NRL Memorandum Report 2103

Report of Cyclotron Operation 1 July - 31 December 1969

CYCLOTRON STAFF

Cyclotron Branch
Nuclear Physics Division

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NAVAL RESEARCH LABORATORY
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ABSTRACT

The various research programs using positive ion beams of the NRL Sector-Focusing Cyclotron are briefly described, together with facility development and operations for the period 1 July - 31 December 1969. These various experimental programs progressed to the point of presentations at scientific meetings and initial publications. During this reporting period the first major shutdown for engineering improvements was scheduled.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem H01-23

Project RR 002-06-41--5008

Report of Cyclotron Operation

1 July - 31 December 1969

I. INTRODUCTION

This memorandum report is the continuation of a series of semi-annual reports covering the operation and use of the NRL Cyclotron. The intent of these reports is to identify the active experimental programs with a brief statement of problem status - the detailed results are presented in the scientific literature. Facility improvements, which include modifications for optimizing the operational characteristics of the cyclotron as well as additions to the overall experimental capability, are also discussed. The use of the cyclotron by the various experimental groups, together with the operational efficiency, are covered in the last section.

The organizational arrangement of the Cyclotron Branch as of 31 December 1969, is as follows.

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II. RESEARCH PROGRAM

The introductory paragraph of the National Academy of Sciences Report on the "Developments in Nuclear Physics" states: "The recent history of nuclear physics exhibits a surprising number of significant and in many cases unanticipated developments. There has been steady progress on many fronts. New and unforeseen forms of nuclear motion and interaction have been observed, old concepts have been shown to require important revisions, and new horizons have been viewed. In retrospect many of these advances can be ascribed to a revolution in the technology of experimental nuclear physics, e.g., in accelerator design and performance, in new detectors, and in the more sophisticated use of computers for data acquisition, evaluation, and interpretation as well as for the exploration of the consequences of theoretical hypotheses." The NRL Cyclotron Facility is in the forefront of this . . . "revolution in the technology of experimental nuclear physics." The specific experimental programs are chiefly concerned with the investigation of nuclear structure and nuclear reaction mechanisms in order that the experimentalists may test existing models and theories, and provide new data for further development.

A. Neutron Particle Correlation Studies

(R. B. Theus, E. L. Petersen, R. O. Bondelid, A. G. Pieper, R. G. Allas and C. M. Davisson)

Objective: To examine reaction mechanisms and nuclear

structure of light nuclei using neutron particle correlation techniques. To investigate the limit of applicability of the impulse approximation to quasi-elastic proton-neutron scattering in light nuclei, and to investigate the mechanisms of proton-induced deuteron breakup.

Approach: Neutron-proton correlation spectra are obtained using the associated charged particle time-of-flight technique. Two-parameter data analysis affords a kinematically complete measurement for the three-body final state.

Progress: The energy variation of quasi-free scattering in the D(p,pn)p reaction has been studied between 15 and 50 MeV. These results have been reported at the Boulder Meeting of the APS, and also have been accepted for publication in Physics Letters. A neutron reaction scattering chamber has been installed and data obtained at 24 MeV on the correlation spectra of the D(p,pn)p reaction as the detectors are moved away from the quasi-free scattering angles.

B. (^{3}He,n) Reaction

(R. O. Bondelid, G. A. Herling,* E. L. Petersen, A. G. Pieper and C. M. Davisson)

Objective: To study nuclear structure of residual nuclei by observation of spectra and angular distribution of high energy neutrons. To develop a neutron time-of-flight capability

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*Nuclear Physics Division, Theory Branch

for general neutron spectroscopy.

Approach: The shell model with j-j coupling and residual interaction derived from the Hamada-Johnston potential has been used to predict the two-particle structure and spectrum of ^{210}Po. The two-nucleon transfer reaction provides a sensitive test of the wave function thus obtained. Neutron time-of-flight techniques and subnanosecond electronics will be used.

Progress: The neutron reaction chamber has been installed and a 50-ohm passing horn has been designed so that time signals can be derived from the beam bursts. Neutron detectors and appropriate electronics have been acquired and are being prepared for installation.

C. Doppler-Shift Attenuation Measurements

(C. R. Gossett, L. A. Beach, P. A. Treado, J. M. Lambert, J. J. Kolata and C. M. Davisson)

Objective: Measure lifetimes of nuclear excited states in the range of 10^{-12} to 10^{-14} seconds by means of the Doppler-Shift Attenuation technique for comparison with the predictions of nuclear models.

Approach: Moderate energy beams of protons or alpha particles from the cyclotron are passed through selected target materials to induce inelastic scattering reactions which excite the states of interest and impart sufficient momentum for Doppler-Shift measurement. The shift in energy of the resultant gamma rays detected in coincidence with the inelastically scat-

tered particles is determined for comparison with theoretical predictions yielding the lifetimes.

Progress: Experimental difficulties uncovered in the analysis of data for proton inelastic scattering from ^{24}Mg have been resolved. A discrepancy in earlier proton results compared with alpha-particle scattering results has been resolved and satisfactory agreement reached. Analysis of all ^{24}Mg data continues in preparation for publication. A preliminary run has been made using proton scattering from ^{64}Zn; additional runs will be necessary on this nuclide. The possibility of utilizing particle identification to allow study of nuclear states other than in the target nucleus by other reaction types is under consideration.

D. J-Dependence Studies

(L. S. August, P. Shapiro, L. R. Cooper,* and J. J. Kolata)

Objective: To study the reliability of J dependence in (α,p) reactions as a spectroscopic tool. After the range of applicability is established, J dependence will be used to determine, where possible, the spins of previously uninvestigated states. DWBA calculations are to be made concurrently with the experimental work in order to gain greater insight into the fundamental nature of the mechanism leading to J dependence.

Approach: Proton angular distributions of known states

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from the reactions $^{58}Ni(\alpha,p)^{61}Cu$, $^{60}Ni(\alpha,p)^{63}Cu$, and $^{28}Si(\alpha,p)^{31}p$ have been studied for J-dependent effects at incident alpha energies of 30 MeV and 40 MeV. Strong J dependence was observed for the Ni reactions at 30 MeV, whereas essentially no J dependence was found for the Si reaction at either 30 MeV or 40 MeV.

Progress: During this reporting period the above mentioned results were published in Physical Review Letters. Also, additional DWBA calculations were made that took into account finite range and nonlocality effects. Two $^{28}Si(\alpha,p)^{31}P$ experiments are scheduled to be run at lower alpha energies.

E. Rotational States, (α,xn)

(P. P. Singh,* G. T. Emery,* L. A. Beach and C. R. Gossett)

Objective: To determine experimentally the variations as a function of neutron number in electromagnetic de-excitations of collective states produced by (α,xn) reactions on odd A nuclei in the highly deformed region. These results will be compared with theoretical calculations considering the changing number of neutrons in the deformed potential.

Approach: Excited states of high angular momentum easily excited by alpha particle bombardment of deformed nuclei decay by cascade gamma-ray emission through collective states. These

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*Indiana University, Bloomington, Indiana. (P. P. Singh is full time WAE during summer months.)

gamma rays will be observed in singles and in coincidence by Ge(Li) and NaI(Tℓ) detectors.

Progress: Gamma rays from the (α,xn) reactions on ^{181}Ta, ^{175}Lu, ^{169}Tm, ^{165}Ho and ^{159}Tb were observed using a Ge(Li) detector with 3-keV resolution. Over 500 gamma ray-transitions have been assigned to product nuclei from their intensity variations as a function of incident alpha energies ranging from 25 - 63 MeV. For odd Z, even N nuclei produced by the (α,2n) and (α,4n) reactions on each target, many of the most intense gamma rays have been tentatively assigned to rotational bands built upon the ground states and other low-lying intrinsic levels. These assignments are consistent with levels in neighboring nuclei established by radioactive decay studies. Although many gamma rays have been assigned to odd-odd product nuclei, coincident data is required before any meaningful decay schemes can be proposed for these nuclei.

F. Charged Particle Correlation

(J. M. Lambert, P. A. Treado, R. B. Theus, L. A. Beach, E. L. Petersen and R. J. Kane)

Objective: Study nuclear reactions involving three or more particles in the final state. Investigate decay modes of these breakups, looking for possible simultaneous reactions, but concentrating on sequential decay systems. Study properties of sequential decay states with short lifetimes ($< 10^{-12}$ sec.) to obtain spectroscopic information (spin, parity, isospin, level

width, etc.) Also study reaction mechanisms in terms of DWBA, clustering, and direct interactions. Look for competition of different decay modes, and in particular, look at sequential decay versus quasi-elastic processes. Perform angular correlation of decay products, both in and out of the reaction plane.

Approach: Fast-slow coincidence techniques are used in conjunction with particle identification to specify completely the breakup mode being observed. Outputs of two detectors are used for a two-parameter analysis system utilizing dual ADC's and an on-line computer, with gating requirements set by coincidence, particle identification, and particle energy requirements. Data are collected on magnetic tape for full resolution analysis, and displayed on an oscilloscope screen for preliminary identification.

Progress: Study of the $^{7}Li(\alpha,t)^{8}Be$ reaction has produced identification and angular correlation measurements for states in ^{8}Be corresponding to excitation energies of 0, 2.9, 11.4, 16.6 - 16.9, and 19.9 MeV. In addition, two states of ^{7}Li corresponding to excitation energies of 4.63 and 7.48 MeV have been identified, confirming the alpha plus triton decay mode for these states. More recent experiments have been performed to investigate the quasi-elastic scattering of alphas on ^{6}Li and ^{7}Li for comparison of the quasi-elastic versus sequential cross sections for these nuclei. These experiments have been extended

to study all of the possible quasi-elastic scattering cross sections of alphas on ^{6}Li, that is $(\alpha,\alpha\alpha)$, $(\alpha,\alpha^{3}He)$, $(\alpha,\alpha t)$, $(\alpha,\alpha d)$ and $(\alpha,\alpha p)$. Preliminary results have been obtained, and analysis is in progress.

G. Polarization Measurements

(C. D. Bond, W. I. McGarry, L. S. August and P. Shapiro)

Objective: The objective is to measure the energy and angular dependence of the polarization which results from nuclear reactions and elastic scattering. These polarization measurements, together with the corresponding differential cross section measurements, are to be correlated with existing model theories and reaction mechanisms.

Approach: The polarization measurements are carried out using double scattering in the 30-inch scattering chamber. This procedure is quite effective for making polarization measurements which are not in competition with the more efficient polarized ion source work with $^{1}H^{+}$ and $^{2}D^{+}$. However, the double scattering technique remains an effective tool for such interactions as $^{12}C(^{3}He,^{3}He)^{12}C$, which is essentially unexplored in the 20 to 90 MeV region, and stripping reactions such as $X(d,p)Y$ and $X(^{3}He,p)Y$.

Progress: A preliminary polarization measurement with 30 MeV ^{3}He ions was carried out on the week of 17 November 1969. Satisfactory procedures for collecting and handling the data were established. Alpha particles of 30 MeV were also double

scattered in order to measure directly the system effectiveness in eliminating instrumental asymmetries. A special procedure was also developed to conveniently produce thermally rugged self-supporting carbon foils in the difficult 1 to 20 mg/cm^2 range. Development of the ^{3}He gas recovery system is in progress. A paper describing this system is in preparation and will be submitted to Nuclear Instruments and Methods.

H. Two-Particle Transfer Reactions

(J. J. Kolata, P. Shapiro and L. S. August)

Objective: To develop and implement an experimental method for investigating nuclear structure by means of two-particle transfer reactions such as the $(p,^3He)$ and (d,α) reactions and their inverses, and the (p,t) reaction. Special attention is to be paid to related states in different nuclei, such as the isobaric analog states and the "configuration" states.

Approach: Reaction data obtained using ion beams from the sector-focusing cyclotron and 30-inch scattering chamber are to be analyzed on the basis of current theoretical models, particularly the microscopic model of two-particle transfer reactions in the context of the distorted-wave Born approximation.

Progress: Data have been obtained for the $(p,^3He)$ and (d,α) reactions on ^{209}Bi. The $(p,^3He)$ results were presented at the Boulder, Colorado Meeting of the Nuclear Physics Division of the American Physical Society. A paper is currently being prepared to be submitted for publication.

^{42}Ca targets have been obtained during this period in preparation for the next experiment, which will be an investigation of the (p,t) and (p,^{3}He) reactions on ^{42}Ca to states in ^{40}Ca and ^{40}K.

I. Alpha-Induced Fission of Light Nuclei

(P. P. Singh,* D. A. Sink* and J. J. Kolata)

Objective: To study the production of "heavy-ions" $Z > 2$ and $(A > 4)$ in alpha-particle induced reactions on light nuclei $(A \leq 40)$. Interesting possibilities exist in this experiment for the investigation of: (1) competing fission reactions, (2) symmetrical breakup vs. asymmetrical breakup, (3) "clustering" inside nuclei, and (4) reaction mechanisms for related heavy-ion scattering.

Approach: Coincidence is required between events in two detectors situated at the appropriate kinematic angles for the two-body breakup under consideration. These detectors are quite thin to help discriminate against events involving the hydrogen or helium isotopes. It is expected that multiple-detector arrays will be used to increase data collection efficiency, and that charged particle time-of-flight techniques will be used to further define the reactions of interest.

Progress: One preliminary run was made to investigate the heavy-ion production from 40-MeV alpha particles incident on

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isotopically separated targets of ^{28}Si, ^{30}Si, ^{24}Mg, and ^{26}Mg. The following reactions were definitely observed:

$$^{24}Mg + \alpha \rightarrow \begin{cases} ^{12}C + ^{16}O \\ ^{14}N + ^{14}N \end{cases}$$

$$^{26}Mg + \alpha \rightarrow \begin{cases} ^{14}C + ^{16}O \\ ^{12}C + ^{18}O \end{cases}$$

$$^{30}Si + \alpha \rightarrow \begin{cases} ^{16}O + ^{18}O \\ ^{10}Be + ^{24}Mg \end{cases}$$

Several other final-state products were tentatively indentified, including reactions in which one of the final-state products is in an excited state. Note that no appreciable heavy-ion production was found for the ^{28}Si target. More data must be taken before reasonable results can be quoted.

J. Neutron Effects on Metal-Oxide-Silicon Chips

(P. M. Zeitzoff and H. L. Hughes*)

Objective: Bombard various metal-oxide-silicon (MOS) chips with a 2- 25-MeV neutron beam. Determine the threshold level of neutron dose for significant changes in the electronic properties of the chips. Investigate the density and properties of trap states produced in the silicon-silicon dioxide interface, and the

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*Electronics Division, Solid State Electronics Branch

density of ions produced in the oxide; these trap states and ions are the agents producing the changes in electronic properties.

Approach: A thick beryllium target was bombarded with 25-MeV deuterons, and the resultant neutrons impinged upon the MOS samples. The neutron dosage was measured by activation detectors consisting of wires made of either nickel, aluminum, titanium, copper or iron. The electronic properties of the chips were measured before and after the bombarding.

Progress: We had a total dosage of about 4.5×10^{12} neutrons/cm^2, but we had very little change in the electronic properties of the chips. Thus, the threshold for such changes (for 2- 25-MeV neutrons) is greater than 4.5×10^{12} neutrons/cm^2. In the future we hope to bombard similar targets with a higher total neutron dose.

III. FACILITY DEVELOPMENT

The cyclotron facility is under constant development. In most cases development is in parallel with operation of the cyclotron. However, major changes may require shut-down of the cyclotron for these modifications to be effected. Such an engineering period was scheduled during September and October of this reporting period. The major changes are reported under separate headings.

A. Beam-Emittance Measurements

(J. J. Kolata and R. E. Surratt)

Objective: To develop the hardware and software for a computer-controlled rapid emittance measuring device which can be operated at a rate of approximately one measurement per second.

Approach: The time-correlated current signal from a wire scanner sweeping across the beam at a rate of 1800 rpm is superimposed on a constant "zero-offset" signal. The resulting signal is sampled by a linear gate driven by a chopping oscillator, and the output pulses are analyzed by a Nuclear Data ADC. The resulting time-correlated data points are sequentially stored in a matrix in the EMR-6050 computer. Alternate scans are taken with the beam on and with the beam cut off by a computer-driven beam stop to enable digital subtraction of the "zero-offset" signal, which is originally introduced to preserve the time-correlation when the scanner signal itself is too small

to trigger the ADC.

Progress: This system has been installed and is working properly. Beam scans are made with a standard emittance grid in place in the beam tube. The resulting pattern of peaks is analyzed by the associated software to obtain the beam emittance and the position of the virtual source. The operation of this program is controlled by remote switches on the cyclotron conscle. Provisions are also made for the readout of emittance and the flagging of various error conditions at the console; in addition a hard-copy is output on the line printer. A complete report of this system is currently being prepared for submission to Nuclear Instruments and Methods. A paper describing the wire scanner is also under preparation for submission to the same journal.

B. ND-120 Memory Dump

(R. E. Surratt and J. J. Kolata)

Objective: To develop and implement a means of rapidly transferring the information contained in the memory of a ND-120 (512 channels) analyzer into the EMR-6050 computer.

Approach: The binary-coded decimal (BCD) serial output of the analyzer and its accompanying channel-strobe signal were interfaced to be compatible with the external sense lines available in the EMR-6050 computer. (Four data lines and one strobe line were required.) In this way, each successive digit of the analyzer memory is read out. After six strobes, the

digits are assembled into a word which is stored in memory. The analyzer then produces two additional strobes to indicate "SPACE" and "CARRIAGE-RETURN," which the program ignores. After eight words are processed, the analyzer produces an extra word containing all zeros which is a delay for completion of the carriage reutrn. This word is ignored. The total number of strobes is counted to assure that memory has been properly transferred.

Progress: The system is installed and is working very successfully. The time required for a memory dump is one second, compared to eight minutes for typewriter output and 1.5 minutes for paper tape output. The resulting saving in time has encouraged various experimental groups to use this analyzer, which was previously being ignored. For this reason, provision was made to start, stop, and erase the analyzer under computer control, and the required programs are now a part of the SOPHYA system. It is expected that all in-house analyzers will eventually be interfaced in this manner.

C. A Fault Annunciator System

(R. E. Surratt and S. E. Gordon)

Objective: To design and construct a device capable of detecting and recording the failure or abnormal condition of cyclotron equipment.

Approach: The cyclotron system has a large number of error detectors on the various magnet power supplies, R. F.

system, etc. which shut down the equipment under abnormal conditions. Much of the equipment is interlocked so that the failure of one device inhibits the operation of other equipment resulting in cyclotron shutdown. Some error conditions such as an overtemperature indication on one of the magnets may correct itself by cooling off after shutting down the magnet power supply. This may happen before the operator can determine the sensor causing the fault condition. Therefore, a device was needed which could detect and store the location of a large number of possible faults. Two basic types of error conditions exist on the cyclotron equipment. One is assigned as priority faults, errors which must be corrected to continue cyclotron operation. An example of this type is an over temperature indication on one of the magnet coils. The other is non-priority faults, such as the failure of a mechanical vacuum pump which may be bypassed and operation continued. Under these conditions it was decided to utilize logic design techniques and build a solid state electronic scanner, which accepts a standardized input as a fault indication on any of 200 coded inputs or channels, and then display a number identifying the device which presented the fault. One-hundred channels were assigned as priority inputs. An annunciation from one of these channels cannot be cleared until the fault is corrected. The other 100 channels are non-priority inputs and the annunciation may be cleared with the fault present, but the number of the

channel is displayed until the fault is corrected.

Progress: A fixed-program computer was designed and constructed which sequentially scans 200 channels at a 1 MHz rate. Any device having a fault indication may be assigned to one of these channels. When the device presents a fault to the annunciator, the channel number of the device is stored in a memory unit displayed to the operator by nixie tube readout and begins an audible annunciation. Two priority channels (and up to six non-priority channels) may be displayed simultaneously. The device is operating and the cyclotron equipment is now being coupled to the annunciator system.

D. Computer Controlled Pulsing of the Cyclotron Beam

Experimenters desired to pulse the accelerated particle beam on and off at a duty cycle and repetition rate determined and controlled by the EMR 6050 computer. This "pulsing" was obtained by first adjusting the cyclotron parameters for acceleration and extraction of the desired beam with normal R. F. voltage on the dee. Then, when the beam "off" state was desired the R. F. dee voltage was lowered to approximately 50% of its normal value which is less than the threshold voltage. This change of dee R. F. voltage was accomplished by changing the d.c. reference voltage fed into the dee R. F. voltmeter which is in the dee voltage regulator loop. The lower magnitude of dee voltage was chosen sufficiently high to maintain proper operation of the automatic tuning circuitry and the dee voltage regulation

equipment. The computer supplied either a "short" or an "open" signal across a resistor in a dividor network to change the level of the dee d.c. reference voltage.

E. R. F. System

During this reporting period modifications were designed and implemented on the cyclotron R. F. system to increase system reliability and decrease undesired modulation of the dee accelerating voltage. These modifications include a D.C. power supply with polarity reversal provisions for the filament of the 6949V1 power amplifier tube. Additional protective circuitry was also provided for the 6949V1 filament so that if the filament current even momentarily drops below predetermined value, the filament voltage is immediately removed. The filament voltage of the 6949V1 must be raised slowly from zero to the normal operating value to prevent filament current from exceeding a value of 1,700 amperes, even momentarily. Thus, this protective circuitry is of great importance in preventing damage to the 6949V1 tube by the application of normal filament voltage to a cold filament caused by an intermittent tube socket connection.

The four PAA tuning capacitors are now coupled together by a heavy-duty chain driven by a single large servo motor with one translator. No trouble has been experienced since this modification. Formerly, each of the four capacitors was driven by its separate servo motor with a pair of servo motors being fed by one of the two translators. This had resulted in

capacitors being driven to unequal capacities upon the loss of a signal from a translator for any of several reasons. This then necessitated the removal of the capacitors to reset them for equal capacity tracking which is required for equal sharing of the RF current and for maximum tuning range.

Changes in the cooling water path for the 6949V1 anode increased the flow rate sufficiently that the allowable anode dissipation was doubled. This increased anode dissipation permits operation with higher dee voltages at the higher frequencies with a margin of safety for detuning of the anode circuit.

The output voltage of the radiofrequency oscillator for the cyclotron proved to vary with frequency and to contain undesired frequency components. At some particular operating frequencies, the undesired frequencies appeared as modulation of the dee voltage and could not be eliminated. These problems were solved by replacing the oscillator with a frequency synthesizer. In addition, the frequency synthesizer has a larger output voltage.

During the past year the R. F. system was in operation at over fifty frequencies, ranging from 7.4002 MHz to 21.0784 MHz for beam acceleration.

The modulation on the dee voltage, defined as the peak-to-peak ripple riding on the RF voltage as a percentage of the peak RF value, has recently been reduced to about 0.5% from 1.5%. Work continues to reduce further this dee voltage modulation.

F. Ion Source Mechanism

The Buna N, chevron shaped vacuum seals between the cyclotron accelerator tank and the radial and azimuthal drive mechanisms, integral in the ion source assembly, were unreliable and displayed a short life expectancy. To improve seal reliability the ion source assembly was removed from the cyclotron, cleaned, thoroughly inspected, and reinstalled with two newly designed vacuum seal units. The seal units consist of two 1/4-inch cross section O-rings mounted in polished, close toleranced, machined aluminum adapter rings, which were correctly fitted in the drive mechanism housings for maximum sealing performance.

In addition to replacing seals, a design-modified filament and anode housing incorporating an enlarged filament well with greater cooling effect was assembled on the lower end of the ion source filament power housing. The water cooled filament power leads at the upper end of the housing were reshaped for added rigidity, and redesigned for acceptance of demineralized-water quick-connector devices.

After reinstallation of the ion source assembly into the cyclotron, the ion discharge aperture (0.09" x 0.50") was optically aligned with respect to the median plane of the cyclotron magnetic field and the electric field of the dee.

G. Iron Channel

Approximately 60% of the circulating beam was lost when

extracted through the iron channel. Remote instrumentation indicated that the vertical copper walls inside the iron channel were collapsing when the inner coil of the channel was energized with current in excess of 2000 amperes.

To prevent future collapsing, which caused narrowing of the ion beam extraction channel, two NEMA Grade G-10 glass epoxy laminated rigid structural members, 1/4-inch thick and contoured to fit snugly the upper and lower inner channel wall configuration, were firmly fitted into the iron channel. Subsequent physical measurements after installation of the glass-epoxy, with the coils energized to 3500 amperes, revealed a negligible deflection of the inner walls (about 0.002 inch) which eliminated the possibility of future collapse since the induced bending stresses in the walls were well below the 2% elongation elastic limit of copper.

There were three additional design changes made in the iron channel to enhance the ease and extend the range of its remote positioning capability. The changes made were: (1) the replacement of bushings with ball bearings in the entrance and exit drive mechanism of the channel; (2) the relocation of the positioning drive motors from their former mounting on the cyclotron accelerator tank wall (approximately 50 inches from the ion source and in the median plane) to their present location on the outer main magnet wall (approximately 80 inches from the ion source) where the adverse effects of the magnetic field on the motors

is greatly diminished (also the positioning sensors and transducers are now more readily accessible for maintenance); and (3) the replacement of iron channel power leads and water lines to facilitate the increased travel capability of the iron channel. In addition, two copper, power junction blocks were designed, fabricated and installed on the iron channel assembly to facilitate relocating the drive linkage.

H. Analyzing Magnet

The rectangular cross-section neoprene gaskets, used to seal the vacuum tank of the 135°, 9-foot radius analyzing magnet, were leaking through their butt joints such that a vacuum below 1 x 10^{-4} torr in the vacuum tank was unattainable. To replace the gaskets required raising the upper 40-ton magnet pole half, after application of rigid constraining forces to the radially shaped sides of the vacuum tank. After disassembly and removal of the damaged gaskets and before reassembly, the end plates of the vacuum tank were modified so that in the future access to the gasket butt will not require disassembly of the magnet pole halves.

While the magnet was disassembled a port was machined in the 1-inch thick aluminum vacuum tank end plate to permit installation of an automatic tracking NMR fluxmeter probe.

The end plate additionally serves to support the remote controlled, single action, electro-pneumatically operated vacuum couplings, which disconnect the 8-inch entrance and exit beam lines from the analyzing magnet assembly. The remote disconnect

feature is utilized when switching the position of the analyzing magnet to accommodate experiments in different rooms. The single action serves to disconnect the vacuum coupling, and a compression spring reunites it. However, the vacuum sealing is dependent on the force derived from atmospheric pressure acting over the flange area inside the perimeter of the O-ring seals. To assure more positive sealing at the joint a larger diameter O-ring groove was machined in the flange to increase the pressure area by 20%.

I. Demineralized Water System

The closed-loop demineralized H_2O plumbing for the many magnet coils and various R. F. components in the cyclotron vault consisted of one 6-inch low pressure (150 psi) supply header, one 4-inch high pressure (250 psi) supply header, but only one 6-inch return pipe. That piping arrangement induced impedance in the H_2O system to such extent that it was not possible to achieve the rate of water flow required to cool sufficiently the 6949V1 power tube in the R. F. system for the high plate dissipations required at high dee voltages at the upper frequencies of operation. In order to achieve high dee voltage, we increased the flow rate to the 6949 tube plates from 42 gpm to 60 gpm by the addition of a 4-inch return pipe to separate the high pressure and low pressure water loops inside the vault. Moreover, the plumbing to the 6949V1 tube was re-engineered and modified in a manner which deleted fluid friction due to approximately 200

feet of equivalent straight pipe.

In an attempt to decrease future outages due to water pump failure, the mechanical and structural installation of a standby 200HP, 1400 gpm, 150 psi, demineralized water pump was completed with associated plumbing that places it in a parallel loop with the existing low pressure demineralized pump.

J. Cyclotron General

The trim coil pancake bolts were checked for tightness and found to be adequate.

The carbon septum of the electrostatic deflector and demineralized water-cooled copper tubular power leads were removed and replaced.

The physical locations of the electrostatic deflector, the coaxial magnetic channel and the iron channel were calibrated to within 0.010 inches of their respective meter readouts in the control room.

The warped, untempered, low carbon steel tracks supporting the R. F. resonator housing were removed and replaced with hardened, stainless steel guide rolls which eliminated friction losses that had prevented fully automatic transport of the tank on its rails.

The dee-shorting-plane limit stops were modified and redesigned to prevent back-lash between the position potentiometers, and a visual position indicator was designed and

installed on the dee shorting plane drive unit.

A shorting plane power screw and its driven nut assembly were redesigned to eliminate binding due to misalignment of a support yoke that apparently underwent stress relief after initial assembly. The 12'-long, 1-12 NS acme screw thread was rechased and its mating nut was remade with more threads to reduce the stress per thread and thereby decrease wear.

The shorting-plane-shoe vacuum pump was mounted directly to the shorting plane drive structure eliminating the possibility of the electrical leads of the pump being fouled on the resonator tank tracks.

A thicker, light-tight, low electrical resistance copper grounding ring was installed between the R. F. drive line capacitor housing and the PA housing.

An ionization vacuum gauge tube was installed in the R. F. drive line capacitor house, and another mounted on the cyclotron accelerator tank in the near vicinity of the leading edge of the dee.

K. Beam Path Wiring

A switching magnet for Room 3 is under procurement; consequently, our efforts were concentrated in providing wiring primarily for Room 3. The 500-MCM cables for the switching magnet were pulled between the vault and the equipment room where the power supply will be located.

In Room 3 both control and signal cabling were provided

for all five (A to E) beam lines. Junction boxes were installed for beam lines A and E, and both ends of the control wires were terminated. Each beam line requires AC power. A balanced distribution of available power in Room 3 was arrived at and A.C. power has been brought into each junction box.

In addition to existing (500 MCM) cables for quadrupoles, provision was made for using another doublet to extend beam lines if desired. All the heavy cables from six power supplies (for three doublets) are terminated on a large switch board in Room 3. From this switch board, by properly energizing a series of heavy duty contactors, D.C. power for three doublets can be provided on any one of three beam paths (A, C, E).

Work was initiated for a second beam line installation in Room 2 by providing control, signal, and 500-MCM cables.

IV. CYCLOTRON OPERATIONS: 1 July to 31 December 1969

		Hours	Hours	Percent of Scheduled Time
A.	OPERATING TIME			
	Beam on Target	518.7		
	Beam Adjustment	56.0		
	Target Set Up	147.2		
	Total Experimental Time	721.9		
	Cyclotron Development	109.4		
	Total Operating Time	831.3	831.3	60.1
B.	OUTAGE, hours			
	Beam Tuning	55.0		4.0
	Start Up and Shutdown	77.5		5.6
	Source and Filament Change	13.5		1.0
	Vacuum	128.6		9.3
	R. F.	22.1		1.6
	Power Supply	140.4		10.2
	Electrical	45.9		3.3
	Mechanical	37.5		2.7
	Scheduled Maintenance	24.0		1.7
	Miscellaneous	6.7		.5
	Outage Total	551.2	551.2	39.9
	Scheduled Operating Time		1382.5	
C.	ENGINEERING SHUTDOWN	360.0	360.0	

D. EXPERIMENTAL TIME: 1 July to 31 December 1969	Hours
Neutron Particle Correlation Studies	137.8
Doppler-Shift Attenuation Measurements	141.3
J-Dependence Studies	3.3
Rotational States, (α,xn)	127.3
Charged Particle Correlation	85.7
Polarization Measurements	37.7
Two-Particle Transfer Reactions	56.5
Alpha-Induced Fission of Light Nuclei	40.3
Neutron Effects on Metal-Oxide-Silicon Chips	21.6
$^{16}O + \alpha$ Breakup Modes	18.6
Material Analysis	28.7
	698.8
NASA	23.1
	721.9

V. PUBLICATIONS

A. Articles

E. L. Petersen, R. G. Allas, R. O. Bondelid, A. G. Pieper and R. B. Theus, "Quasi-Free Scattering in the D(p,pn)p Reaction from 15 to 50 MeV," to be published in Physics Letters.

E. L. Petersen, R. O. Bondelid, P. Tomas, G. Paic, J. R. Richardson and J. W. Verba, "The Study of the Reaction D(p,pn)p at 46 MeV In and Out of the Scattering Plane," to be published.

B. E. Corey, E. L. Petersen, R. E. Warner, R. W. Bercaw and J. E. Poth, "The p-p Final-State Interation in the Reaction ^{3}He(d,tp)p," to be published in Physical Review Letters.

J. A. Eisele and R. E. Larson, "Gamma Rays from the Decay of ^{44}Sc, ^{44m}Sc and ^{48}Sc and Energy Levels in ^{44}Ca and ^{48}Ti," to be published in Radiochimica Acta.

J. A. Eisele, R. E. Larson and P. E. Wilkniss, "Oceanographic Investigations Using a Sector-Focused Cyclotron," to be published in International Journal of Applied Radioactivity and Isotopes.

C. L. Tipton, J. J. Bagley, J. A. Eisele, J. M. Krafft, I. M. Leising, L. B. Lockhart and J. A. Reynolds, "Anticompromise Emergency Destruct Systems, Capabilities and Requirements " (U) Published by NRL,

Code 2040, 31 October 1969.

John A. Eisele, "A Blueprint for Space," Brochure printed by NRL, 12 November 1969.

B. Books

John A. Eisele, "Modern Quantum Mechanics with Applications to Elementary Particle Physics," John Wiley and Sons, Inc. (1969)

C. Abstracts

J. J. Kolata, P. Shapiro and L. S. August, "$^{209}Bi(p,^{3}He)^{207}Pb$ Reaction at 40 MeV," APS Meeting, Boulder, Colorado, 30 October - 1 November 1969; Bull. Am. Phys. Soc. Series II, 14, No. 12, 1228 (1969).

E. L. Petersen, R. O. Bondelid, A. G. Pieper, R. B. Theus and R. G. Allas, "Study of the Energy Dependence of the p-n Quasi-Free Scattering in the Reaction D(p,pn)p," APS Meeting, Boulder, Colorado, 30 October - 1 November 1969; Bull. Am. Phys. Soc. Series II, 14, No. 12, 1212 (1969).

D. Talks

John A. Eisele, "Blueprint for Space," Springfield High School, Springfield, Virginia, 12 November 1969.

J. J. Kolata, "$^{209}Bi(p,^{3}He)^{207}Pb$ Reaction at 40 MeV," Nuclear Physics Seminar, University of Indiana, Bloomington, Indiana, 3 November 1969.

John A. Eisele, "Introduction to Rockets, Satellites,

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and Space Travel," (Seminar Session I) - 11 October 1969, 9:00 a.m.; 13 October 1969, 7:30 p.m. The Twelfth Annual Seminar for Teachers of Science and Mathematics - Autumn Seminars 1969 - 1970 (NRL).

John A. Eisele, "Introduction to the Theory of Orbital Dynamics," Physics Journal Club, University of Maryland, College Park, Maryland, 18 September 1969.

E. Formal Reports

None

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13. ABSTRACT

The various research programs using positive ion beams of the NRL Sector-Focusing Cyclotron are briefly described, together with facility development and operations for the period 1 July - 31 December 1969. These various experimental programs progressed to the point of presentations at scientific meetings and initial publications. During this reporting period the first major shutdown for engineering improvements was scheduled.

14 KEY WORDS	LINK A		LINK B		LINK C	
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Cyclotron						
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Alpha particle scattering						
Ion beams						
Irradiation						