rather than a linear type display. The display in a two dimensional network shows the constraints and the inter-relationships between the tasks by connecting lines. Time flows roughly from left to right and shows how one is going to get things done, what tasks constrain the start of another one, and so on. One of the big powers of the network comes into play here, because scientists and engineers like to see pictures and graphs, not lists of numbers. Also it turns out that networks can give insight into what the problems are, in a way that a long listing of tasks does not. Next, one needs to look at each task and estimate how long it is going to take. That requires a judgement as to who, and how many, are going to do it. Depending on the type of automated scheme used, sometimes the entry would be man months, in other cases it would be duration. We use Mac Project, which requires duration. I happen to believe that that is the right parameter. If I have a job that shows 30 weeks long and I want it done in 15 weeks, changes must be made. Suppose I am using one person for a 30-week task. If I put two people on the task, it will not done in 15 weeks, it may be done only in 20 or 25 weeks. That depends on who I put on the job. So management judgement comes in at this point. Doubling the number of people does not halve the time and in fact sometimes increases it, particularly if you add people late in the project. So I think it is important that durations be entered and that the manager must look at the task and decide who and how many is appropriate. You cannot give that responsibility to any computer; it has to be a manager's judgement on how he's going to get the task done.

Also needed for network planning are early start, late finish data. How early can I start anything at the beginning of a project and how soon do I really want it done? The answers to these questions usually come from some outside constraint and then it is just a bookkeeping task to calculate the critical path. "Critical" here means the path of longest length. Other things could also be critical, such as most expensive or highest risk. The way to account for risk or uncertainty is to increase the estimated duration. In our network planning, we are using fixed estimates for duration, not probabilistic type estimates.

I try to stress to people around here that it is good to have a plan even if it is wrong, that we should get something down so that we can start modifying it, that we should not stand in fear of a blank sheet of paper. When we get the network on paper, we can start communicating with people and get inputs to change it.

I am rather pleased with some of the results we have achieved. Figure 33 is a network that we put together trying to show the entire Phase II construction activity on one sheet. The planning is still on-going, and some of the details may change. What I have done in Fig. 33 is to block it off into major subprojects, such as the K800 cyclotron construction, the superconducting ECR project and the 4π detector project. Part of the objective was to group things that were reasonably separable. Also I wanted to group things which were either inactive or had not received the full go-ahead. Another thing to consider in making these subdivisions is that the persons responsible for managing and planning each of them should be readily identified. So Fig. 33 is the big picture we have got, as it were. We can zoom in on any one part of it which is in a state of flux. When we are down to a sufficiently detailed level, we can see how to work out particular problems.

Once the network plan is settled, the required schedule of people and resources automatically comes out; you assign your resources where they are needed. Once a project is completed, it also provides a document which can

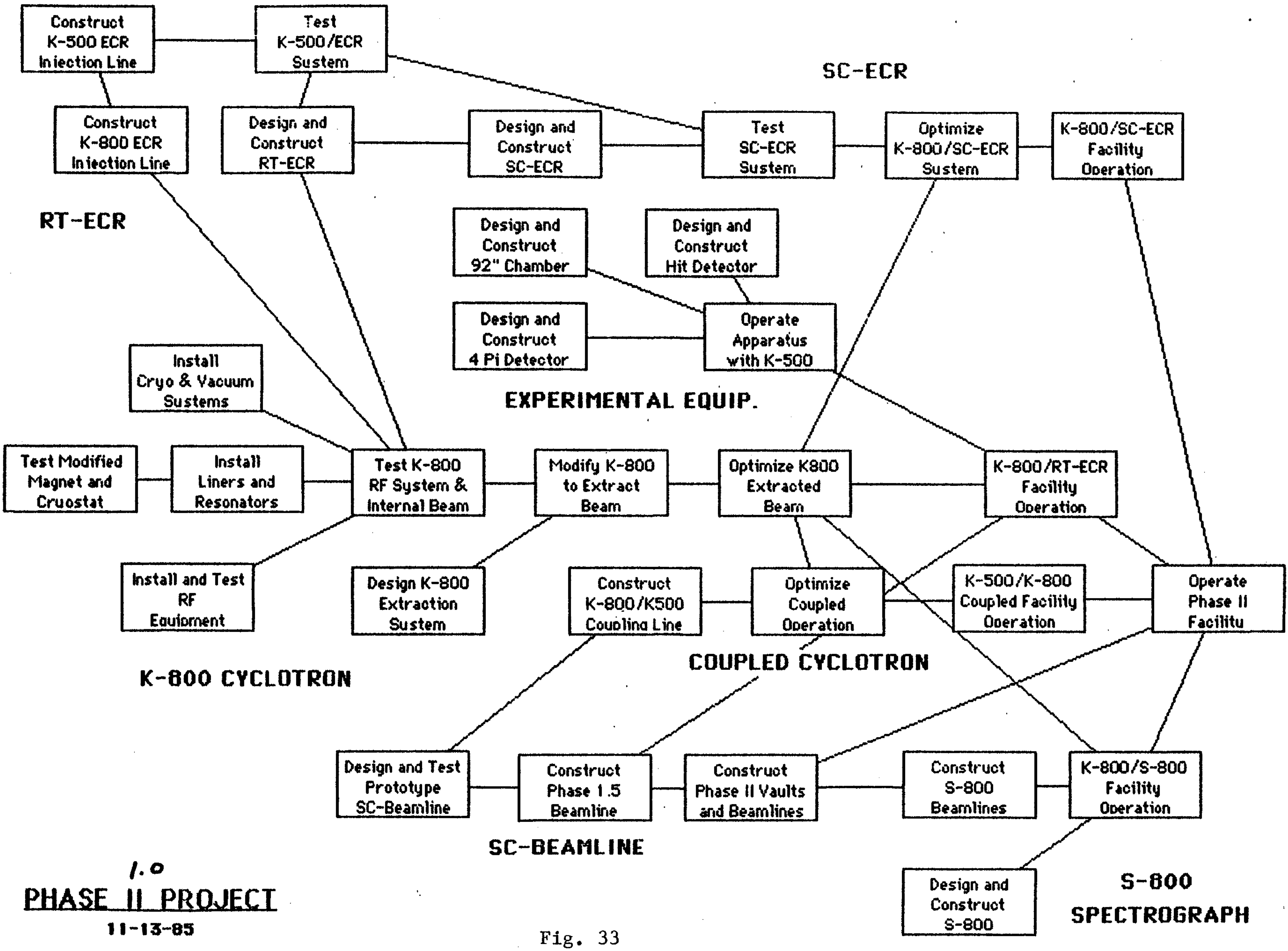
Construct K-500 ECR Injection Line
Test K-500/ECR System
SC-ECR
Construct K-800 ECR Injection Line
Design and Construct RT-ECR
Design and Construct SC-ECR
Test SC-ECR System
Optimize K-800/SC-ECR System
K-800/SC-ECR Facility Operation
RT-ECR
Design and Construct 92" Chamber
Design and Construct Hit Detector
Design and Construct 4 Pi Detector
Operate Apparatus with K-500
Install Cryo & Vacuum Systems
EXPERIMENTAL EQUIP.
Test Modified Magnet and Cryostat
Install Liners and Resonators
Test K-800 RF System & Internal Beam
Modify K-800 to Extract Beam
Optimize K800 Extracted Beam
K-800/RT-ECR Facility Operation
Install and Test RF Equipment
Design K-800 Extraction System
Construct K-800/K500 Coupling Line
Optimize Coupled Operation
K-500/K-800 Coupled Facility Operation
Operate Phase II Facility
K-800 CYCLOTRON
COUPLED CYCLOTRON
Design and Test Prototype SC-Beamline
Construct Phase 1.5 Beamline
Construct Phase II Vaults and Beamlines
Construct S-800 Beamlines
K-800/S-800 Facility Operation
SC-BEAMLINE
Design and Construct S-800
S-800 SPECTROGRAPH
1.0
PHASE II PROJECT
11-13-85

Fig. 33

be used to generate tracking schemes: one writes down how long each task really took, which is what is needed in order to build up a personal data base so that one can start making improved estimates the next time. By having this document, we can avoid the problem we all have of forgetting how long it takes us to do a task. Further, at least in principle, by looking at the requirements of each subproject in detail and summing them up, we could come up with an integrated resource plan. In practice, however, we cannot do this, for not all the Phase II projects have started.

We will soon have a system where the person who really understands a project (the project leader) can do his own networking and try his "what ifs". Then we will have progressed another step.

Let me end by emphasizing an important point which I have mentioned to Sam Austin and Henry Blosser many times. We have to recognize that we are not in the business of making plans, we are in the business of building things. So we have to make sure that we cut our planning off at the appropriate level.

POWERS: I am very familiar with the planning technique you have described. It is a very powerful tool for estimating time, money and people. We have had good luck with it. When we make components to a machine, each component will have a traveler (a history log that travels with the component) that tells everything about it.

Cost Estimating Procedures--Don Lawton

Our traditional way of estimating the cost of a project has been to list the individual tasks that are involved in the project. We then estimate the cost and manpower requirement of each task, either using historical data or asking an expert in each area to make an off-the-cuff guess. Our most recent application of this procedure was for the ECR ion source project. Sometimes, when trying to estimate the construction costs for the cyclotrons, we have listed the parts for the cyclotron on a sheet of paper and asked several people to make independent estimates. Occasionally we talk to a vendor or consult an equipment catalog.

Historically, our estimates have been consistently short, underestimated mainly in manpower. That has to do with not thinking of all the little tasks that are involved in getting the final product, and with having unanticipated problems come up. But, as we heard from Rex Morin, we are on the verge of getting into a system that will greatly improve our planning and estimating capabilities. Something that appears important to me is that we now seem to be using cost estimates for general planning. Historically, it was a separate issue or separate task; we would stop designing and and start doing cost estimates for a while. We were not integrating it into the planning of the project.

POWERS: How do you assess contingency when you make an estimate? Do you have any particular rules? Do you use a rule of thumb and say, for example, "Well, the last time I did this it cost me 30% more than I thought it was going to cost"? Do you have a historical data base like that at all? Do you use an algorithm of any kind?

BLOSSER: We tend to assess contingency according to the social customs of the community.

POWERS: For standard construction--building, pouring concrete, things like that--you can usually get by all the problems with a 25% contingency. On things that have never been done before and have very high technical input (high risk), you have to use a much higher percentage.

BLOSSER: Well, 100% up front probably would not be viable.

MORIN: In my previous position, I insisted that my people divide their job into three categories: tasks they had done many times before, tasks which were modifications of something they had done before, and new tasks. We applied different contingency factors to each of them. On the tasks we had not done before, my factor was 100%. It is important not to use 100% contingency for the whole project, because hardly ever does one start on something that is completely new.

BLOSSER: Projects which are intrinsically repetitive, e.g. the construction of accelerators for high energy physics, find it much easier to be accurate in their cost estimates. But innovative projects like the fusion project find it difficult. We do have the flexibility of falling back on the operating budget; that is, we can adjust the goals of the construction project to match the level of the funding. In any case, doing a better job on estimating would be helpful for everybody concerned.

MORIN: In my experience, another important aspect of estimating is that, once an estimate is made (no matter how experienced and smart the person making it is), it should be reviewed and critiqued by one or two other people, because they will have different perspectives and different ways of looking at the project. The end result might well be an improved estimate.

POWERS: There is a national data base in Washington, D.C. that you can access. It has all kinds of data, like dollars per pound for various types of fabrication. It would be prudent to compare it with the figures you are using. There is always the question of how good the data in a data base are--after all, it is only because one cannot make a perfect estimate that one needs a contingency--but there is some value in using the same data base that everybody else is using.

Fabrication Procedures--Harold Hilbert

We use one of two approaches for fabricating the pieces we want. First, we have a fairly decent in-house machine shop. But it does not have sufficient capacity to meet all our needs promptly. So about half of our fabrication work goes to outside vendors. Quite a bit of the inside work is generated by experimenters in the Lab, by the K500 operations group, and by the electrical, mechanical, and vacuum groups. Also, of course, we have to do the maintenance repair of existing equipment, an ongoing fabrication process that is always present.

Several steps are involved in the construction of new cyclotron experimental equipment. The design group first designs it. Then the drawings come to our group, we review them to ensure that they contain no gross mistakes and that they can be read and interpreted by outside shops or our own shop. Then the parts are ready to be built. We look at the nature of the job and the available manpower, to decide whether the job should go to the inside shop or to an outside shop. In some cases, we split the job in two. We have no programmable equipment in-house yet, and the equipment we do have is slow, so those pieces that are better done on programmable equipment or are more economically done with high-speed tools, automatically go to outside shops. The jobs that stay inside are assigned a group from the machine shop, an electrical group and an assembly group.

Jobs that go outside are split into various categories. If it is a small job (usually under $1000) which I think can be done quickly in an outside shop, we put it out on what we call a quick bid basis. Generally we go to about three shops but once in a while, when the job must be done really quickly, we will only go to one and sole-source it. In most cases we furnish materials, simply because procuring them takes a long time. We give a job to a shop and they then have to order the material that we have in-house. A job costing between $1000 and $5,000 we normally bid out on a two week basis, it always goes to the lowest bidder, and the shop normally furnishes the material. The list of shops we use has been developed over the years we have been in existence and at times we hand select the shop that the job goes to. But we are also always on the lookout for shops run by minority groups and for new shops that may bid low and yet do quality work. We have sources, people send us their names, and so we continually add new shops to our list.

We have a full time person in the Laboratory to handle the outside shop work. It is his job to visit the shops not only while the construction is going on but even before, to talk the jobs over and to see that the shop has the equipment to do quality work that will meet the drawings and written specifications. We try to follow the work as closely as we possibly can. Because of that requirement, we normally keep within a radius of 75 miles, which includes areas around Detroit and Grand Rapids. We have ended up with a couple of shops that are in different directions; our man tries to visit them on different days of the week.

Construction of large pieces has been done both in inside and outside shops. In some cases, because of unsatisfactory fabrication, we have literally had to take back unfinished pieces from outside shops and finish them in-house. Two significant examples are the K800 bobbin and the K800 cryostat. Both were let to outside shops, work was done to a certain extent, we negotiated our way out of the contract, and brought the pieces in-house and finished making them. The bobbin in particular was a real problem. We had a shop in the Chicago area that was doing what appeared to be an extremely good job. Their machining of the cylinders was excellent, the welding they did looked first class, but when they came to put the two pieces of the bobbin together, they ended up about 0.5" out because of the distortion in the welding process. So we brought that job in and developed welding techniques here that used high vacuum and low arcs.. Both the welding and the machining came out very well.

BLOSSER: But we have a continuing background of problems in fabrication, like companies not meeting their schedules, substandard performance, etc. We have had to send back lots of stuff.

HILBERT: Yes. Big items that had to be redone, either by ourselves or by the outside shop, include the K800 bobbin, K800 cryostat and various K500 RF pieces. We have set up an inspection group for that reason. It is nice to have long lead times because of this problem. We can then actually send the items back and have the company do them over.

BLOSSER: Some of these steps slow down our progress. For example, the drawing reviews slow it down, though there is always a tradeoff there. What we do is to look at what we are giving up.

POWERS: If you want to go to a really reliable vendor, you might end up paying a higher price than you want to. Where is the optimum? If you are making cryostats or magnet iron, you have to go to very good shops. And the shops you would select for those two jobs would be different. You have to balance the vendor's capability to the task you are giving him to do. It is tremendously difficult.

HILBERT: One of the things we do with a new shop, after it picks up a low bid, is to inspect it. If we think it is not capable of doing the job, we try to throw it out by telling the agency what we find. But we have to have proof that the shop is no good before we can do that, and that is hard to do if it is the first time it has bid.

BLOSSER: It is easy for us to leave a shop off the bid list, but much more difficult to throw it out after we have put it on the list and got a low bid from it. So what should be the process by which we decide who goes on that bid list? The process should involve some form of inspection of the shop's facilities--leak detectors would be relevant for certain jobs and not for many others. We do not do that right now--we put them on the bid list and we inspect them only if they bid low. What we have now is a random process, with our purchasing people just putting the names they know on the bid list. They will do what we tell them to, but we are not telling them anything. I have had the thought that we would be better off with some more organized system for bid lists; it certainly ought to have a way of putting new vendors in there. Also, I feel that some vendors bid with the intention of negotiating out of the purchase order rather than meeting specifications.

POWERS: That is not a unique problem. The general tendency for a company doing a complicated job is to do mediocre work and charge you top bucks for it. But if you enforce your requirements, it might bid higher the next time around. As you get to know the level of experience of the shops you deal with, you might want to graduate the level of difficulty of the jobs that you send to each.

NOLEN: We have an interim plan when we have a job in say the $50,000 range. If the low bidder is a company that we cannot easily inspect--e.g., it is spread all over the State--we will put in the contingency that it has to make a satisfactory test piece before continuing the job. For example, U.S. Steel bid for the bobbin of the S800 spectrograph. When we visited the company, it looked like it was in a state of shambles; it could not possibly have done the job. The only way we could convince it of that was to ask it to do a test piece. It utterly failed that piece and then it bowed out gracefully. That test piece cost us $5000--small compared to the full order, which was in the $100,000 range.

BLOSSER: The cost effectiveness of going to visit jobs is another matter I am unsure of.

HILBERT: One of the problems we find is that the job sits on the back shelf and nothing gets done, week after week. The K800 magnet was a perfect example; it sat in the shop for months without being worked on till we finally put down some very stringent rules for the vendor.

POWERS: Well, the ability to lay down such rules will depend on the size of the job. It would be very difficult to do for a $500 part. On the other hand, if you have a $100,000 part, the company might pay attention.

NOLEN: One of our problems is connected with the fluctuations in the auto industry in the last few years. When times are good, the local shops do a lot of work for the auto companies at high prices; at such times, they bid our jobs high. But after a while, things get slack and then they bid us low. So we can not rely on any one shop being always consistent in pricing. For jobs in the $10,000-$20,000 range, involving just machining of parts from existing drawings with no assembly or welding, we get a fluctuation in bids by a factor of 3. We think we can correlate the bid offered by a shop with whether or not it has a lot of work at that time.

Possible Consultant Assistance--Bob Powers

Let me thank all of you for your nice presentations and hospitality over the last two days. I want to address the question: What can I or my firm, Powers Associates, do to assist your Laboratory? Having heard the discussions, I think that I understand most of what goes on here and that there are many things that we can help you with, by bringing in specialized help. There are some areas where our help would be too expensive, you can do them better by yourselves. I would like to go over the things that I flagged in my mind, for which our help would be cost effective for you, and then try to summarize. Please forgive my lack of preparedness; obviously, I have had no time to formally prepare this speech.

There was a great deal of discussion regarding what I would call pressure vessel code and safety aspects. I think it would be a very good idea to know the ratings of the pressure vessels which you are using and have the safety valves and other devices reflect those calculated pressure ratings. While I agree that many of them are inside cyclotron enclosures and under heavy slabs of iron, nevertheless I feel fairly certain that there are other places in the Laboratory where you have pressure vessels, fabricated by you, which are not code stamped. They may be operating against the law of the State of Michigan. Since yours is a federally funded Laboratory, you can run it any way you want to. But if anybody ever gets hurt, there may be a liability for the Lab. So I would propose that we should look at that. I think we can do it very quickly, prepare the necessary documentation to give you some fall-back information, and correct as necessary any flaw that shows up.

One of my recommendations is for you to have a safety code manual which discusses general things like pressure vessel safety, electrical safety, etc. The Laboratory does not seem to have a policy guideline in terms of a safety manual, other than the radiation safety manual. It is certainly an understandable state of affairs because, until recently, all the people who worked here had grown up with the Lab over the years--they know what is bad and dangerous. But suddenly you have become big and are getting uninitiated people; that greatly increases the chance that someone could get hurt. If some underwriter comes in and asks what you do about people working in the hall, how you erect barriers, etc., you ought to be able to give him a manual which states your policies. What I hope to do is to bring in a safety manual very quickly, perhaps something paraphrased from the Fermilab manual. You could decide if you want to adopt their procedures. I believe you should have such a manual; and if I were part of the Lab management, I would do it right away.

Let me change the subject to the large cryogenic refrigerator that Helmut Laumer talked about yesterday. There appears to be a situation where you are creating ice blocks or oil blocks or solid air blocks at various parts of the system. I would like to propose two things: (i) you should get a gas purity device such as the Walker spectrometer that we talked about; and (ii) you should get data on your system. I can coordinate that with Ron Walker, whom I know and with whom I have talked about the development of his device. You should get data on what the purity of the gas stream is in various parts of the system in various operating modes and find out the conditions where you can cause the blockage to occur. By doing that, you can also probably pinpoint the source of the oil leak--which appears to be obviously in the compressors. You would then be in a position to clean up the system and put in the necessary amount of coalescers, filters and absorbers to preclude oil getting into the system. I would like to get one of my colleagues, Claus Rode, who is the cryogenic refrigeration expert at Fermilab, who is available to you through my firm. I would suggest that, after you have obtained some of the spectroscopic information, Claus come up here, work with Helmut for a couple days and try to psyche out what is going on. I have a drawing here which shows the refrigeration system and the positions where the ice blocks occur. I do not think we need much more information than that to start cleaning up the system. You can do that yourself but it would probably take three times as long; and you may not have enough scrubbing equipment. That is why I am suggesting Claus, who runs a whole lot of refrigerators all the time and is constantly engaged in cleaning up oil systems. We may want to bring in what we call a mobile purifier. We have two of them at Fermilab, we could drive one over here, hook up your helium supply to it, and run the helium through it for several days until we clean all the oil out. I do not know whether that is a practical thing to do or whether Fermilab would permit it, but I could ask. That summarizes what I feel we should do about the refrigerators.

There is also a lot of detailed stuff that I would like to talk to the cryogenics people about. For instance, why do the bayonets give you the heat leaks that you think they do? Bayonets are very fussy in regard to tolerances, and you can get into trouble with them. It is just a matter of taking some measurements, talking to the manufacturer for half an hour, and making sure that the capillaries are okay. The easy way to tell if a bayonet is right is to turn it horizontally and blow helium through it, but that is difficult with the U tubes you have. Instead, we can check it by making some measurements. If it is not okay, we can take some teflon or mylar tape and wrap it around the male bayonet to take up some of the space. If we wrap about 18 inches of the bayonet, we can significantly reduce the heat load by cutting off the convection currents.

Another matter I would like to address is the procurement problems that you have talked about. In the preparation of the specification for a complicated device that is to be fabricated outside, the first thing people have to know is what its place is in the overall system. The structured charts that Rex Morin talked about this morning would show when the device is needed and what it is for. The drawings you send out should be very good ones and should indicate the specifications that you want. Such specs can for the most part be prepared from existing ASTM specs, ASME specs, etc. Where they do not exist, we could prepare them ourselves--for instance, vacuum specifications, superinsulation specifications, general things of that nature. I have had a lot of experience in procuring this class of equipment. I know that in the end you pay the minimum amount if you make the design yourself, accept the design responsibility, and put in the specs. Then, if it does not work and it is built right, it is your fault; if it does not work and it is built wrong, it is the shop's fault. You cannot expect a vendor to accept design responsibility but you certainly can expect him to accept the responsibility for the work that he does. If you write the correct specification, then theoretically you should be able to bring the right thing in through the door. We would be happy to assist in this, if necessary. I have a colleague, Bruce Strauss, who is a metallurgist and has a Masters in business administration from the University of Chicago. He would be very helpful in terms of both the technology end and the preparation of specs for fancy metals and things like that. So, at the level that we need him, we could get him to assist you.

Let me change to another matter. I am a mechanical engineer by training and education and I have been project engineer for many years at different companies that do research in all kinds of areas. For fifteen years I have practised private consulting. One of the things I can offer is an outside review of cryogenic equipment--that is, I can make an independent assessment of heat leaks and designs and things like that. I am thinking specifically of the ECR ion source. I could help a lot with suggestions and how to deal with some of the tricky little design problems. I think it would generally be a good idea to get another view on complicated devices, to see if there might be a simple way of doing some of the things.

I can help you a great deal with bakable insulation systems and cryopumps. I know a great deal about those two subjects. Forgive my lack of modesty, but when selling one's consulting service it is not a good idea to hide under a bushel.

Another problem you mentioned is an RF power supply that has apparently never worked correctly. Again, I have a colleague, Dr. John W. Humphrey, sometimes known as Rusty, who is a Ph.D. in Electrical Engineering from the University of Washington, who was in charge of the power and instrumentation aspects of the Isabelle project at Brookhaven. He is with a private firm now, in the telecommunications industry. He is very talented in regard to RF equipment. I would suggest that he call whoever is in possession of the most knowledge on the subject, talk to him about the problem by telephone for perhaps an hour or two, and if necessary come out here, take a look at what has been done, and see if he can put the supply on-stream for you. I do not know if there is still a problem with the supply. I think it is yet another thing that is within our capacity to assist you with in a cost effective manner--we could probably do it faster through Rusty than your doing it yourself. That is the reason for our existence, we can come in and do what is necessary.

We talked about injuries and injury frequency. I think my previous mention of the safety manual covers most of that. If you are going to keep records of injuries, you probably should have a reporting procedure for any kind of injury that people receive. People should be encouraged to speak out if they think something is unsafe. I do not think people should be put in a position where they feel intimidated. Some kind of informal procedure for getting suggestions, perhaps a box where they can drop a note, anonymously if they wish, ought to be available.

There are some general safety problems that I think need looking into. There is in general no enforcement of safety at present. We talked about that this morning; and it is obvious if one walks around the shop. The aisles are obstructed, they are not always marked. In general, unsafe housekeeping conditions prevail. People who have worked here all their lives get used to such conditions, but when there are new people here, you can have them walking into pipes, climbing ladders that they should not be climbing, etc. Regular insurance-type inspections are in order. The weights that each rigging fixture can carry ought to be marked; that is a simple enough task.

It is a very good idea not to have a person work in a dangerous situation by himself. It is prudent to have a two-man rule, particularly in the experimental vaults and the cyclotron vault, and especially on the night shift. I think you should look at areas of possible oxygen deficiency and classify them so that people are aware of the dangers. Ways of doing that are described in the safety manual I mentioned. I am not trying to make work, but safety things can shut down a Lab. I have seen that happen.

As regards cryogenics safety, single relief valves are not adequate; you should also have simple burst-disks on the pipe jackets and other places. They can be designed and made very inexpensively and they are vacuum tight and reliable, if installed properly.

In regard to Rex Morin's procedural charts, I would like to chat with you about some of the things that in the past we have found it useful to include on the charts in order to turn them into more versatile instruments --cost information, quality control information, scheduling information, etc. You can then get printouts of information on various subjects off of the master inputs. I think that there should be a guideline on the procedures to estimate costs in different situations--depending on whether the task has been done before, whether the level of prior experience is full, partial or zero, what contingency is to be used, etc.

Those are some of my specific suggestions. Basically they would involve getting Humphrey to look at the RF power supply, getting Rode to look at the refrigerator, getting me to look at cryopumps, transfer lines, and handling equipment and pressure vessel problems, bringing you around the safety manual for consideration.

BLOSSER: I put together the agenda for this meeting as a mixture of areas I thought we needed help in and areas you had told me you were active in. When you say you would do a pressure vessel check for us, how big a job do you picture that to be?

POWERS: Well, if you have the drawings for the vessel and if I can readily get them, it is a two hour job per vessel to run a couple of good calculations. If you have a hundred vessels, it would take a couple of hundred hours to get them checked. But just to look at pressure vessels for safety takes less time, and it does not have to be done by me. One way to do it would be to use a form, give every supervisor who has pressure vessels in his domain the responsibility to fill the form, and then get somebody to review the data. The form should ask for such things as safety relief valves, the operating and the burst pressure of the vessel, the secondary safety pressure, whether there is a secondary, the code if it is a coded vessel, the maximum allowable working pressure, etc.

BLOSSER: What kind of working situation would be most efficient? Would it be best for you to come here for a week or two?

POWERS: If you want me to do it, the easy way is for me to come here and do it. If you want to do it yourselves, the easy way is for me to sit with somebody for a couple of days and show him how to do it. You <u>can</u> do it. It might not be a bad idea to have one of your people become sort of a vessel expert. I can show him what I did at various other places, you can decide how far you should go with it. But you should do something, you should at least look. I just hate to see you with all these vessels as so many potential problems. Maybe they are not, but until you know, you cannot be sure. When I asked questions, nobody knew the answers. Why do you have a coalescence vessel in a cryogenic refrigerator? What is the maximum allowable working pressure? They run on 280 psig, and yet they do not have a relief valve: why? If you get a blockage in front of a vessel so that cold helium in the vessel starts to expand and reaches a pressure of 400 psig, what is going to happen? One can make any number of hypothetical situation--most of which, thankfully, do not occur. But if you knew that putting a few relief valves here and there would take care of potential problems, would you not do it? I take an approach which I believe the insurance companies call "reasonable man's approach". It is the approach courts of law expect when they ask the question: "What would a reasonable man do?" A reasonable man would put a little safety valve in the system just to make sure that a helium vessel does not burst.

BLOSSER: What pressure vessels do we have?

POWERS: A pressure vessel by definition is any vessel subject to a pressure of over 15 lbs and having a certain minimum volume. A vacuum vessel, unless it has an amount of stored energy that exceeds a huge value, is not necessarily a pressure vessel. All your cryostats are pressure vessels, including their vacuum jackets. In an emergency situation, the cryopumps Jerry Nolen talked about can also become pressure vessels.

BLOSSER: We could have you come in for a week and see how it all works.

POWERS: If you want me to do that, I could spend a fair amount of time trying to help, bring the safety manual, show you what I am talking about. If you want to go into other things, such as RF, I do not have any expertise in RF and will have to bring Humphrey with me.

BLOSSER: The K500 RF is not a problem right now. On the K800, an anode power supply transformer is being repaired, and a sensible course of action would be to see how it works when it gets back. It may be that we do not have problems any more. But we probably would like advice on cavity design and transmission for the K800 RF system; we have a problem with fingers right now. Possibly we could have John Vincent talk to Humphrey about RF power supplies. Actually, I am a little puzzled that I have not heard of Humphrey before.

POWERS: You know Rich Orr. Humphrey worked with him.

BLOSSER: Well, I miss out on important people now and then.

NOLEN: It would be useful for us to have a really good power supply man on call for advice on general magnet power supplies. I wonder if Humphrey is a general power supply man or not. There are very few power supply companies in the United States or even in the world.

BLOSSER: You were telling of spending half of your time at Fermilab. Is that a continuing commitment you have?

POWERS: I have been at Fermilab half the time in the last ten years, on and off. Fermilab is a very good client, let me put it that way. But I can certainly take up for you any of the things we have discussed.