OPERATIONS

SUMMARY OF 1990 CYCLOTRON OPERATION

D.R. Poe, H.A. Thulin and P. Miller

Introduction

From February to September 1990, the K1200 cyclotron was shut down to complete construction of the experimental halls, the A1200 and the other parts of the beam transport system. The K500 was operated intermittently during that period for nuclear science research. This activity was assigned lower priority than both the construction and the K1200 operation, which preceded and followed it.

K1200 Operation

Starting in August, the K1200 beam was first employed to test the A1200 beam analyzer/fragment separator, and then to use that new device to perform experiments. By the end of the year, eight experiments had been performed, using several target stations and detector systems. Among the beams used were 120 MeV/nucleon ^{36}Ar and 115 MeV/nucleon ^{40}Ar. Tables I and II show data pertinent to the K1200. Table I shows operating time statistics for the K1200, and Table II shows the beams that the K1200 ran.

TABLE I K1200 Time Distribution 1990

	Hours	
Operation		
Research	952.50	36.9 %
Development	149.25	5.8
Overhead	650.50	25.2
	-------	-----
	1752.25	67.9
Maintenance	192.75	7.5
Breakdown	633.75	24.6
	-------	-----
TOTAL	2578.75	100.0
OFF	6084.00	

EFFICIENCY = E = (R + D + O) / (TOTAL - MAINTENANCE)

E = 1752.25 / 2386 = .734 = 73.4 %

TABLE II K1200 BEAMS 1990

MeV/u	ion	ECR
	JANUARY	
45	40 Ar 10+	RT
75	40 Ar 13+	RT
70	3 (H-D) 1+	CP
75	40 Ar 16+	RT
100	40 Ar 16+	RT
26	129 Xe 22+	RT
26	6 (D-He) 1+	CP
26	12 C 2+	CP
70	12 C 4+	CP
26	12 C 2+	CP
26	129 Xe 22+	RT
26	12 C 2+	CP
26	6 (D-He) 1+	CP
26	36 Ar 6+	RT
26	84 Kr 14+	RT
26	12 C 2+	CP
31	129 Xe 23+	RT
	FEBRUARY	
18	20 Ne 3+	CP
30	20 Ne 4+	CP
40	14 N 3+	CP
40	20 Ne 5+	CP
40	40 Ar 10+	RT
	AUGUST	
40	4 He 1+	SC
	SEPTEMBER	
40	4 He 1+	CP
40	4 He 1+	CP

MeV/u	ion	ECR
	OCTOBER	
40	4 He 1+	CP
40	16 O 4+	RT
85	20 Ne 7+	RT
70	15 N 5+	RT
70	18 O 6+	RT
65	40 Ar 12+	RT
40	16 O 4+	RT
	NOVEMBER	
40	20 Ne 5+	RT
40	20 Ne 5+	RT
90	12 C 4+	CP
90	6 Li 2+	CP
65	14 N 4+	RT
65	78 Kr 22+	RT
120	36 Ar 16+	RT
50	36 Ar 10+	RT
120	36 Ar 16+	RT
40	4 He 1+	RT
80	36 Ar 13+	RT
	DECEMBER	
120	36 Ar 16+	RT
110	36 Ar 15+	RT
20	6 (He-D) 1+	CP
20	12 C 2+	CP
40	20 Ne 5+	RT
25	40 Ar 8+	RT
65	40 Ar 12+	RT
105	40 Ar 16+	RT
115	40 Ar 16+	RT
95	40 Ar 14+	RT
45	40 Ar 10+	RT

Table II shows the various beams which were run on the K1200. Tables II and IV together, pertaining to both cyclotrons, show a beam change and ECR injection approximately every 40 hours of operation.

The acceleration of deuterium helium $(D\text{-}He)^{1+}$ molecules and hydrogen deuterium molecules $(H\text{-}D)^{1+}$ became routine in 1990. $(H\text{-}He)^{1+}$ is also useable. This provides a method whereby relatively low energy protons, deuterons or helium ions may be produced.

In order to improve the reliabilty of the K1200 cyclotron, the indium seals on the dee stem insulator for the C upper dee stem were replaced with silicone rubber O-rings. Indium seals typically begin to leak after several months of operation. In contrast, the O-rings on C upper have been running for about a year without apparent difficulties, and we are planning to begin using O-rings as

TABLE III K500 Time Distribution, 1990

	Hours	
Operation		
Research	560.5	36.6%
Development	8.0	0.5
Overhead	302.0	19.7
	870.5	56.8
Maintenance	8.0	0.5
Breakdown	652.0	42.7
TOTAL	1530.5	100.0
OFF	7229.5	

EFFICIENCY = E = (R + D + O) / (TOTAL - MAINTENANCE)

E = 870.5 / 1522.5 = 0.571 = 57.1 %

TABLE IV K500 BEAMS 1990

MeV/u	ion	ECR	MeV/u	ion	ECR
	APRIL			SEPTEMBER	
53	4 He 2+	CP	35	6 Li 2+	CP
10	14 N 3+	CP	35	6 Li 2+	CP
53	4 He 2+	CP	35	36 Ar 12+	RT
20	4 He 2+	CP	35	12 C 4+	CP
53	4 He 2+	CP	35	36 Ar 12+	RT
			20	4 He 1+	CP
	MAY		20	20 Ne 5+	CP
			20	12 C 3+	CP
20	4 He 1+	CP	20	4 He 1+	CP
53	4 He 2+	CP	20	20 Ne 4+	RT
20	4 He 1+	CP	15	10 B 2+	RT
53	6 Li 3+	CP	15	35 Cl 7+	RT
20	40 Ar 11+	RT	40	4 He 1+	CP
27.5	7 Li 2+	CP	35	40 Ar 13+	RT
			35	40 Ca 13+	RT
	JUNE				
				OCTOBER	
35	36 AR 12+	RT			
6	18 O 3+	RT	10	12 C 2+	RT
6	12 C 2+	RT			
13	4 He 1+	CP		DECEMBER	
	AUGUST		2.5	20 Ne 2+	CP
13	4 He 1+	CP			
35	36 AR 12+	RT			

replacements whenever a repair is necessary. For this replacement, we will use slightly shorter insulators. Silicone rubber has the properties required to withstand exposure to radio frequency, which can damage most elastomers. Alternative metal seal systems are also being considered for the future.

Calculations of K1200 cyclotron settings are no longer performed by the cyclotron design group, but rather by the operations group. This is now a routine function. The calculations give accurate predictions for most of the 65 adjustable parameters that are changed for each new beam or energy. The average time for a complete beam change (beam to experiment) is eleven hours.

K500 Operation

Following a shutdown period of about seven months, resumption of operation in the spring of 1990 was difficult, with many breakdowns. After a few weeks, operation became reasonably reliable. Table III gives the K500 operating statistics, and Table IV lists the beams run on the K500.

ECR OPERATION SUMMARY

D.G. Cole, T. Antaya and P. Osborne

In 1990 the three ECR ion sources at NSCL ran in excess of 4000 hours and injected a total of 87 ion beams requiring 83 separate injections of the K500 or K1200 cyclotron. These beams, in support of 3409 hours of cyclotron operation, represent on average a separate injection every 40.06 hours. The CP-ECR using its single stage geometry supplied 20 beams to the K500 cyclotron and 13 beams to the K1200 cyclotron. The RT-ECR using a single stage 2*B geometry supplied 15 beams to the K500 cyclotron and 42 beams to the K1200 cyclotron. The SC-ECR during its first development studies supplied one beam to the K1200 cyclotron.

ECR development in support of the experimental program has included development work on two metal-vapor ovens. A low temperature oven (T<800°C) with precise temperature control is expected to be able to vaporize 30% of the elements in the periodic table. A high temperature oven (T<2200°C) is expected to be able to vaporize 65% of the elements in the periodic table. Both have consumption rates much less than 1 mg/hr. Both ovens have been used to supply calcium beams in the last year, while current efforts are directed towards producing vapor from enriched-isotope powdered-metal feeds.

Plasma chamber liner development to shield the chamber walls during metal beam operation has compared liner designs, materials, and wall coatings. Copper liners treated with silane conditioning (SiH_4 + 0_2) have compared well with source performance employing the same conditioning without a liner. An alternative wall coating of MgO gave results similar to silane conditioning.

A system of beam attenuators has been installed and used in the K1200 injection beamline. The attenuators, made up of a combination of etched stainless steel screens lowered into the beam's path, are designed to reduce beam intensity before cyclotron injection, thus reducing excessive radiation at intermediate tuning points, conserving scintillator surfaces during experimental beamline tuning and allowing sensitive detectors to view the beam head on. The range of available attenuation factors at present is 0.33 to 3×10^{-7}.

In 1990 the ECR switchyard system completed its first year of operation in its fully operational state. Originally designed to allow the injection of either the K500 or K1200 cyclotron from the RT-ECR, the switchyard was redesigned and expanded to allow any of the three ECR ion sources to inject either cyclotron or both by two different sources, as shown in Fig. 1. The switchyard uses rotatable analysis magnets to couple a source to different cyclotron injection beamlines. A programable logic controller is used to swap vacuum and beamline magnet interlocks and to monitor the system configuration to ensure adequate safeguards for equipment and personnel. A system of large

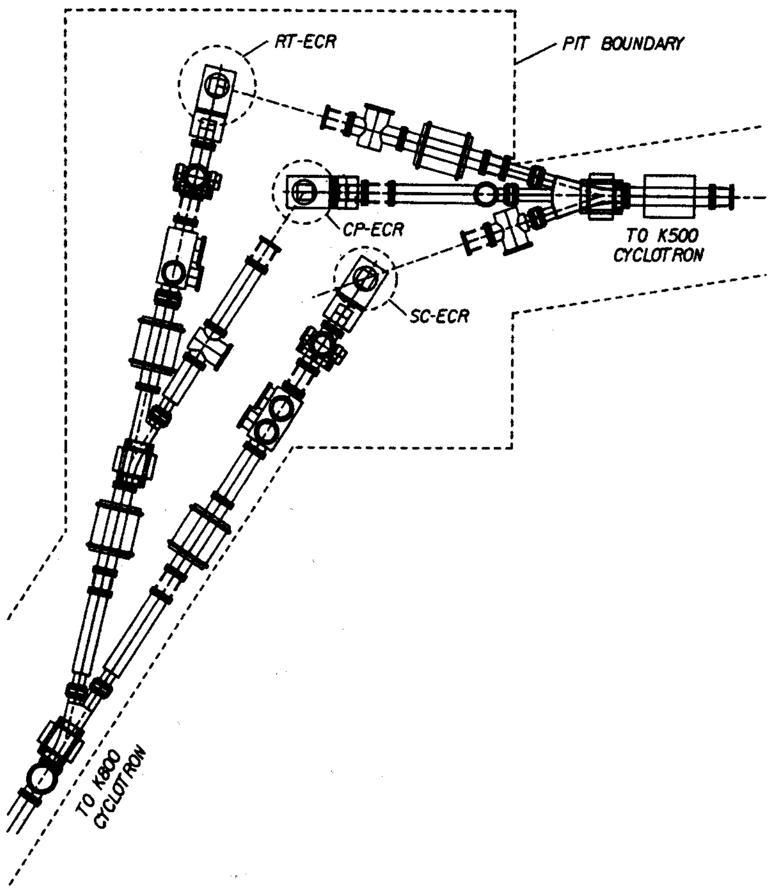

Fig. 1. ECR Switchyard.

contactors is used to switch power supply assignments or polarity of some beamline magnets to reduce the number of power supplies required to support the switchyard. The average time required to reconfigure the injection of a source is about five hours.

CURRENT STATUS OF THE K1200 RF SYSTEM

F. Pigeaud, J. Vincent, J. Brandon

This year's work on the K1200 RF was highlighted by the succesful redesign, installation, and testing of the new transmitters. Work initiated last year on the dee stem insulators and final anode power supply was continued with several issues being resolved. The entire system ran quite reliably with few problems to report. This report will discuss the present status of all the topics found in last year's report, in addition to the few problems we encountered during operation.

RF Amplifiers

The transmitters were retro-fitted to use Thomson TH555 tetrodes in the final stage because the previous tubes proved to be unreliable. In order to implement this change, a significant mechanical and electrical redesign was required. The driver box components and geometry were changed, plus a new neutralizing circuit was implemented.

One transmitter was reassembled as a prototype, with most testing and computer simulation finished early in the year. Construction of all three transmitters was completed by July 1990. The redesign of the final filament supplies, necessary to make them compatible with the new tubes, was also completed at this time. The results of testing which occurred in August through September can be found in our internal publication, "RF Note 109."

Final Anode Supply

Due to major redesign and fabrication of all aspects of this equipment, it has been officially renamed the "NSCL Phoenix Power Supply." The first change implemented in this system was the newly designed crowbar circuitry, which provides more accurate detection and recording of crowbar events. This is a critical aspect of the supply since it is the basis of protection for the load and the tubes, and its proper operation reduces wear on the transformer system. Fabrication of the power supply cabinet and control electronics also began toward the end of the year, with the hope of completing this stage by the summer of 1991.

In December we did have a failure of the main transformer which was caused by stresses induced when the transformer was momentarily short-circuited because of a crowbar. This is the typical failure mode for this type of transformer, but we will be looking into an improved design for this system in the future.

Dee Stem Insulators

As previously reported, a technique called "graying" was found to improve the performance of the alumina insulators. This process increases the robustness of the component by lowering secondary electron emission and making it more impervious to radiation effects. We are unable, however, to find a company with the appropriate facilities willing to perform this treatment. At present we are using regular alumina insulators, but will consider treating these pieces if the opportunity arises.

The vacuum seal of the dee insulators was another concern which received attention. Silicone rubber O-rings were installed in one stem early in the year to replace the more problematic indium seals. The silicone rubber has performed well, showing no leaks after being subjected to both thermal and high-voltage stress. New insulators, machined to be compatible with this O-ring system, are on order. We hope to have all the seals replaced in the near future.

Anode Filter

The year was not without unusual problems, the most severe of which was a failure of the final anode supply filter. This filter consists of an inductor connecting the final anode to the supply. Several capacitors to ground on the power supply side are used to shunt any RF to ground. The inductor is wound around the tube and sits between the tube jacket and the output blocking capacitor. This capacitor is a cylindrical sleeve which encloses the entire tube and inductor.

Unfortunately, the geometry of the inductor/blocking cap forms a transmission line with resonant and anti-resonant regions falling within our operating frequency range. The failure was assumed to be caused by large circulating currents being generated in this high-Q resonant circuit. These currents were significant enough to cause the inductor's 1/4" copper tubing to melt. Destruction of parts of the coil led to sparking and complete failure of this system.

These resonant points had very narrow bandwidths, and each center frequency fell within the same general region. The precise location of these points varied by small shifts from transmitter to transmitter. This minor difference in each station resulted in two of the filters burning up while the last was completely intact.

To prevent a recurrence of this problem, air flow past the inductor was increased to improve cooling. This will also help prevent arcing within the coil since gasses are less likely to build up inside. The coils were rewound with a different geometry, which shifted the resonances and may have altered the coupling to this circuit so high currents cannot be established. Additionally, an effort to avoid the resonant frequency of these circuits will be made, since the region is very narrow and does not severely limit the energy of beams which can be run. In the future a redesign of this component may be implemented so that the problem is removed completely.

Operation

The C-station transmitter, having been the prototype TH555 system, logged the most hours of operation. This tube in 1990 ran approximately 5,000 filament hours, and an estimated 4,000 hours of RF.

The tubes in A and B stations logged approximately 2,500 filament hours each, and over 2,000 RF hours. We also briefly conditioned a spare tube so it is available for rapid installation and operation.

Conclusion

The entire RF system is running very reliably and has so far operated to 90% of its maximum dee voltage. It is expected that the low voltage central region will be installed in the coming months. This will lower the maximum required dee voltage for a given beam, thereby reducing demands on the RF system. Completion of the Phoenix power supply will enhance both the reliability and ease of operation for the system. Beyond the scheduled changes in the Phoenix power supply and associated transformers, there are no more major changes foreseen for the system.

MEETING INCREASING DEMAND FOR CRYOGENS

H. Laumer, T. Changrani, J. DeKamp, R. Fontus II, J.A. Nolen, D.E. Pendell and R. Zarobinski

The cryogen distribution system has experienced significant modifications since the last Annual Report. The list of new equipment includes a cold compressor, manufactured by Cryogenic Consultants Inc., a valving box to select expansion engines operating on the helium liquefier, the supply lines for operating beamline magnets, and the branch of supply lines for operating a superconducting ECR.

Cold Compressor

The K-500 and K-1200 magnet cryostats have a relatively small volume of liquid stored above their minimum operational level. If the pressures in these coils change, as is likely when liquid consumption in the system exceeds liquefier production, the liquid helium level may drop below the minimum operational level and the magnet then has to be deenergized. There are a number of methods to counteract these effects. A compressor with sufficient spare and variable capacity would minimize liquefier upset under unbalanced operation. The coils could be operated with a return pressure control valve at an elevated pressure to generate a margin for upset operation; however, the dewar pressure would also have to increase to supply the coil at the same rate with liquid. Since the energy gained as liquid turns to gas decreases with increased pressure, the net flow to the coil would actually have to be increased. Level sensors become less reliable, and magnet operating temperatures increase with higher operating pressures. A cold compressor which is operated to drop coil and dewar pressures is a much better solution. In this case net flow to the coils can actually decrease. There is, of course, the penalty of lower net liquid production since heat introduced by the additional hardware and the work of compressing the gas does affect the reliquefaction process. However, since room temperature gas compressors can now operate at higher suction pressure, they may be able to supply higher gas flow rates which then at least partially restore liquefaction rates. The reliquefier can in principle handle higher flow rates when a cold compressor is installed since the increased pressure drop in the low pressure side of the heat exchanger, which would lead to excessive dewar and coil pressures without it, can be sustained. The expanders have to operate at higher speeds; however, so that this gain is expected to lead to more equipment maintenance.

The cold compressor has operated satisfactorily over 9 months with continuous use. A CR10, Campbell Scientific measurement and control module has been interfaced and programed to control it. It measures the suction pressure to the cold compressor and compares this value to an operating band. If the pressure is outside the band, a signal is sent to speed up or slow down the compressor.

Minimum and maximum speed settings are also limiting the compressor action. In manual mode a fixed operating speed can be selected. A unit similar to this has been tested at Fermilab, and some of its operating characteristics have been published.[1]

Box 7

Box 7, which is a gas manifold making it possible to operate any combination of three expanders at the 65 K or 20 K gas supply high pressure tap point, has been installed. This addition is extremely useful during engine maintenance. The engine at the 20 K tap point is the most important one while operating in the reliquefying mode, which is the mode our system usually operates under. If this engine fails, the engine operating at the 65 K tap can then be switched over immediately with very little impact on the process. The engine that was off is usually in a state of being ready for cooldown which takes approximately 45 minutes. After this time the system is back operating normally. The defective engine can then be warmed up if that is needed to carry out the required maintenance and it can be worked on without affecting reliquefier operation.

In box 7 there are pressure sensors and temperature sensors installed which make it possible to measure the expander engine efficiency. The first production rate measurements, after the cold compressor and box 7 where installed, confirmed what had been apparent before their installation, that the liquefier production rate had declined from its benchmark measurement in 1985. The new ease of working on the engines and accurate engine performance evaluation measurements contributed significantly towards achieving the goal of restoring the liquefier performance. We found that gas blowby losses in the engines were degrading the refrigerator efficiency. We have replaced one piston and cylinder unit and plan to replace a second to restore all three operating engines to full efficiency.

The possibility of operating two engines in place of one to reduce engine operating speed or to possibly gain liquid production capacity is also afforded by the addition of box 7. In tests up to the present no such liquid production gains could be achieved. The pressure at the engine intake is lower when two engines operate in parallel. This pressure head loss and the added heat load experienced by adding a second device seems to compensate for any gain in refrigeration, so that operating two engines at a slower speed in parallel so far has been only marginally useful.

Superconducting ECR

The branch line to and including box 4 which controls cryogens to the superconducting ECR has been installed and put in service. On the liquid helium feed line we included a subcooling dewar in box 4. This dewar is filled by the excess liquid returning from the ECR. A length of copper coil immersed in this liquid acts as a subcooling heat exchanger for the liquid helium supplied to a metering control valve which delivers liquid to the ECR cryostat. The advantage is that, provided there is liquid in the dewar, only single phase fluid passes the metering valve whitch results in more precise control for the liquid needed by the ECR cryostat. This coil, like the cyclotron cryostats, has but a small liquid helium reserve to buffer it from liquid transfer irregularities. The subcooling dewar in the cold helium return line also serves as a phase separator in which the helium level can be monitored to control helium feed rates.

Beamline magnets

The short section of beamline which made initial experiments possible has been replaced. The beamline steering and focusing magnets are practically all in position and over thirty have been operating . Presently there are thirty magnet cryostats that are operable at any time and are periodically refilled as required by their varying liquid consumption rate as reported elsewhere in this report.

Compressor maintenance

The compressor which developed an oil leak in 1985 did so again in 1990. The gasket seal requires dismantling the compressor which the manufacturer recommends be done at the factory. We followed the usual procedure where a replacement unit is shipped and the compressor is swapped out in an eight hour period so that the system is back in operation. A compressor motor bearing was also replaced this year, again with a down time of about one day. The refrigerator was maintained in operation, though at reduced capacity, by the 30g/s compressor during these maintenance periods.

Refrigerator capacity measurements

As the new magnets are put into service, the demand for liquid helium is proportionally increasing. In a three month period between July and October of 1990, both cyclotrons were operated with cryopanels on, the superconducting ECR was being supplied, and at the same time about 24 beamline magnets were kept in operation. While the reliquefier was keeping up with the load, it was evident that we were operating close to the capacity of the system.

The system performance during liquid production is measured reliably using liquid level sensors in the dewar. The performance for reliquefaction is measured by operating a heater in the dewar while maintaining a constant liquid level. These measurements are only meaningful while no liquid is sent to operate magnets and no cold gas is received from them. There are therefore very few occasions when performance can be measured accurately.

The capacity of the system was initially limited by the available compressor power. Before 1985 the flow rate available was 55g/s, this was increased to 80 to 85 g/s at that time, where the supply pressure is nominally 250 psig with a suction pressure near 16 psia. The compressor output alone does not determine refrigerator capacity. The refrigeration cycle employs a liquid nitrogen precooler as well as two gas expanders and finally either a J.T. expansion valve or a 'wet' expander.

The engine and heat exchanger efficiencies determine the effectiveness of the cycle. Depending on the mode of operation, the engine speeds have to be adjusted for optimum liquid production or reliquefaction. The response time of a liquefier is on the order of fifteen to twenty minutes for relatively minor system perturbation. The time taken to cool down the refrigerator from room temperature to operating equilibrium is from 6 to 8 hours. Finding optimum operating conditions can be a time consuming task. Generally it is true that the best performance is not a sharp function of any one parameter. The interaction of variables leads to this result. Running one engine faster will affect the pressure and temperature of other engines on the heat exchanger string, usually leading to lower efficiency for these other engines.

Table 1

Date	Dewar Level Rise (l/hr)	Compr. Output (g/s)	Pressure Drop Profile Compr. Supply (psig)	LIN HX Outlet (psig)	Wet Eng. Inlet (psig)	Expander Engine Speeds Wet Eng. (rpm)	20K Eng. (rpm)	65K Eng. (rpm)
12/85	300	83	253	240	210	165	395	420
9/87	210	73	247	231	192	120	460	315
3/90	170	86	241	220	187	120	410	460
2/91	230	69	253	240	210	110	435	380

The liquid production rate has been measured only a limited number of times. Table 1. is a summary of the history. It includes some of the more relevant parameters. The 1985 values were obtained after the refrigerator piping had been cleaned with solvent. The 1987 values indicate a decline most likely due to diminished engine performance, but oil aerosol deposits can not be completely ruled out. The performance had declined some more when the time had come to install box 7 and the cold compressor. Unfortunately we could not measure the capacity of the refrigerator just before this installation because we had lost all helium gas due to a failure in the 2500 l dewar pressure control valve. Other unfortunate circumstances led to an introduction of air into the helium gas system at the same time. Decontaminating the helium gas storage tanks took about two weeks and by then the installation of the mentioned equipment was well underway. Upon startup we then measured a very disappointing liquid helium production rate. Fortunately the new flexibility and instrumentation provided by box 7 made it much easier to work on the system. The engine efficiency of the best engine is now near 76% of adiabatic expansion when operating at the 65 K tap point and 72% when operating at the 20 K tap point for engine speeds near 220 rpm. The next most efficient engine yields 68% when operating under the same conditions at the 20 K tap point. At 200 rpm engines operate close to their maximum efficiency but the efficiency changes little between 200 and 400 rpm. At 250 rpm, engine failure rate, resulting in unscheduled cyclotron down time is less than one failure a year. What happens when the engines are operated routinely at 400 rpm remains to be seen.

A glance at Table 1. may lead to the conclusion that the only action needed is to operate the wet expander at 165 rpm and the 85 benchmark production rate could once again be attained. However, wet expander speeds to 200 rpm had been tried on 2/91 without radical effects on production rate. The main change between 12/85 and 2/91 is that box 7 and the cold compressor were installed. The heat load generated by the cold compressor depends on its operating speed and intake and exhaust pressures. An average heat load of 80 watt may account for this and new piping losses at the 4.5 K operating point. There are also new heat loads associated with box 7; but, since they occur at warmer operating points they do not contribute as heavily to liquefaction or reliquefaction losses.

The mass throughput of 83 g/s vs. 69 g/s is significant. The only indication of an increased pressure drop is the fact that the same wet engine intake pressure was maintained for 165 rpm vs. 110 rpm of 2/91. The 3/90 operating conditions show higher mass flow to the refrigerator; it and the increased pressure drop in the heat exchanger are both due to piston blowby reducing engine and liquefaction cycle efficiency.

Liquid helium needs may eventually exceed present reliquefier capabilities. The upgrade options appear at present limited. One option that is a novelty of this reliquefier design and that has never been implemented is the operation of a turbine in series with the gas expander at the 65K operating point. The other possibilities are to attempt to identify preventable heat loads and then to eliminate them. The practice of oversupplying coil cryostats with liquid belongs in this category. Providing buffer dewars, if a more sophisticated level control alone is not successful, may yield some capacity savings. We may also attempt to reduce heat loads at a few "U" tube bayonets where vapor cooling can be implemented easily.

References

1. Test of Cold Helium Compressors at Fermilab. T.J. Peterson and J.O. Fuerst; Adv. in Cry. Eng. 33,655(1988).

RADIATION MONITORING AND PERSONNEL SECURITY DEVICES

R.M. Rønningen, R.A. Blue, M. Fiasky, T.R. Jones, M.R. Maier, J.J. Vincent and D. Scott

Construction and installation of radiation safety devices continued this past year to meet the requirements of new vault construction and to make system improvements. Devices installed include a visual/audible warning system, an improved preamp/shaper circuit for high-energy neutron counters, vault security status indicators, and local status modules for BF3 counters.

A visual/audible alarm system is now operating in all the shielded vaults. The system provides a warning of anticipated operations by a rotating red beacon, which produces light flashes on surfaces throughout the vault, and an audible alarm. The warning is triggered by pressing an arming button, as required to initiate the procedure for securing a vault. An audible warning, which is broadcast via a public address speaker, includes musical tones covering a broad frequency range and a recorded message stating that all occupants of the vault should leave. A modified telephone answering machine proved to be the most satisfactory means of providing both tones and message of good quality. We are also evaluating a digital voice recorder, which would then replace the answering machine.

A new module (see Fig. 1) has been added to each installed BF3 neutron counter, to give both audible and visual indicators of neutron counts. In the future this module will be added to each high-

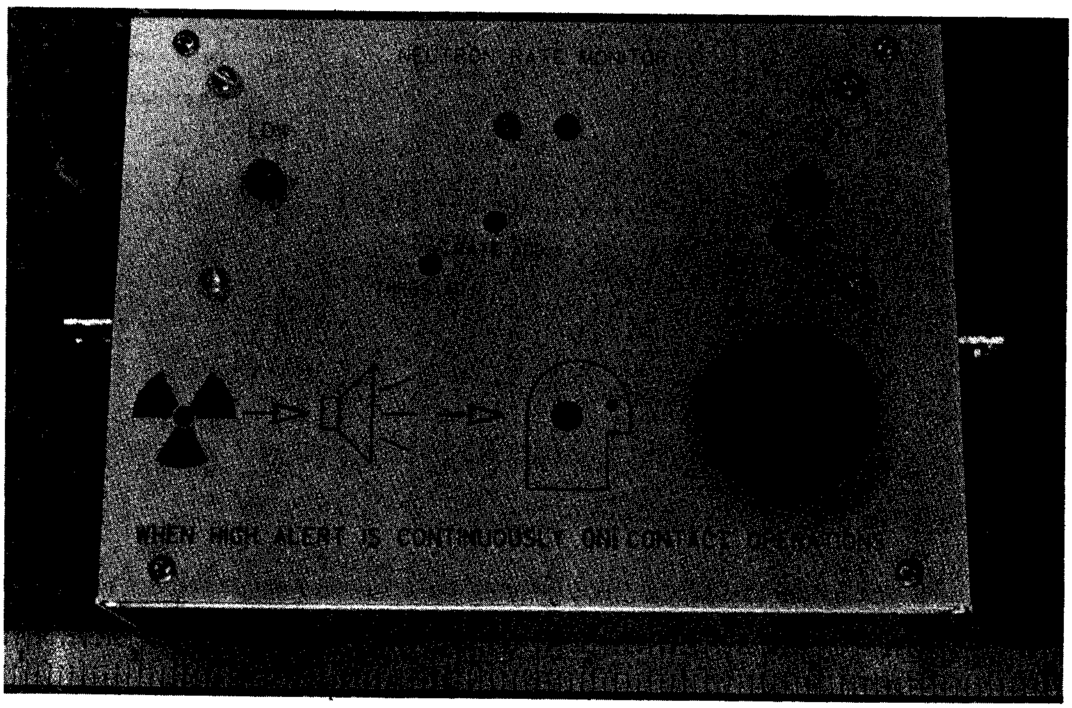

Fig. 1. A neutron rate monitor module, giving audible and visual indications of neutron rates. Each module is placed near a detector.

energy neutron detector. The module is connected in series with the detector, and is powered by the same 24 VDC that provides all the detector power requirements via the same coaxial cable that transmits counter pulses. Each preamp pulse above the module's threshold produces a "chirp", and causes the red LED's to blink on. At high rates the green LED's appear to dim and the red LED's appear to become brighter. These features combined with the typical detector response give adequate warning of low radiation levels.

A new local status module now under construction, as shown in Fig. 2, will be mounted outside the door to each experimental vault. LED's will indicate the status of: vault security, the cyclotron rf, the wall plug, and the presence of significant neutron radiation.

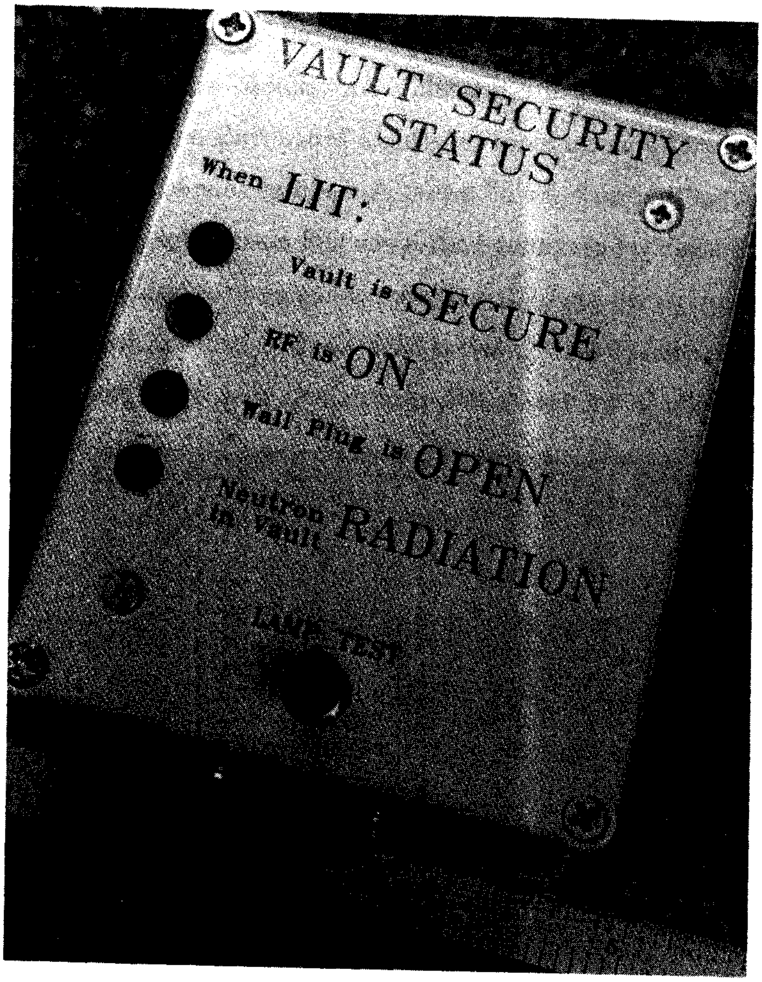

Fig. 2. A vault status module, to be installed locally to experimental vault entrances.

Figure 3 shows a high energy neutron detector with a new design for the preamplifier, pulse shaper, and high voltage supply. As the figure shows, all components are on an annular printed circuit board which fits around the neck of the photomultiplier mu-metal shield. The advantages of this new design are that the board is now internal to the detector housing, the pulses are discriminated and shaped at the detector, rather than at the remote logic circuit, the circuitry is

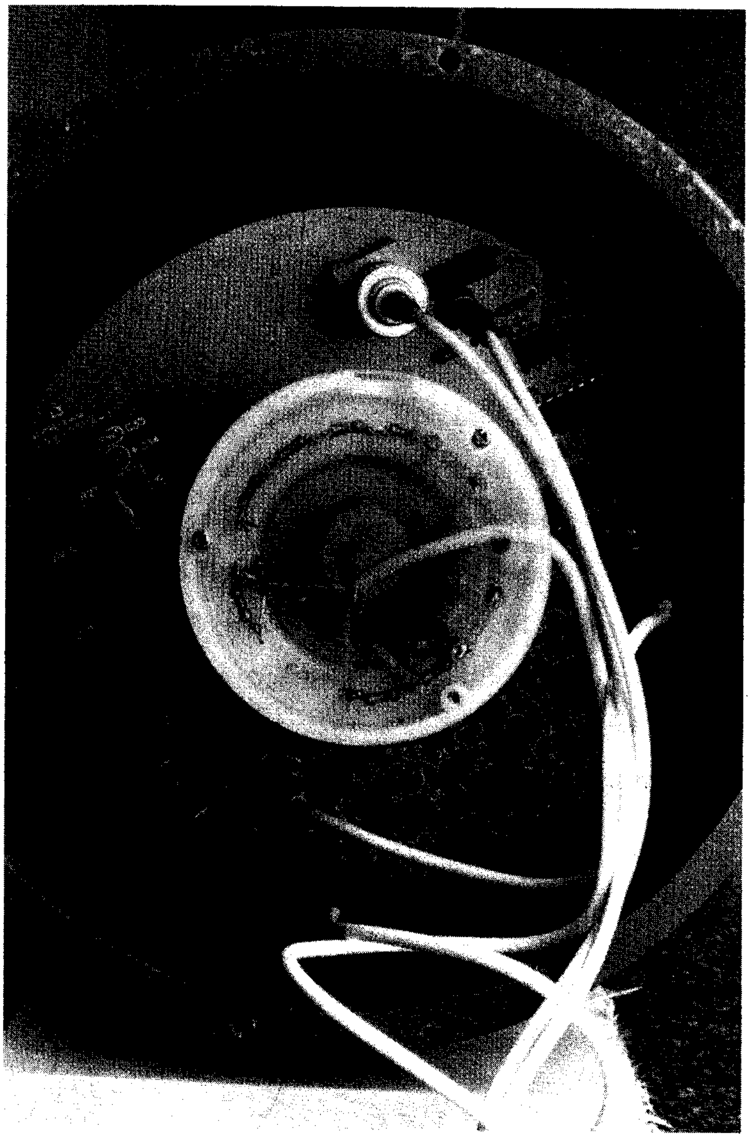

Fig. 3. A high energy neutron detector is shown with a housing cover removed. Newly designed preamp, high voltage supply, and pulse shaper circuits are shown on the annular board that fits around the photomultiplier tube neck below the tube base socket.

easier to adjust, and outputs are provided for diagnostics. Assembly has now been completed and we are starting testing.

Finally, a discriminator/shaper circuit is being designed to retrofit the BF3 detector preamplifiers. As with the high energy neutron detector electronics described above, these functions will be performed at the detector. Less sensitivity to electromagnetic interference pickup, hence false alarms, should result. The switch from RG58/U to MM11/50 "superscreened" cable (as noted in our 1988 annual report) has greatly improved this situation, but welder-generated noise, main RF power supply crowbars, and possibly ECR source unstable plasma situations have been observed to produce false alarms. The retrofit should be completed this next year.

CURRENT STATUS OF NSCL PHASE II BEAMLINE ELECTRONICS

A. McGilvra

The electronics for the Phase II beamline that connects the K-1200 cyclotron to all the experimental vaults are complete. They (see NSCL Phase II Beamline Electronics from the 1988 Annual Report for a complete description) consist of controls, power supplies, and instrumentation.

The electronics are grouped into two major installations: one controls the Analysis Hall (A1200), which is a single S-shaped beamline at the exit of the K-1200 cyclotron; the other controls the Transfer Hall, which is a multiple beamline switchyard that connects the K-1200 (via the A1200) and the K-500 cyclotrons to five experimental vaults. The electronics that control the Analysis Hall beamline are housed in a set of control racks in a room above the Analysis Hall called the Control Shack. The electronics that control the Transfer Hall are housed in a set of control racks in the South Wall Alcove just outside the Transfer Hall. The 10 Volt, 100 Amp Power Supplies and the Instrumentation units described below are not in the control racks, instead they reside in the Halls close to the devices they are controlling or monitoring.

The description and status of the controls, power supplies, and instrumentation are given below.

Controls

VME crates: Used for controlling power supplies and instrumentation via analog I/O and serial communications for setpoints and readings.
Status: Installed and operational.

Gould-Modicon PLC (programmable logic controller) modules: Used for interlock logic control; turning devices on and off, telling status of water flow switches, etc.
Status: Installed and operational, some advanced programming to do.

Power Supplies

20 Volt, 20 Amp DC Power Supplies: Four quadrant (+V/+I, +V/-I, -V/+I, -V/-I) supplies used to power the quadrupole focusing magnets. Controlled via VME analog I/O points and the Modicon PLC.

Quantity required is 49.
Status: Installed and operational.

10 Volt, 100 Amp DC Power Supplies: Four quadrant supplies used to power the dipole steering magnets. Controlled via VME serial communications and the Modicon PLC. Quantity required is nine.
Status: Installed and operational.

Instruments

Beam Current Meters: Used to read beam currents from 10 pA to 300 uA at several points on the beamline via VME serial communications. Quantity required is 12.
Status: Installed and operational, 5 more planned.

Bang-Bang Servos: Used to control motor drives for moving beam diagnostic apparatus and experimental apparatus. Controlled via VME serial communications. Quantity required is 21.
Status: Installed and operational.

Cryogenic Monitor Unit: Used to monitor health signals of the magnet cryostats: helium pressure, helium level, and magnet lead voltage drop. Output signals are read by VME analog inputs, the Modicon PLC, the LED Panel described below, and the Cryogenic Dual Meter Selector Panel described below. Quantity required is 33.
Status: Installed and operational.

Dual Channel Thermocouple Vacuum Guage Controller: Used to read vacuum from two thermocouple vacuum sensors. Output signals are read by the Dual Meter Selector Panel described below. Quantity required is 19.
Status: Installed and operational.

Local Monitoring Devices in the Control Racks

LED Panel: Used to monitor the cryostat status signals that come from the Cryogenic Monitor Unit. Two are required.
Status: Installed and operational.

Cryogenic Dual Meter Selector Panel: Used to read the cryostat helium level and helium pressure signals that come from the Cryogenic Monitor Unit described above. Two are required.
Status: Installed and operational.

Vacuum Dual Meter Selector Panel: Used to read the vacuum signals that come from the Dual Channel Thermocouple Vacuum Guage Controller described above. Eight are required.
Status: Installed and operational.

THE N4 VAULT: A GENERAL PURPOSE USER AREA

D.P. Sanderson

The N4 vault (See fig. 1) is a large room designed to house large pieces of experimental apparatus. A single superconducting beamline crosses the vault approximately 2 m. above the floor. This report will describe a few of the features of the vault. If a specific experiment needs additional utilities, special cabling, or other custom work, the laboratory will do its best to provide.

As in the other vaults, several building utilities are available. Cold city water is provided for cooling turbo pumps. Low conductivity water can be used in magnets or electrically isolated systems. Chambers can be vented to dry nitrogen gas, and 80 psi compressed air is used in the vaults for valves and actuators. All mechanical vacuum pumps are exhausted through the building roof. A separate plumbing system is provided for exhausting explosive detector gases. If an experiment needs liquid helium, a cryoline is easily run to the laboratory's CTI-1400 LHe refrigerator, which is located on the other side of the east wall of the vault.

The beamline ahead of the experiment is four inch beamtube with "conflat"[1] style flanges. The exit beamline is eight inch tube to account for multiple scattering in the target. ISO flanges are used in the exitline since a section is often removed for alignment purposes. The laboratory will provide small turbomolecular pumps for evacuating the beamline and small experimental setups. If a large volume detector is to be installed, it should include its own high vacuum pumping system. The faraday cup is an isolated aluminum tube with a graphite plug, followed by 100 mm of aluminum. It is surrounded by two feet of steel and embedded in the concrete wall.

For viewing the beamspot, two of the laboratory's standard diagnostic "pots" with scintillators are installed in the vault. One is attached to the exit of the superconducting quadrupole. The other can be placed wherever the experimenter needs it.

As in the N3 vault,[2] a removable mount and benchmark for the laboratory's alignment telescope are installed near the faraday cup. If an experiment needs to be aligned from the front, a piece of beamtube in the transfer hall can be removed and a transit installed there.

Running back to the data area are 35 low noise 50 ohm signal cables, 39 fast timing RG-213 lines, and 20 SHV high voltage cables. A branch of the data CAMAC parallel highway and an ethernet line are installed in the vault for self contained aquisition systems.

The N4 vault should be able to adapt to most users. Since each experiment is so different, no permanent detector mounts have been built. Each experiment should plan to either provide its own target chamber and detector support or adapt an existing system at NSCL. If there are any additional questions, the author can be contacted at NSCL.

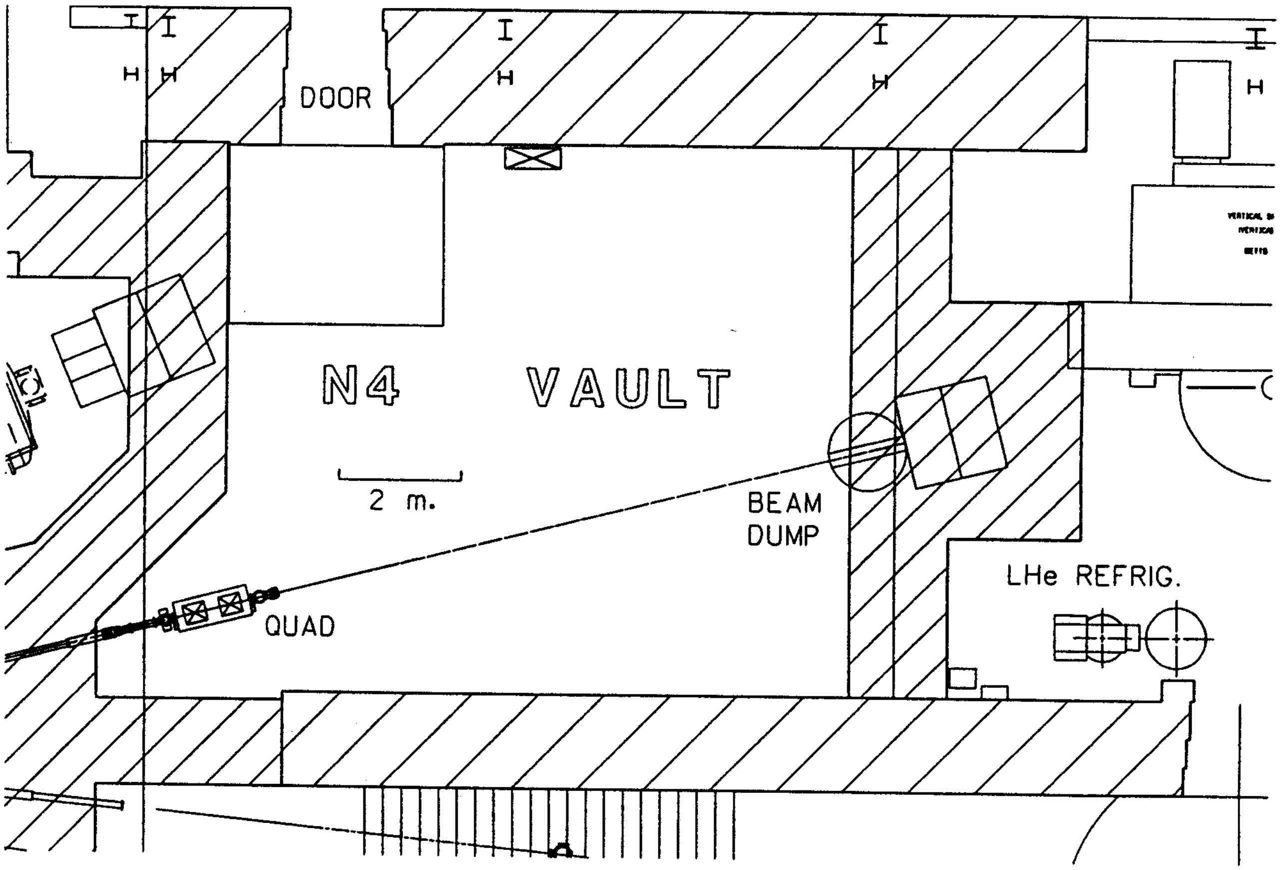

Figure 1. The N4 vault.

References

1. Varian Associates Inc.
2. NSCL Annual Report 1989, p. 198.

EXPERIENCE WITH 8mm TAPE DRIVES AT NSCL

Ron Fox, John S. Winfield

In the past the cost of magnetic tapes has been a major part of the NSCL computer department operating budget. In addition, large amounts of floor space have been dedicated to storing tapes in an environmentally controlled room. Other nuclear and high energy research groups have slowly migrated to the use of 8mm digital tape cartridges for various forms of data storage. Compared to traditional 9 track media, 8mm tape cartridges offer many benefits including higher density, and much lower cost. Higher density translates to reduced requirements for precious storage space. Lower media cost taken together with higher densities result in lower yearly tape budgets. 8mm drives are not without their drawbacks, however. They are not nearly as fast as 9 track drives and the jury is still out as to their reliability. In addition long start times can be extremely annoying, and lead to further data rate reductions if drives are forced to run in start/stop mode.

This article explores the use of 8mm tape drives at NSCL. In the first section we describe the vendor selection process. The second section describes the process of integrating the 8mm drives with the NSCL data acquisition system. The third and final section describes our level of satisfaction with the drives.

Vendor selection

While there is only a single manufacturer of 8mm digital tape drives (Exabyte), there are a number of value added vendors. Vendors of 8mm drives fall into three major classes:

Bare bones: These vendors just take the drive as sold by Exabyte, package them into boxes with power supplies and sell them to the outside world.

Integrators: These vendors sell the drives along with controllers for processors which do not have direct connect SCSI controllers. These vendors produce controllers for Q-bus, Unibus and HSC series cluster disk/tape controllers.

Bells & whistles: Vendors which make functional additions to the base Exabyte tape drive. These include vendors that sell drives with status and tape remaining indicator lights.

We decided to accept bids only from vendors of the third (bells & whistles) category with a special eye towards vendors that supplied status and tape remaining indicators. We decided to require status indicators because while it is possible to tell what a 9 track drive is doing by visual inspection, it is not possible to know what an 8mm drive is doing since the tape cartridge is completely swallowed up by the drive.

Eventually, after an open bid process, we settled on Transitional Technologies Inc. (TTI) which adds the following functionality:

1. Detailed status indicators which show what the current tape operation is as well as the tape remaining and percentage of ECC recoveries required to read or unambiguously write tape.
2. Emulation of DEC TKZ-50 tape drives which, in turn allows trouble free attachment to direct SCSI machines such as VAXstation 3100 workstations. See Ref. 3.
3. Q-bus controllers which can interface drives to the NSCL Q-bus systems with TK-50 emulation.

At the time of this report we have six 8mm drives. Four of these were purchased in the operating year covered by this report, the other two were purchased in the following operating year.

Integrating drives with the NSCL data acquisition system

This section describes the work that was necessary to integrate the 8mm drives into the NSCL VMS data acquisition system as it is described in Ref. 1. We also describe new software that has been written and additional hardware that has been purchased which allows event data to be recorded locally in the VME front end systems described in Ref. 2.

Integrating 8mm tapes with the VMS system: The VMS data acquisition system records event data on tape using a tape logging process. This process produces tapes with labels which follow the ANSI labelled tape format described in [3]. This results in a file structured tape where each run is a separate tape file with a filename that is generated from the run number. The tape program controls the tape drive via the VMS $QIO system service call and expects a standard VMS style tape device driver to respond to these requests.

There are several qualitative differences between 8mm drives and "standard" 9 track tape drives. These had to be considered when determining what if any modifications needed to be made to the tape logging program.

1. 8mm tapes have a long start time when they have been at rest for longer than about a minute. By contrast, 9 track drives have essentially no start up time.
2. 8mm tape drives take a long time to write file marks. In addition, there are two kinds of file marks, short (see below), and long. Long file marks require approximately 2.2 megabytes worth of tape space, while short file marks require approximately 0.5 megabytes of tape space. By contrast, file marks don't take too much time to write on 9 track tapes, and there is only a single kind of file mark.
3. 9 track tapes can be positioned to rewrite arbitrary records, while 8mm tapes may only write in the following very well defined positions:
   - Physical beginning of tape.
   - Following the last written record on tape.
   - Prior to a long end file mark.

When a new run file is opened on tape, it is necessary to write several ANSI labels and an end file mark. Similarly, when the tape file is closed, it is necessary to write an end of file mark, the file trailer labels, two more file marks, and then the tape must be positioned prior to the last file mark written. On an 8mm drive, this whole process can take several minutes. During this time, we felt that end users might become concerned that the taping process was hung. Therefore, we added messages at several points in this procedure to let the user known that everything was alive and well. We also issue a message when the run file is finally completely closed to prevent the user from inadvertently removing tape cartridges when the tape is not in a safe state.

One concern that many people have expressed was the amount of space required by end file marks on 8mm tapes. As indicated, there are two types of end file marks, short file marks which require about 0.5 Mbytes of tape space, and long file marks which require about 2.2 megabytes worth of tape space. When writing an ANSI formatted tape, this implies that a fair bit of tape length goes into the file marks which separate labels from data and runs from runs (3 file marks per file).

The TTI drives have a mechanism for enabling short file marks. It might seem that short file marks could be used to reduce the amount of space taken up by file marks on tape. However close examination of the sequence of steps required to ensure that tape removal or system failures which result while runs are stopped or paused indicates that using only short file marks leads to cases where run files cannot be properly extended. It would be possible to use a mix of short file marks and long file marks, however the TTI drive and VMS software do not support this. This combined with the fact that typical run files are several hundred megabytes long led us to choose to just use long file marks and accept the capacity penalty.

The final issue was the difference in capacity of 8mm and 9 track tapes. Ideally, we would like to keep the same tape logging program for 8mm and 9 track tapes as this decreases the software maintenance effort required. The NSCL taping program uses the translation of a logical name to determine how many blocks of data can fit on a tape. A separate startup command file for 8mm taping allows the default (9 track number) to be superseded with a value which is suitable for 8mm drives. This number is much less than the actual full capacity of the drive to allow room for a "typical" number of end file marks.

Integrating 8mm tapes with the VME systems: The NSCL front end system is a networked system. Since it allows multiple data receivers, the throughput is determined by the network bandwidth divided by the number of active data receivers. In larger experiments, it is not unusual for the rate limit on data to tape to be due to the number of data receivers, rather than the characteristics of the tape drive or per event dead time. One way to beat this would be to do event recording locally on the front end system and just sample data back to the VAXes either at some fixed sample fraction or in an on-demand mechanism. The low cost of 8mm tape drives, and high availability of SCSI controllers for VME bus makes this a viable option.

Prior to our work in this area, Fermi National Laboratories reported on a data acquisition system[4] which was capable of writing data logs to tape. In order to reduce the effort required to implement tape logging software, we started by obtaining a copy of the FNAL tape interface software and the VME controller (Ciprico RIMFIRE 3510) it was built to operate with. The package FNAL had written was primarily a low level set of interface routines to the RIMFIRE SCSI interface board. On top of this, we designed and implemented the multilayered structure shown in figure 1.

Each layer adds a well defined set of functionality to the basic FNAL RIMFIRE support software:

```
+-------------------------------+
| Volume management level       |
+-------------------------------+
| Block I/O level               |
+-------------------------------+
| Device level synchronization  |
+-------------------------------+
| FNAL RIMFIRE package          |
+-------------------------------+
```

Figure 1: Software structure for front end taping

- The device level synchronization layer maps device completion conditions into pSOS operating system calls which can be used by higher levels to synchronize with I/O completion and I/O exception conditions. This layer also provides routines to allocate and deallocate drives.
- The Block I/O level provides basic block I/O functions (read, write, space file, space record, rewind etc.) needed to access the drive. It makes calls to both the device level synchronization routines and the FNAL package. It implements a synchronous completion I/O model.
- The Volume management level is implemented solely in terms of the Block I/O level routines. It supports the maintenance of ANSI X3.27-1987 formatted tape volume sets. This support is limited to single volume sets at present. Support is provided to mount and dismount volumes, to open and close files, and to write or read data from these files.

Some commentary on the functionality described above is appropriate. It might be thought that the choice of a synchronous I/O model for the block I/O layer would have adverse effects on performance. However the drives themselves contain relatively large (128Kbyte) buffer memories and so do multibuffering without host intervention. I/O writes complete when data has been transferred over the SCSI bus to the drive transport, it is then the drive's responsibility to ensure that this data is written to tape which it does using a combination of ECC an retry/rewrite's. Completion is only delayed if the drive buffer is full, and that means that the host is generating data faster than the transport can record it anyway. I/O reads do readahead buffering to similarly improve performance.

The volume management layer is currently restricted to support for single cartridge volume sets. This is not really a restriction at NSCL since users have indicated that they prefer not to see runs split across physical media boundaries. There is a further restriction on access to the media. Volumes can be mounted for read or write, but not for read/write. In practice, the front end is just writing tapes so this is not a restriction. Read support was added because the development cost was small, and in the future it might be advantageous to use this package to support a tape server system for use in playback analysis.

The front end software was further modified from the description in Ref. 2. A routing program similar in function to the one in use in the VAX acquisition system (described in Ref.1) was added to the system. The buffer sending process was modified to be a client of the front end router, and the local buffer dumper section was split off into a separate process. A tape log process was coded as a client to the front end ROUTER accessing the tape systems primarily through the volume access layer.

The tape logger is an optional part of the front end software. Some users might prefer not to use local taping, or not even to use 8mm drives. The taping system in the front end therefore initially is dormant. The user can activate the taping program. Once activated, the program:

1. Checks for the existence of a RIMFIRE controller on the VME bus.

2. Locates the drive with the lowest SCSI id on the bus (usually there's only one).

3. Requests a tape.

Once a tape is loaded, the program attempts to mount it. If the user puts an ANSI volume in the drive, the program will append data to the volume. If the tape is not a valid ANSI volume, the program initializes it ad then mounts it.

When a run is begun, if taping is enabled, the program opens a new file on tape and records each buffer to file. The volume layer supports a routine called volmksafe(). This routine writes ANSI trailer labels and file marks for the currently open file, but repositions the tape prior to the file mark preceding the labels. If a run is paused, the tape program invokes this function to temporarily close the file. When a run ends, the tape program closes the file.

The tape program periodically senses the number of bytes remaining on the cartridge. When the cartridge gets close to the end, messages are issued warning the user that there is a limited amount of tape left. If the tape becomes nearly full, the tape program will automatically end the run preventing runs from spanning tape boundaries.

How things worked out

We have had several 8mm drives at our disposal now for about a year. The front end taping process has been running for about seven months. This section describes how happy we are with these drives and the software we have written in this time period.

The user reaction to 8mm drives is rather interesting. Everybody seems to love them, but observations indicate that this is really more a love-hate relationship. People are pleased with the capacity and compactness. It is much easier to manage an experiment on a few 8mm cartridges than on 50 or 60 9 track tape reels. People don't seem to be too worried about the speed loss.

However, it seems clear that the reliability of the 8mm media is not nearly as good as that of 9 track tapes. Not one experiment has *not* had some problem either recording or reading one or more 8mm event tapes. This includes those tapes that were written by the VMS tape logger. Problems include:

- Unreadable blocks.
- Tapes which became physically damaged by the drive.
- Defects in the cartridge (usually broken reel spools) which prevent cartridges from even being mounted.

It would appear to an objective observer that these problems, taken together with the larger amount of data at risk on a single cartridge, might cause experimenters to reject the use of 8mm equipment. On the contrary, however, experimenters locally are still enthusiastically supporting this technology.

Somehow there is something about 8mm technology, the compactness or the convenience of the media, or possibly just the sense of whizz bang, that makes people more willing to put up with or work around problems that it has. Several workarounds are in fact employed. One typical workaround is to record more than one tape on-line, in the hopes that one of the copies will turn out to be usable. This is frequently done by recording on the front end and also recording on one or more VMS tape loggers simultaneously. There are no systematics to indicate that either VMS tapes are better or worse than front end tapes. There have been requests to support simultaneous recording on multiple front end tape drives. These requests do not involve producing striped tapes to gain speed, but rather mirror tapes to increase redundancy.

It seems clear that 8mm tapes are here to stay. The low media cost and high density offer many advantages. Many institutions in the NSCL user community are already capable of reading 8mm tapes. However while these seem paradoxically not to be concerns for the current users, reliability and low speed continue to worry the computer group at NSCL.

In the intermediate term, Exabyte recently announced the availability of a double density, double speed drive. We have a purchase order out for a pair of these drives and will evaluate them in the coming year. These drives will also be able to read the lower density tapes already in existence and are supposed to be able to write low density tapes as well for compatibility with older drives. We would guess that the speed improvement will be at least as welcome as the additional capacity.

For the long term, we feel that optical media is likely to have a higher reliability. Optical "paper" disks and optical paper tapes offer very high capacity, reasonable speed, and seem like they should offer much better reliability. However until these devices reach the market penetration levels that the 8mm drives have in the nuclear physics community, we are not able to reasonably exploit these options.

References

1. R. Fox, R. Au, A. Vander Molen, B. Pollack, T. Glynn, "Progress on the Data Acquisition System at NSCL", Proceedings of the 4th Conference on Real-Time Computer Applications in Nuclear and Particle Physics, IEEE Trans. on Nucl. Sci. NS-32 No. 4 (1985), p 1286.
2. R. Fox, R. Au, A. Vander Molen, "A Multitasking, Multisinked, Multiprocessor Data Acquisition Front End", Proceedings of the 6th Conference on Real-Time Computer Applications in Nuclear, Particle and Plasma Physics. IEEE Trans. on Nucl. Sci. NS-36 No. 5 (1989), p 1562.
3. American National Standard for information systems – file structure and labeling of magnetic tapes for information interchange (ANSI X3.27-1987), American National Standards Institute, Inc.
4. P. Constanta-Fanourakis, K. Kaczar, G. Oleynik, D. Petravick, M. Votava, V. White, G. Hockney, S. Bracker, J. M. de Miranda, "Exabyte Helical Scan Devices at Fermilab", Proceedings of the 6th Conference on Real-Time Computer Applications in Nuclear, Particle and Plasma Physics. IEEE Trans on Nucl. Sci. NS-36 No. 5 (1989), p 1696.