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PROGRESS REPORT
TO
THE UNITED STATES ATOMIC ENERGY COMMISSION
CONTRACT AT(30-1)910
BIOLOGICAL EFFECTS OF RADIATION AND RELATED BIOCHEMICAL
AND PHYSICAL STUDIES

Proposal #4: Cyclotron Facility and Radionuclide Production
Contract Period: January 1, 1971 - December 31, 1971
Report Period: May 1, 1970 - May 1, 1971
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Section 5509

1. Introduction

The operation of the cyclotron by the cyclotron section (5509) has the following objectives:

- a) Research on nuclear reactions and target design for production of radionuclides.
- b) Research on labeling of biologically important compounds with cyclotron produced radionuclides.
- c) Production of radionuclides and labeled compounds for metabolic isotope research in patients and in animals carried out by the metabolic isotope study section (5507).
- d) Production of neutrons and charged particle radiations for biological and dosimetry research projects carried out by other sections.
- e) Development of improved cyclotron operation and beam handling technology.

2. Summary of Cyclotron Usage

Table 1 gives a summary of the cyclotron use during the period of this report (May 1, 1970 - May 1, 1971).

Ninety-two runs of ^{18}F were made for the clinical investigative program of section 5507 in collaboration with Memorial Hospital, amounting to 4,260 mCi as of 12 noon on the day of production. Included in this were eighty-five shipments of ^{18}F to outside institutions as part of a collaborative research effort.

The ^{52}Fe runs were all for the metabolic isotope studies in patients in section 5507. The ^{11}C runs were for H^{11}CN production as starting material for the synthesis of labeled amino acids by Dr. A. Gelbard in this section (5509). The ^{127}Cs runs were for research and development purposes with some being used in mice for tissue distribution studies by section 5507. A new target chamber has been designed for the irradiation of iodine vapor but has yet to be tested. The ^{30}P and ^{13}N runs were made for metabolic isotope studies by section 5507 which were carried out in collaboration with their consultant, Dr. W.W. Hunter, Visiting Investigator from Ohio State University. These were for the production of phosphine gas, phosphate labeled with ^{30}P , and ammonia labeled with ^{13}N . The neutron rat irradiations were carried out for the biological and clinical dosimetry section (5511) for studies in collaboration with the radiotherapy research section (6303). Their objective is the study of the effect of neutron irradiation on the reproduction cycle of rats and on the production of birth defects over several cycles of reproduction.

Table I
Summary of Cyclotron Usage

<u>Use</u>	<u># Of Production Runs</u>	<u>Beam "ON" Time (Hours)</u>
^{18}F	97	71.2
^{52}Fe	5	25.9
^{11}C	28	27.2
^{127}Cs	10	10.9
^{30}P	14	21.8
^{111}In	7	10.5
^{67}Ga	9	13.8
^{51}Cr	3	8.2
^{52}Mn	1	1.0
^{73}Se	1	1.1
^{167}Tm	2	3.4
^{75}Se	1	1.3
^{15}O	49	78.3
^{123}I	17	16.5
^{13}N	35	42.3
^{43}Sc	4	2.5
Neutron dosimetry	21	44.4
Neutron LET studies	5	19.1
Neutron HeLa cell irradiation	7	37.0
Neutron rat irradiation	6	21.8
Neutron Sea Urchin irradiation mechanism studies	14	13.5
Chemical bonding by characteristic X-ray spectra	4	5.6
Test Runs	10	30.05
Beam Profile Monitor	2	2.0
Scanning Magnet	2	9.0
$\text{H}_2 + \text{O}_2$ Recombination	2	0.4
Area Monitor	1	6.0

Neutron irradiations were also carried out for dosimetry and LET distribution studies by section 5511. Other neutron radiations have been carried out for studies of the oxygen enhancement ratio in HeLa cells for section 5503 and for sea urchin irradiation mechanism studies (section 5502). α -particles are being accelerated for chemical bonding studies by section 5502 utilizing shifts in characteristic X-ray spectra. The ^{15}O runs represent the production of radioactive gases O_2 , CO and CO_2 labeled with ^{15}O for pulmonary function studies on dogs being carried out by sections 5507 and 5613. The ^{167}Tm runs are part of a collaborative effort with Dr. R. Chandra of N.Y.U. Medical Center on the possible usefulness of this radionuclide in bone scanning.

3. Radiochemistry

Only those aspects of radiochemistry associated with the cyclotron project which are considered worthwhile reporting at this time will be discussed here.

a) Fluorine-18

Hydrogen, Oxygen Production - The rate of production of hydrogen and oxygen gas was measured in a fluorine-18 target chamber by measuring the increase in pressure with no $\text{H}_2\text{-O}_2$ recombination catalyst in the catalyst cup. The target chamber was set up, filled with water and then pressure tested with nitrogen by connecting to a cylinder of gas, fitted with a pressure regulator. The overpressure was released and the irradiation started. The beam current was increased slowly until at $5\mu\text{A}$ a pressure rise was noticed. The beam current was then maintained at $5\mu\text{A}$ and the pressure and time noted. The pressure rose monotonically to 10 psig during 11.8 minutes. The beam was then switched off and the leakage rate measured to be 0.0417 psi/min. Thus the corrected rate of pressure rise was 0.89 psi/min at $5\mu\text{A}$. The internal volume of the target catalyst cup, and connecting tubing was then calculated to be 57.3 ml., and so the volume of hydrogen and oxygen produced was calculated to be 3.4 ml/min at $5\mu\text{A}$. From this the G-value for the production of hydrogen from water using 19.7 MeV helium-3 particles was calculated to be 0.35. The volume of water lost by radiolysis during a normal run (40 μA for 1 hour) was calculated to be 0.68 ml., assuming no recombination of hydrogen and oxygen. As a result of this we have stopped using the catalyst pellets with no decrease in yield, and with only a small decrease in volume recovered. We had occasionally found ^{18}F activity on the catalyst pellets, probably due to improper irradiation conditions resulting in local boiling of the water.

Heretofore, ^{18}F was removed from its target chamber by inserting a hand held lead shielded syringe into the solution removal port. This procedure has been eliminated in favor of a rather simple device which automatically withdraws the solution with a minimum risk of radiation exposure to personnel. The device, bolted to the chamber, consists of a small electrically activated rotating

solenoid to which a metallic straight pin has been soldered. Adjacent to this pin is a pinch clamp through which a long piece of plastic tubing has been placed between the removal port and a 10cc flask located within the inner of two concentric pigs. Connection is made at both ends by syringe needles punctured through sealed rubber caps; a vacuum hose also enters the flask via another syringe needle. Before irradiation the pinch clamp is closed to prevent flow. Afterwards however, the solenoid is activated at a distance, the clamp is released, and the solution flows readily into the flask, the whole procedure taking only a few seconds.

b) Carbon-11 Labeled Amino Acids

The synthesis of ^{11}C labeled amino acids requires a rapid procedure for mixing the reactants and separating the reaction products. Although most reports describing the Strecker synthesis of amino acids involve techniques of several days in duration, we have been successful in demonstrating the synthesis and isolation of ^{11}C labeled amino acids within 2 hours.

In our procedure, gas mixtures of 5% hydrogen and 95% nitrogen, which had been passed over a catalyst to combine any O_2 impurities with H_2 , and dried, are bombarded with protons at a current of 10-15 μamps at a temperature of 300°C in a target chamber made of Vycor glass (Figure 1). 50-100 millicuries of H^{11}CN (identified by gas chromatography and by precipitation as silver cyanide) are generated during a typical run. The ^{11}C hydrogen cyanide is bubbled continuously through a solution containing the appropriate aldehyde and ammonia during the period of irradiation (40 minutes).

Millicurie quantities of carrier-free racemic alanine labeled with ^{11}C have been produced by reacting H^{11}CN with acetaldehyde and ammonia and hydrolyzing the resulting aminonitrile with hydrobromic acid. The solution is boiled down to a paste, stirred at -40°C with methyl alcohol and filtered. The filtrate is absorbed onto a Dowex-50 column and labeled alanine is recovered from the column after washing.

The product of the reaction of ^{11}C labeled hydrogen cyanide with acetaldehyde and ammonia could be identified as alanine by its migratory behavior in 3 different solvent systems on thin layer cellulose sheets. An isotonic solution of 0.91 mCi of ^{11}C -labeled D-L alanine was injected into a normal dog and gamma camera pictures were taken. The distribution of ^{11}C -alanine is shown in the scintiphotos in Figure 2. Figure 2A shows a general distribution of radioactivity in the blood with slight visualization of the liver and heart. Figure 2B shows the uniform distribution of radioactivity in the dogs head, and figure 2C shows the accumulation of radioactivity in the urinary bladder due either to the direct excretion of the D-form of alanine ^{11}C or due to decarboxylation of the alanine- ^{11}C leading to ^{11}C -labeled bicarbonate in the urine. Attempts to incorporate ^{11}C labeled alanine into protein in a HeLa cell tissue culture system was unsuccessful.

Fig. 1

Target chamber and apparatus for the production of ^{11}C -labeled hydrogen cyanide.

A

B

C

Fig. 2

Scintiphotos of ^{11}C -labeled alanine in a dog.

Our efforts were next directed towards the rapid synthesis of essential amino acids labeled with ^{11}C . The formation of phenylalanine, valine, leucine and methionine from phenyl acetaldehyde, isobutyraldehyde, isovaleraldehyde and β -methylthiopropionaldehyde respectively were attempted. When millimolar quantities of sodium cyanide are added to the reaction containing either phenylacetaldehyde or isobutyraldehyde, methanolic ammonia and ^{11}C labeled hydrogen cyanide, the rapid synthesis of phenylalanine and valine can be demonstrated. After hydrolysis of the ether-soluble layer of the reaction mixture, a ninhydrin reacting component is found that migrates with the known amino acid in three different solvent systems of thin layer chromatographs. Most of the radioactive label is located with the ninhydrin reacting component. We have had difficulty separating out the labeled valine and phenylalanine from the other components of their reaction mixtures. In the case of valine, the radioactivity is retained on the ion exchange column after known valine is eluted, but comes off the column under the same conditions as the aldehyde and thus may be still associated with the aldehyde. More drastic conditions for hydrolyzing the aminonitrile may be necessary for separating out ^{11}C labeled valine from the mixture. In the preparation of ^{11}C labeled phenylalanine, an emulsion forms after hydrolysis and interferes with passage through the ion exchange column. Further work on the purification of these ^{11}C labeled amino acids as well as the synthesis of other labeled amino acids is currently being carried out.

c) N-13 Labeled Ammonia

^{13}N labeled ammonia has been shown to be a valuable new radiopharmaceutical for scanning the myocardium and for liver function test (1,2). It has been produced previously by irradiating metallic carbides, particularly aluminum carbide, with 7 MeV deuterons, when ^{13}N is produced by (d,n) nuclear reaction on carbon-12. On dissolving the aluminum carbide in either acid or alkali, ammonia labeled with ^{13}N is produced which is recovered by distillation (3). A disadvantage of this method is that ^{28}Al is also produced in the irradiation, which, with its 2.4 minute half-life, and high energy beta and gamma radiation (1.78 MeV) constitutes a considerable radiation hazard in handling and processing the target. About sixteen times as much ^{28}Al is produced as ^{13}N at the end of irradiation.

We have made $^{13}\text{NH}_3$ by irradiating methane gas with 8 MeV deuterons. The target chamber, shown in figure 3, is lined with a pyrex glass tube and the out-gas is bubbled through water or isotonic saline in which the ammonia dissolves. By irradiating at 5 μA for ten minutes, and allowing the methane to flow at 1 cu. ft. per hour for an additional 5 minutes, 20 mCi of $^{13}\text{NH}_3$ activity can be collected in the bubbler. A decay study of the radioactivity in the bubbler showed a pure 10.0 minute half-life from 5 to 95 minutes after the end of irradiation.

Analysis of the solution in the bubbler by radioactive gas chromatography showed that the radioactive products were 95% $^{13}\text{NH}_3$, 4% CH_3NH_2 , 0.2% $\text{C}_2\text{H}_5\text{NH}_2$. Less than 3% HC^{13}N was detected in the solution and no $\text{CH}_3\text{C}^{13}\text{N}$ was detected. No significant differences

in the product composition were found by adding hydrogen gas to the methane in the range 0 to 50% H_2 in CH_4 . No noticeable differences in product composition were noted when methane was irradiated at 5, 1, 0.2 μA of beam current for the same length of time. These results are summarized in Tables II and III.

Gas chromatography using three different column packings was used to analyze the product for both its chemical and radioactive content. A column of Poropak QS (8 ft. x 1/4 in. stainless steel) was used to analyze for NH_3 , H_2O , HCN , CH_3NH_2 , $C_2H_5NH_2$, CH_3CN and $(CH_3)_2NH$. The column was operated isothermally at $70^\circ C$ until the H_2O came off the column and then the temperature was increased to $250^\circ C$ at the rate of $20^\circ C/min.$, and held at $250^\circ C$ for an additional 10 minutes. An example of a chromatogram is shown in figure 4. This shows radioactivity peaks due to NH_3 , and CH_3NH_2 , and thermal conductivity peaks due to NH_3 , H_2O , CH_3NH_2 , $C_2H_5NH_2$ and CH_3CN . HCN elutes at the same position as CH_3NH_2 , so a second column was used to measure radioactive HCN content. This was 30% triacetin on Chromosorb P (10 ft. x 1/4 inch) isothermal at $70^\circ C$. No HCN was detected, and an upper limit for its content was set at 5%. Analysis of the undissolved gas on a 2 ft. column of molecular sieve 5A showed the presence of small amounts (11%) of ^{13}N labeled nitrogen and nitrous oxide but no radioactive methane.

Confirmation of these results was obtained by adding a few drops of the $^{13}NH_3$ -water solution, containing 1 mg of NH_4OH as carrier to an excess of Nessler's reagent, a specific test for ammonia. The characteristic brown precipitate of $Hg_2(NH_2)I_3$ was found, after centrifugation and washing, to contain 95% of the ^{13}N activity. A small amount of ^{13}N labeled cyanide was detected by adding carriers of $NaCN$ and NH_4NO_3 and precipitating silver cyanide from a solution made acid with HNO_3 . The precipitate was centrifuged off, washed with water and redissolved in concentrated ammonium hydroxide solution. Silver cyanide was then reprecipitated by making acid with nitric acid. The $AgCN$ precipitate was found to contain 2.6% of the total activity in the ^{13}N solution.

The presence of a very small amount of methane in the solution was not objectionable, as methane is non-toxic, odorless, and has a low solubility. The methylamine- ^{13}N impurity is present in sufficiently small quantities as to present no interference with the $^{13}NH_3$. Both are carrier free radiochemicals. The aluminum carbide method also produces trace impurities of methylamine.

Two previous papers on the formation of ^{13}N in irradiated methane failed to detect ammonia or amines labeled with ^{13}N (4,5). This was probably because they used metal target chambers and only analyzed the gas phase whilst the $^{13}NH_3$ was deposited or reacted with the walls of the chamber. Indeed when we tried to detect ammonia in the gas stream by leading it through 200 ft. of polyethylene tubing to a metal gas sampling valve, no ammonia was detected. Also we had to change the copper tubing leading from the thermal conductivity detector of the gas chromatograph, to stainless steel, to prevent the ammonia sticking to the walls of the copper, and not being detected in the proportional counter.

Table II

Variation in Product Composition (%)

with CH₄ : H₂ Ratio

<u>CH₄/H₂</u>	<u>NH₃</u>	<u>CH₃NH₂</u>	<u>C₂H₅NH₂</u>	<u>Total ¹³N (mCi)</u>
∞	96	3	1	20
2	95	4.9	0.1	6
1	96	3.6	0.4	4

Table III

Variation in ¹³N Yield with Beam

Current - Pure Methane Irradiated

<u>Beam Current (μA)</u>	<u>Total ¹³N Activity (mCi)</u>
5	7.6
1	1.3
0.2	0.83

Fig. 3. Target chamber for the irradiation of methane gas and bubbler for the dissolution of $^{13}\text{NH}_3$ in water, saline or dilute acid.

Fig. 4. Radio-gas-chromatogram of 10 µl $^{13}\text{NH}_3$ solution. Carriers added: NH_3 , HCN , CH_3NH_2 , $\text{C}_2\text{H}_5\text{NH}_2$, CH_3CN . Solid line is the radioactivity trace on a logarithmic scale, dotted line is the thermal con-

d) P-30 Labeled Phosphate

^{30}P is a radioisotope of phosphorus having a half life of 2.5 minutes. It decays to stable silicon by positron emission with 99.5% abundance and emits a gamma ray of 2.23 MeV with 0.5% abundance (6). ^{30}P has been produced previously by irradiation of aluminum with the natural alpha particles of polonium (7), by (d, α) reaction on sulphur-32 (8) and by (p, γ) reaction on silicon-29 (9). Joliot and Curie were awarded the Nobel Prize in Chemistry for their production of ^{30}P , among other radioisotopes, the first production of artificial radioactivity.

We have made ^{30}P by irradiating 0.004 inch thick aluminum foils with 14 MeV alpha particles from the Sloan-Kettering Institute cyclotron. The yield was 10 mCi/ μA at saturation and by irradiating at 10 μA for 10 minutes we made 100 mCi at the end of irradiation. The aluminum foil was removed from the target and dissolved in 5N hydrochloric acid in a 200 ml distillation flask shown in Figure 5. The hydrochloric acid was preheated to 90°C. The aluminum dissolved and hydrogen and carrier free phosphine gas labeled with ^{30}P was evolved. The radioactive gas was swept out of the distilling flask through a trap (to collect water vapor) and into one side of a Tescom welding torch (Model 11-1101). The other side of the torch was supplied with oxygen from a cylinder and the hydrogen and oxygen gases were burnt in a small flame (1 inch long) which was ignited by an adjacent gas burner (not shown). The $\text{H}_2\text{-O}_2$ flame was directed downwards onto the surface of 10ml of isotonic saline in a 50 ml beaker immersed in ice water. Phosphine was oxidized in the flame to P_2O_5 phosphorus pentoxide which dissolved in water to give phosphate ion PO_4^{3-} . The size of the orifice of the welding torch was chosen to be 0.020 in. so that the flame did not overheat the saline. The distillation flask and the Tescom torch were placed in separate fume hoods to minimize the possibility of a hydrogen-oxygen explosion.

The whole apparatus was set up before the irradiation, the hydrogen and oxygen flows started and the flame ignited and adjusted, while pointing away from the saline solution. The aluminum was then irradiated and about 20 seconds after the irradiation the ground glass joint A was opened, the aluminum dropped into the acid, the flask resealed and the flame re-ignited. When radioactivity was detected in the trap, the flame was directed downward towards the saline, and when radioactivity in the trap fell off the preparation was complete.

The saline solution usually contained between 5 and 10 mCi of activity 4 minutes after the end of irradiation. About 75% efficiency was achieved in converting ^{30}P in Al to ^{30}P labeled PO_4 .

The $^{30}\text{PO}_4$ has been injected in dogs and the isotope distribution studied with a gamma camera. Phosphine gas labeled with ^{30}P has also been collected and used in breathing experiments on dogs.

Fig. 5. Apparatus for the preparation of ^{30}P -phosphate.

e) Electroplating Techniques

Targets used in the production of four radioisotopes, Fe-52, Ga-67, In-111 and I-123, are prepared by the electrodeposition of the naturally occurring target elements upon a copper disc. Each of the targets except chromium is plated on a copper disc which has been immersion plated with silver. The copper discs are first polished on one side to a mirror finish. For silver plating the polished disc is rinsed first with chloroform, then acetone, then 10% nitric acid, followed immediately by distilled water and finally dipped in a solution containing 1 gram AgNO_3 and 6 grams NaCN per liter. The solution is well stirred with a magnetic mixing bar. After 5 minutes the copper disc, now plated very thinly with silver, is removed, rinsed with distilled water and then acetone before weighing prior to plating. If the disc is to be plated with chromium for ^{52}Fe production, it is not plated with silver, but only polished and then cleaned with chloroform, acetone, nitric acid, and water as described above. The plating apparatus diagrammed in Figure 6 consists basically of a platinum electrode revolving in an electrolyte filled Teflon holder. The Teflon holder is open on the bottom with a 1 1/4 inch diameter x 1/8 deep groove to hold a 1 1/8" diameter x 1/8 thick disc with a 1/8" thick rubber O-Ring around it. The disc is the bottom of the cell and is held in place by compression of the rubber O-Ring by the chamfered portion of the presser plate. Electrical contact with the bottom of the cell (the target) is maintained by means of phosphor bronze springs. Various metals, including platinum, are used to govern the anode area by hanging pieces of metal on the platinum electrode to control current density. The plating recipes and procedures used are given in Table IV. It must be emphasized that there is considerable latitude in voltage and current density values and that the deposit quality may be improved by slight alterations in electrolyte solution composition. Of paramount importance in obtaining a smooth adherent deposit is the surface to be plated on: it must be very smooth, a mirror finish. One source of reference on plating techniques is by Rodgers (10).

4. Operation

a) Cyclotron Preset Scaler/Timer Interface

A scaler-timer to anode power supply interface was constructed to halt target irradiation automatically by turning off the anode P.S. at a preset time or integrated current, greatly increasing precision of data and eliminating overruns due to operator error. The operator may select preset or manual shutoff by a switch. The "Integrated Current/Time Preset" mode, the desired current or time is set on the scaler-timer, and the anode P.S. turned on. The scaler-timer resets itself if the previous irradiation was completed, and shuts off the anode P.S., at the preset value. If an irradiation is interrupted while in progress as by crowbarring or manual anode P.S. shutoff, the scaler-timer will not reset but continue on when anode power is resumed. Manual reset may be done at any time by using the scaler-timer reset button. In the "Integrated Current/Time Off" mode, irradiation must be halted by manually turning off the anode P.S. The interface

Fig. 6. Electroplating Apparatus.

TABLE IV

Plating Recipes and Procedures

<u>Target Element Plated Out and Approx. Thickness</u>	<u>Recipe (to make 1 liter Plating Electrolyte)</u>	<u>Target Disc</u>	<u>Voltage Current Density Plating Time Electrode</u>
Chromium 0.003" 50mg/cm ²	3g Cr ₂ (SO ₄) ₃ 250g CrO ₃ 1 or 2 drops conc. H ₂ SO ₄	Copper (no covering)	6 V. 155 to 225 mA/cm ² for 8 hours No added electrode area
Zinc 0.003" 50mg/cm ²	70g ZnSO ₄ ·7H ₂ O 30g NH ₄ Cl 15g NaOOC·CH ₃ 120g Dextrose	Silver plated copper disc	0.5 V. 15 mA/cm ² for 4 hours 1 x 4 cm Zn anode strip
Cadmium 0.0015" 25 to 30mg/cm ²	12.5g CdO 5.5g NaCN 7.5g NaOH	Silver plated copper disc	3 V. 6.5 mA/cm ² no added electrode 4 hours
Antimony 0.0025" 40mg/cm ²	60g SbO 120ml 48% HF 2.5g Resorcinol	Silver plated copper disc	0.7 V. 45 mA/cm ² 1 x 2 cm Sb chip or anode

may be removed for service or repair and the cyclotron still operated manually when a jumper switch is thrown.

b) Internal Target Probe

Construction began and is in the final testing stage on a modified internal target probe utilizing an automatic probe removal system and having the dual capacity of internal target holder and internal beam monitor. The increasing use of internally irradiated targets has required altering the system of target removal now in use to reduce radiation exposure to personnel. At present, the probe after irradiation is manually unbolted from its carriage, pulled out against dee box vacuum and the probe exit port closed. The modified system, on signal from the control console, will withdraw the probe, close the exit port, cycle a vacuum lock and halt probe movement. The probe may also be inserted automatically. A beam monitor probe tip with much greater cooling capacity than that presently supplied, will be used on the new probe and is expected to reduce high replacements costs. Dual capacity will permit quick changeover between internal target irradiation and internal beam monitoring, dispensing with changing probes and adapters for their different diameters. The system will fail-safe in case of vacuum or power failure.

c) Movable Faraday Cup

Construction began and is nearing the testing stage on a movable Faraday Cup (see figure 7) to measure beam current accurately, especially to those targets such as gas chambers where beam current cannot now be measured. The cup will be water cooled, mounted in a vacuum chamber and rotate into and out of the beam path by means of a rotary solenoid actuated from the control console. The design stresses long service life and minimum maintenance time.

d) Semi Conductor Relay Trigger

Firing of the SCR's in the magnet power supply induced spurious pulses in the shielded signal leads from target room equipment. A trigger circuit, described elsewhere (report no. 3510) used the firing pulse from the SCR's to gate a logic circuit that rejected these pulses.

e) Cooling Water System Improvement

Earlier in the year the cyclotron cooling water system was occasionally subject to extremes of temperature (40 to 80°F), which seriously affected the overall performance of the machine. With the water running too cold, condensation of water tended to form throughout the oscillator circuitry, and within the resonator cavity. Under load conditions this caused excessive and damaging high voltage arcing to the system. This problem has now been obviated by installing a temperature control valve in the secondary cooling circuit.

The cooling water system has been modified by the installation of valves and quick disconnect couplings so that any water cooled component of the cyclotron can be quickly disconnected to check water

NOTE: MACHINE SCREW LOCATIONS AND INTERNAL WIRING OMITTED FOR CLARITY.

FIGURE 7

ITEM	DESCRIPTION
1	LEDEX ROTARY SOLENOID, TYPE BS, 4.5°R, 26 AWG, FOR VACUUM APPLICATION
2	HOLDING SOLENOID, TYPE TO BE DETERMINED
3	JOHNSON FLEX. METAL HOSE, TYPE DHSS
4	BOSTON GEAR #1616-NS BALL BEARING
5	TRANSFER GEAR, TYPE TO BE DETERMINED
6	" " " " " "
7	PERMAG CAST ALNICO II MAGNET, 250 GAUSS VACUUM OCTAL FEEDTHRU, TYPE OCT-B-1N

CYCLOTRON FACILITY, BIOPHYSICS DIV.
SLOAN-KETTERING INSTITUTE, N.Y.C.

MOVABLE FARADAY CUP ASS'Y

SCALE: 1:2.5 DRAWN BY: R LEE

PROJECT 3005044 DATE: 7/7/71A

SHEET 1 OF 1 DWNG. C-054

leaks into the vacuum chamber or easily disconnected for particle changeover, maintenance or repair. Disconnecting the ion source, deflector septum or deflector negative electrode now no longer requires a half hour to cool the diffusion pump and 3 to 4 hours to restore operational vacuum. Replacing the awkward inductor strap water line connectors with quick-disconnect shut-off couplings has greatly reduced particle change-over time and the loss of demineralized cooling water. Also, leaks in the upper magnet, harmonic coils or dee box plates can now be easily isolated and tested. Flow gauges and switches have been installed to prevent time consuming breakdowns. Separate flow gauges for the upper and lower magnets replaced a single underrated gauge that frequently burst. A flow gauge and flow switch in the deflector negative electrode now prevents the once frequent water leaks in the dee box due to electrode burn-through.

Installation was completed on a cooling water demineralizer system to reduce the failure rate and maintenance time of water-cooled cyclotron components. This system, consisting of an oxygen removal ion exchange resin column, mixed bed resin column and a 0.45 micron particle filter in a bypass loop, purifies the recirculating chilled distilled cooling water.

f) Node Points Determination

As an aid in starting a self-excited oscillator when driving a resonant structure in a vacuum environment, the dees are biased to a high negative D.C. potential. Originally, the bias power supply connection was made at the geometric center of the conductor assembly cross-connector, assumed to be a voltage node. This hookup, plus an additional R.F. filter in the coupling line would ordinarily prevent damaging R.F. voltage from entering the supply. Frequently, these components, along with a mode trap resistor installed to prevent parasitic oscillations in the system, were being damaged or destroyed. A high voltage probe was hooked up to the coupling line under load and monitored by an oscilloscope. By moving the bias contact point along the cross-connector, it became apparent that the geometric and electric node points were not coincident (possibly due to slight structural unbalances in the inductor bar). The proper node points have now been located and the elusive problem no longer exists.

The inductor strap node point at the dee loop RF is now determined and monitored remotely by a high voltage probe, signal driver and oscilloscope. This point must be at RF ground to suppress harmonic oscillations of the dee loop RF that would prevent particle acceleration or cause oscillator tube destruction. A DC bias is applied through a bias filter at the node to suppress multipacting within the cyclotron when turning on. The destruction of several dee bias filters and expensive node point resistors with resulting loss of operation time, led to the findings that the node was not centrally located on the inductor strap as assumed, RF voltage rose steeply with distance from the node, and the node point shifted with each oscillator tuning. The dee bias filter was encased in silicone compound to suppress RF arcing and a spare unit made. No node point resistors or dee bias filters have failed since these modifications were made.

OSCILLATOR TUNING CHARACTERISTICS

• MAXIMUM DEE VOLTAGE W/O CROWBARRIN
 f_A, f_C OSCILLATION FREQUENCY OF ANODE/CATHODE
 LOOP AT CORRESPONDING DIAL SETTING N_A/N_C

Fig. 8.

g) Oscillator Trouble Shooting

On two separate occasions failure of the oscillator to start was ultimately traced to faulty high vacuum R.F. variable capacitors used for gross tuning the anode circuit. The original tuning capacitor, in service for about three years and normally rated at 35KV, began breaking down at one tenth this value (the ionization potential for air) indicating a crack in its sealing bellows. Its replacement worked well for a period of about six months before it too showed break-down symptoms. However, it was quickly replaced by the manufacturer while still under warranty, and to date the oscillator is performing well without similar incident.

Occasionally, extensive crowbarring in the oscillator anode power supply and tripping of its main circuit breaker, presumably induced by parasitic oscillations, was determined to be caused by a defective choke coil, part of an R.F. decoupling filter in the anode circuit, which had been arcing to ground. The coil's inductance was increased by twenty-five per cent and the arcing has since disappeared.

h) Oscillator Tuning Study

The operating condition of the RF oscillator of the SKI cyclotron is determined by the oscillation frequencies of the anode and cathode loops. Therefore, a study of oscillator performance with respect to the turning of these two capacitors was carried out. The result is shown in Figure 8. Oscillator power is plotted against the anode and cathode frequencies, respectively, (dial settings for these tuning capacitors are used which are found reproducible). The maximum dee voltage and the corresponding oscillator tuning can then be determined from these graphs.

i) Scanning Magnet Study

In order to improve efficiency for production of radionuclides a scanning system is being designed. This scanning system is intended to provide uniform irradiation over an area of 5cm x 5cm. There will be two scanning magnets deflecting the beam in horizontal and vertical directions, respectively. One scanner can be an iron core magnet with variation frequency of 0.1 cycle per sec., whereas the other must be an air-core with about 60 cycles per sec. oscillation. The former can be driven by a small power supply and a simple mechanical control. The latter requires a heavy supply and an electronic generator. It was found that sine-wave alternating current cannot be used for the fast oscillating scanner since the time span in the peak region is much longer than that for the crossover region. For uniform irradiation, alternating current with straight teeth-wave must be used.

j) Area Radiation Monitors

Area radiation monitors of the ionization chamber type were installed in the target room, cyclotron room and hot lab to meet

AEC radiation exposure requirements. When exceeding a preset radiation level, the monitor gives a pulsating sound signal, red light warning and meter reading, both at the monitor station and the control console. These units are wired so that turning off one unit will activate the alarms of all the rest.

k) Beam Exit Valve

Installation was made of a pneumatic beam exit gate valve to eliminate a source of radiation exposure to personnel. Operating procedure required manual closing of the valve after each run, thus placing personnel in the vicinity of the radioactive magnetic channel portion of the extraction system. The valve is now operated from the control console with the anode power supply switch, or locked close by the beam exit valve switch. However, the valve will not open with the probe in, as when tuning the oscillator, to prevent loss of dee box vacuum if a new target is being evacuated in the beam transport system. The valve connection may be unplugged from the control circuit and operated non-remotely from a utility outlet. An interlock circuit closes the valve if the vacuum in the beam transport system fails as with target foil window failure, or is below a preset value. The system is designed fail-safe.

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APPENDIX

CIRCUIT DESCRIPTIONS

I. Internal Target Probe

If the probe is not in far enough to trip SW2 (see figure 9), normal probe movement, as outlined in the cyclotron manual, will be present. Here, atmosphere valve S1 will be open. When the incoming probe trips SW2, RE1 is energized, closing S1 and routing the probe control circuit through the T.C. Gauge Controller RE3. If the vacuum in the probe feed-through piece is poor, RE3 halts the probe motion and opens the pumpout valve S2. When the feed-through pressure falls below a value preset on the gauge controller, RE3 is energized, thereby closing S2, causing the probe motion to resume and energizing RE2. RE2 locks itself and opens the pneumatic gate valve V1. With the outgoing probe motion, the sequence is reversed. In case of a vacuum failure with the probe in the dee box, RE2, now locked, will not allow the gate valve to close on the probe. In case of power failure with the probe in the dee box, the gate locking valve S3 closes, immobilizing the gate valve V1 by shutting off its air supply, thus preventing it from closing on the probe as it returns to its normally closed position. S1 and S2 also close or remain closed. J1 permits V1 to be tested or operated manually from a utility outlet. The system is designed to be fail-safe.

II. Beam Exit Valve

The Beam Exit Valve V1 (see figure 10) will open or close when 1100SW4 is turned on or off, respectively, if the following conditions are present: 1160SW3 is in the "Anode P.S. Control" position, valve RE1 is energized or bypassed and 1160 RE1 is deenergized. V1 will close or remain closed with 1160SW3 in the "Closed" position. Valve RE1 is energized when the ionization gauge in the target room vacuum station is turned on. If the vacuum station pressure exceeds 1.5 times the ion gauge full scale setting, RE1 turns off and V1 closes if not closed, providing RE1 is not bypassed. 1160 RE1 energizes when the internal probe reaches its in-limit, closing V1 if not closed. J1 permits V1 to be tested or operated manually from a utility outlet. The system is designed to be fail-safe.

III. Scaler/Timer for Anode Power Supply

With SW1 in "Preset" position (see figure 11) and the scaler-timer gate off, turning on 1160SW4 energizes RE2 which sends a + 6VDC starting signal to the scaler-timer. The scaler-timer resets and the gate turns on. The + 5VDC level from the scaler-timer gate output turns on Q1 which energizes holding RE1. RE1 terminates the

FIGURE 9

- SW1 - T.C. GAUGE CONTROLLER OVERRIDE
- SW2 - PROBE TRIP SWITCH
- S1 - ATMOSPHERE VALVE
- S2 - PUMPOUT VALVE
- S3 - GATE LOCKING VALVE
- RE3 - T.C. GAUGE CONTROLLER
- 01 - INTERNAL PROBE CONTROL DON TERMINAL

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30" CYCLOTRON

INTERNAL TARGET PROBE CONTROL
(LAYOUT SIMPLIFIED)

R. LEE

6/20/71

starting signal by turning off RE2 and completes the power circuit to the anode power supply. When the preset value is reached, the gate and +5VDC gate output go off, turning off Q1, RE1 and the power to the anode P.S. The RE1 coil decays through SR1. With SW1 in "Off" position, the RE2 circuit is open and the RE1 contacts in the anode P.S. loop shorted, enabling power to be delivered to the anode P.S. When J1 is unplugged, as when servicing the scaler-timer, SW8 shorts the RE1 contacts in the anode P.S. loop, enabling power to be delivered to the anode P.S.

Table V shows the number of hours per month that the ion source was on, as measured on the ion source register, since records have been kept. One can see the increase in beam-on time since the machine's acceptance tests in December of 1967.

Table V

Monthly Record of Beam on Time

<u>Month</u>	<u>Beam on time (hours)</u>
Aug. 1968	58.6
Sept.	31.7
Oct.	32.3
Nov.	33.0
Dec.	23.9
Jan. 1969	36.4
Feb.	55.1
Mar.	35.1
Apr.	65.5
May	60.0
June	34.9
July	71.0
Aug.	15.3
Sept.	14.1
Oct.	38.7
Nov.	58.0
Dec.	34.2
Jan. 1970	20.6
Feb.	55.4
Mar.	21.8
Apr.	81.6
May	55.2
June	39.9
July	29.6
Aug.	20.3
Sept.	30.9
Oct.	33.9
Nov.	44.0
Dec.	54.1
Jan. 1971	63.8
Feb.	71.2
Mar.	100.5
Apr.	88.2
May	75.3

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