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AEC RESEARCH AND DEVELOPMENT REPORT

PROGRESS REPORT

Part II

ELECTROMAGNETIC RESEARCH DIVISION

JULY 1, 1951 to SEPTEMBER 30, 1951

DECLASSIFIED

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OAK RIDGE, TENNESSEE

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Index No. ORNL-1235
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Subject Category: Technology-Materials Testing Accelerator

PROGRESS REPORT - PART II

ELECTROMAGNETIC RESEARCH DIVISION

July 1, 1951 to September 30, 1951

Robert S. Livingston, Director

October 15, 1951

OAK RIDGE NATIONAL LABORATORY
Operated By
Carbide and Carbon Chemicals Company
A Division of Union Carbide and Carbon Corporation
Oak Ridge, Tennessee

Contract No. W-7405-eng-26

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ABSTRACT*

Improved operation of the 86-inch cyclotron and improvements in target design have made it possible to bombard bismuth targets with up to 850 microamperes of 19 Mev protons for long periods of time without damage to the bismuth surface. Approximately 1.5 curies of Po 208 have been produced through September 30, 1951. To dissipate the energy of still larger proton currents, larger targets are being designed. Facilities are being designed for the protection of personnel and to prevent dispersion of radioactive materials.

The use of the Thomas-type magnetic field with azimuthal variations to obtain phase compensation in the fixed frequency cyclotron is being investigated in a 1/16 scale model of the 86-inch magnet.

In further investigation of the resolution of isotopes from high current densities obtained from grid-type ion sources, lithium is being used because of the more favorable mass ratio of the two isotopes.

Cyclic thermal stressing of alpha-rolled uranium by resistance heating and by water cooling of the surface results in failure but does not produce linear growth.

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* Due to the sensitivity of the projects described herin, this Section II of the report should be abstracted by title only. Other work of the Electromagnetic Research Division has been reported in Progress Report, Part I, ORNL-1173.

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CYCLOTRON PRODUCTION OF POLONIUM 208

During July, August, and September, 1.4 curies of Po 208 were produced in the 86-inch cyclotron in contrast to the 0.11 curie for the previous two quarters. Continued emphasis on target design has resulted in the ability to operate at currents as high as 850 microamperes for long periods of time without melting the bismuth target surface. Adequate steps have been taken to protect cyclotron personnel from airborne and surface contamination. The alpha contamination problem has been reviewed from the long range point of view and facilities are being designed for the protection of personnel and for preventing the dispersion of radioactive materials.

Polonium 208 Production

The sharp increase in polonium production during the past quarter was achieved through both improved cyclotron operation and better target design. Cyclotron innage time rose from 21 per cent during the month of July to 70 per cent during the month of September. The average proton current on bismuth targets during July was 167 μa, August 337 μa, and 644 μa for the month of September. A bar graph of the weekly production is shown in Figure 1.

Preliminary energy measurements have shown that the energy at a radius of 30.5" from the magnetic center of the machine is 19 Mev rather than the 22 Mev expected if the center of the beam orbit corresponded to the magnetic center. The Po 208 yield at this energy, calculated from the data of Kelly*, is 5.85 mc/mah. The mean specific yield for the 1.4 curies produced during

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* Kelly, E. L., Excitation Functions of Bismuth, UCRL-1044, February 1951.

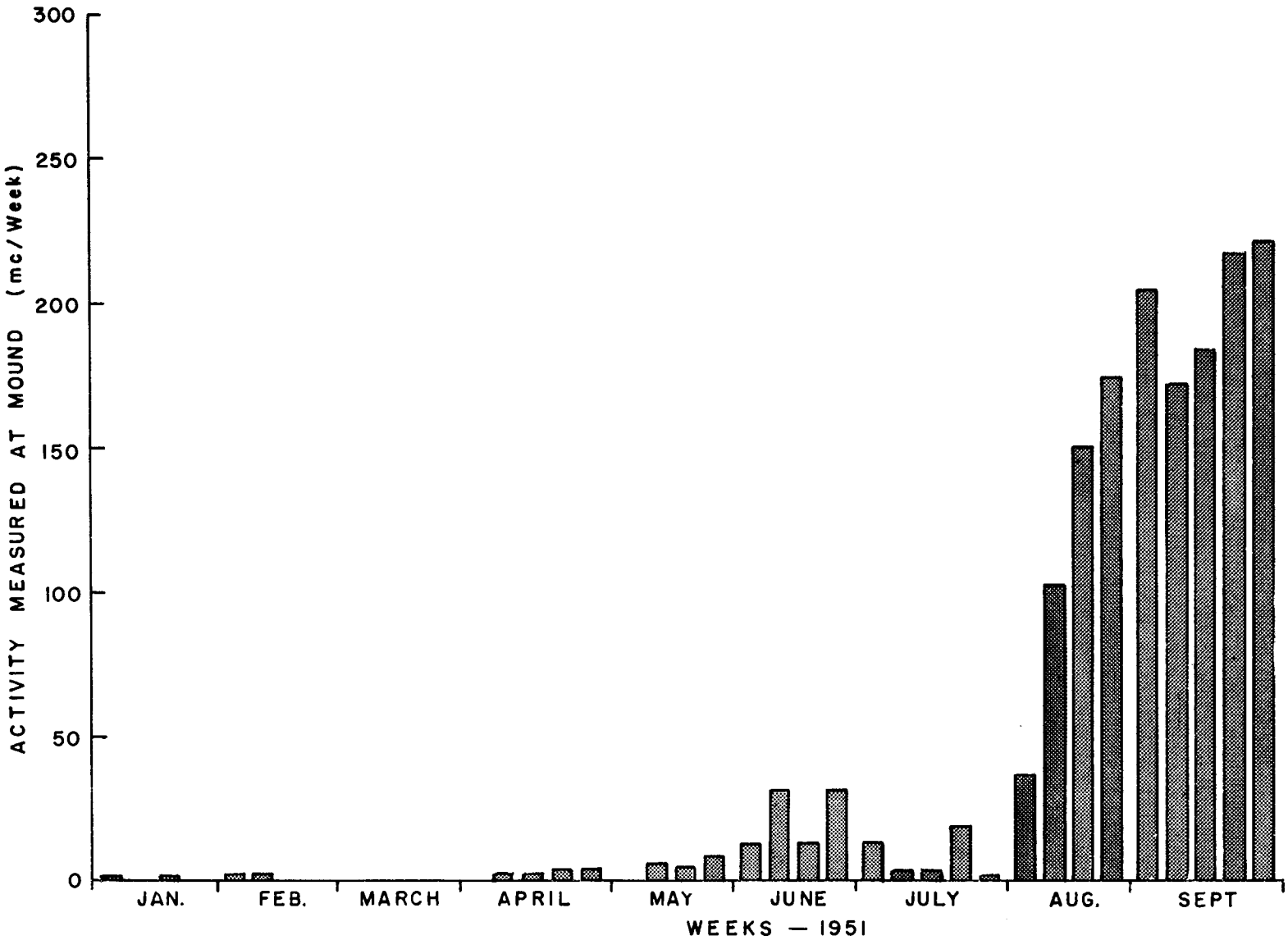

FIGURE 1. POLONIUM 208 PRODUCED

this quarter was 3.39 mc/mah, giving a target efficiency of 57.9%. A data summary for the targets run during this period is given in Table I. Because of the large fluctuations in yield results from target to target it has been difficult to arrive at a consistent explanation of the low yield. A calculation was made to determine the magnitude of the proton loss caused by multiple scattering through the thin (0.004") bismuth target coating, with the following results:

Grazing Angle	% Protons Lost
3°	0.09
2°	0.17
1°	0.22
0.5°	0.24

Since the minimum grazing angle has been 2°, it appears that multiple scattering is a negligible factor in lowering the target yield.

The diffusion of polonium from the target surface during bombardment has been considered as a possible reason for the low yield. Preliminary data from Mound Laboratory and San Pablo Laboratory* indicate that this loss would not appreciably lower the yield, but would be sufficient to highly contaminate the cyclotron components. This conclusion seems to be further borne out by the lack of correlation between the degree of target melting and the specific yield, except in extreme cases where the bismuth coating has been vaporized from several square inches of target surface in intense portions of the beam.

An important possibility for error is in the beam current measurement. To date, no discrepancies of sufficient magnitude to explain the yield variation have been noted. More accurate means for determining the heat input to the target will ultimately confirm or cast doubt upon the accuracy of the metered target current in representing the proton current.

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* Charpie, R. A., Minutes of Joint Meeting, July 30-31, 1951, CF-51-8-260 (ORNL)

Target No.*	Date	Average Beam (μa)	Bombardment Time (μah)	Assayed Yield (mc)	Observed Yield (mc/mah)	Cumulative Activity (mc)
24	7/5/51	90	86	0.90	10.5	111.3
38	7/12/51	100	135	0.723	5.35	112.1
44	7/18/51	124	1286	6.76	5.26	118.8
27	7/18/51	100	130	0.80	6.15	119.6
28	7/19/51	100	79	0.40	5.06	119.9
46	7/20/51	113	136	1.12	8.28	121.1
48	7/20/51	110	132	0.87	6.59	122.0
47	7/21/51	175	1555	6.57	4.22	128.6
50	7/31/51	178	2960	17.30	5.84	145.9
45	7/31/51	247	1800	8.2	4.55	154.0
49	7/31/51	192	456	2.27	4.98	156.3
53	8/2/51	209	9050	42.80	4.72	199.1
54	8/4/51	185	2636	5.02	1.90	204.1
57	8/7/51	324	2254	9.45	4.19	213.6
56	8/8/51	76	599	3.81	6.36	217.4
55	8/9/51	83	806	3.0	3.72	220.4
58	8/12/51	269	10980	37.50	3.41	257.9
59	8/15/51	425	28562	150.00	5.25	407.8
60	8/17/51	450	367	1.91	5.20	409.8
61	8/18/51	596	3010	10.90	3.62	420.7
62	8/23/51	472	28277	104.00	3.68	524.7
63	8/24/51	403	6142	19.8	3.22	544.4
64	8/30/51	325	36144	145.0	4.01	689.5
65	9/4/51	467	30999	146.5	4.7	836.0
69	9/11/51	446	52571	181.0	3.4	1017
66	9/14/51	435	10645	28.7	2.6	1046
70	9/19/51	825	70561	200.9	2.8	1247
68	9/21/51	590	4224	19.95	4.7	1266
71	9/27/51	847	105958	245.0	2.31	1511

*Targets were numbered serially, as fabricated, but they are listed chronologically, as used. Some targets were discarded before bombardment and a number were used out of sequence.

TABLE I: BISMUTH BOMBARDMENT SUMMARY

Target Design

At the time of installation of the new dees, modifications of the target handling dolly were made to allow the use of larger targets. Previous to this time the largest target used with the vacuum lock was 2 9/16" by 6". The first of the largest targets tested was of the 6" by 7" grazing incidence type, Figure 2, constructed with a removable bismuth coated aluminum head, the head being held firmly against a gasketed base by a clamping frame. With the head in place a 1/16" passage remained beneath it to provide the necessary water cooling passage. The difficulties experienced with this target were numerous, the most serious being:

1. Insufficient gasket cooling, which caused leaks.
2. The inability to withstand the pressures required for high water flow without excessive deflection.
3. The inflexibility of the design from the standpoint of changing the target angle or the radius.

Because of these shortcomings this target was replaced by the flattened tube target to be described below.

The steps in the fabrication of the flattened tube target are shown in Figure 3. The starting material for all 6" wide targets is 4" diameter 2S aluminum tubing with 1/4" wall thickness. The tubing is annealed and then flattened against a 1/16" mandrel in a hydraulic press. The flattened pipe is then machined on the ends for the water headers which provide even flow distribution along the width of the target and insure high flow velocity at the ends. From nine to twelve holes are drilled through the target (depending on its size) and pins inserted. The pins and headers are then Heliarc welded in place, resulting in a vacuum-tight assembly ready for the application of the bismuth coating. The pins welded through the target are necessary

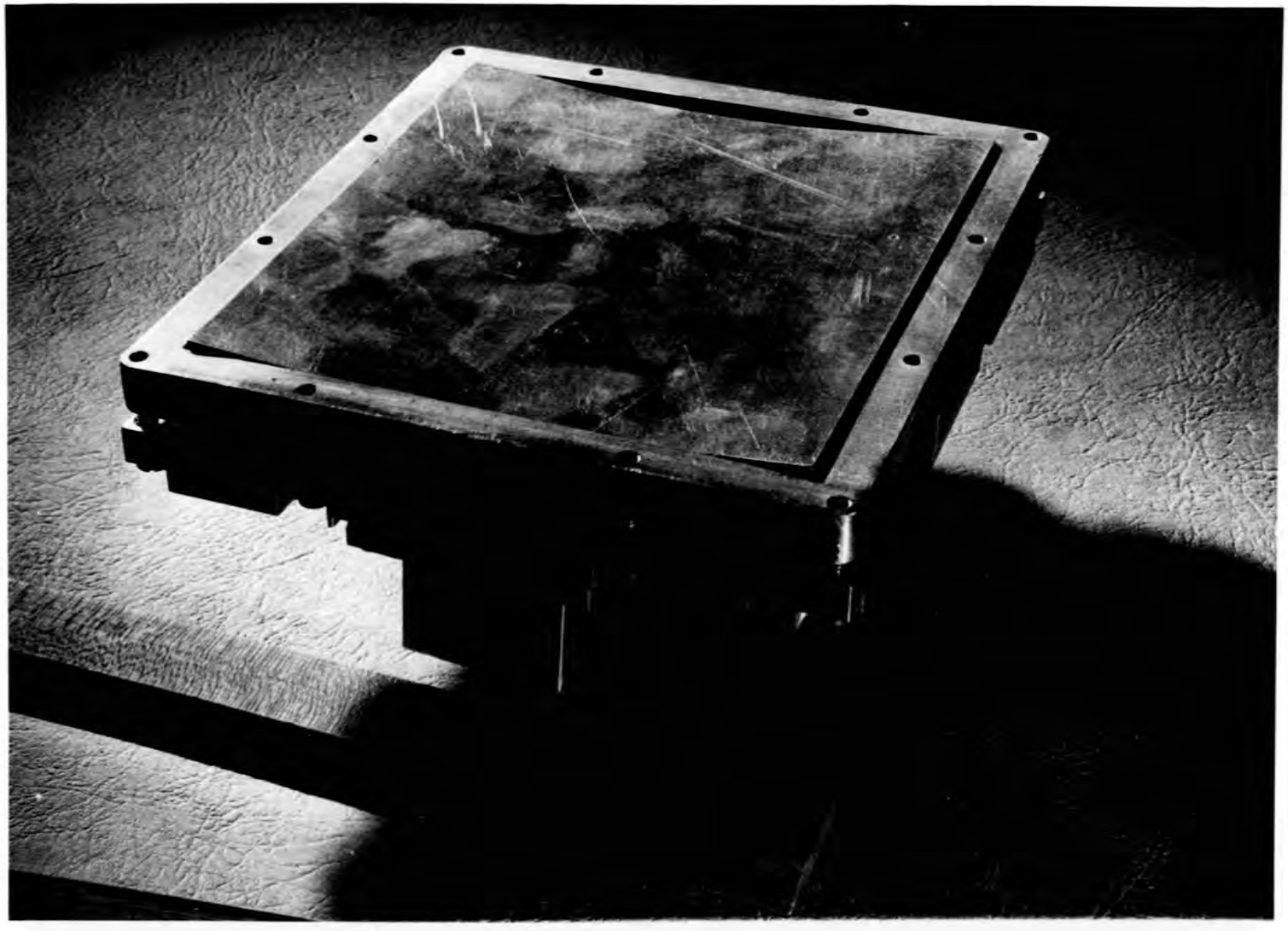

FIGURE 2. ASSEMBLED TARGET, 6" x 8"

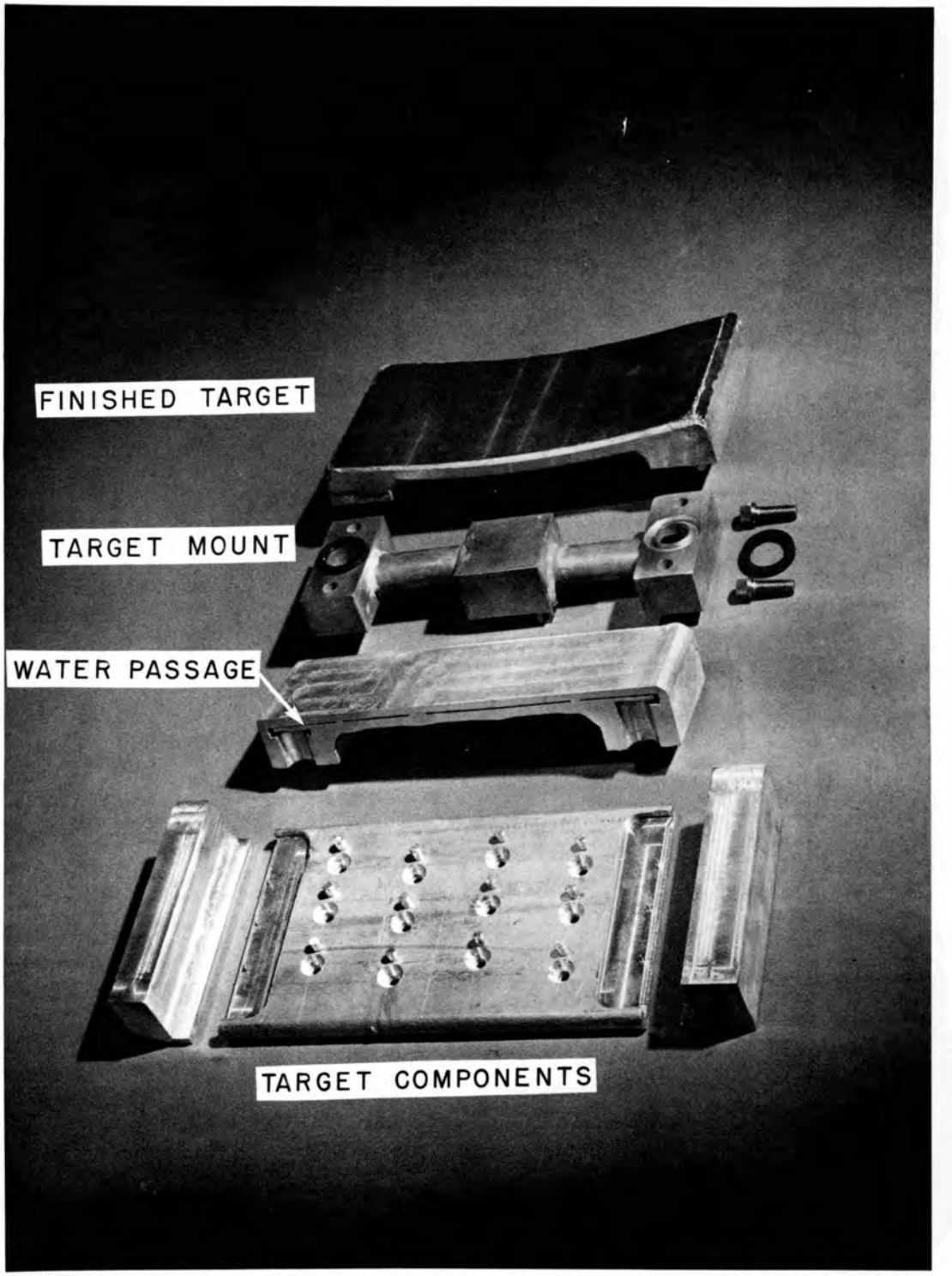

FIGURE 3. GRAZING INCIDENCE TARGET, 6"x 10"

because of the high water pressure (160-180 psi) required to maintain sufficient water velocity. The effect of the pins in reducing the deflection of the target surface is tabulated below:

Target Size	No. of Pins	Maximum Pressure (psi)	Deflection (in)	Flow (gpm)	Water Velocity (ft/sec)
6" x 6"	None	60	0.015	4	3.7
6" x 6"	3	125	0.004	12	11.2
6" x 6"	9	155	0.003	22	20.5
6"x 10"	12	180	0.0015	29	27

The target is prepared for the application of the bismuth coating by milling a 0.004" recess into the surface. The entire target is heated to above the melting point and the bismuth is mechanically abraded into the aluminum surfaces, producing a bond layer due to the partial solution of aluminum in bismuth. After the thin (~ 0.001") bond layer is produced, excess bismuth is floated onto the surface to a thickness of about 1/32". During this process the surface of the melt is constantly combed to remove aluminum particles which float to the surface. After cooling, the surface is machined to the aluminum shoulders of the recess, leaving a 0.004" bismuth layer. After the machining operation the target is bent to a radius of 32" using hardwood dies in a hydraulic press.

Targets both 6" by 6" and 6" by 10" have been fabricated in this manner. The only difficulty that has been experienced is a tendency for cavitation on the downstream side of the strengthening pins which results in poor heat transfer, and thus melting of the bismuth at those points. Attempts will be made to minimize the melting by moving the pin locations away from the more intensely bombarded area.

The present flow rates represent the maximum which can be economically reached with this target. Because of the high resistance of the target handling dolly and the target, the friction factor does not change appreciably with flow, with the result that the flow depends upon the square root of the change in pressure. It is obvious then that significant increases in flow will require much higher pressure and consequently stronger targets. Rifle drilling of aluminum plates is being investigated as a possible fabrication technique to produce targets capable of withstanding at least 500 lbs/in^2 and having better heat transfer characteristics. One disadvantage of the rifle-drilled target will be its greater water passage area, thus requiring higher flow to achieve the same heat transfer coefficient. In view of this the redesign of the target handling dolly to reduce its impedance is being seriously considered.

Alpha Contamination Levels

During the preliminary stages of the program from January 1, 1951 to June 1, 1951, spot checks of the cyclotron pit and general cyclotron area indicated that no contamination was present. The first significant amounts of activity were detected when the original set of dees were removed for inspection in June 1951. The dees were removed by means of the overhead crane and set aside for cooling from radioactivity before being moved to the dee-alignment dock. They were decontaminated by hand washing before the necessary mechanical adjustments were made. The following table lists the airborne contamination in disintegrations per minute per cubic meter during the above operations. Where no mask or equivalent protection is used, the

maximum permissible limit in an 8-hour working day is 70 d/min-m^3.

Date	Location	Air Sample Results d/min-m^3
6/27/51	Removing dees from cyclotron	912
6/27/51	Inside liner after dee removal	355
6/27/51	Inside pit just after dee and liner removal	1064
6/27/51	General area near stored dees	38
6/28/51	General area in cyclotron pit (noon)	9
6/28/51	" " " " " (1:00 PM)	68
6/28/51	" " " " " (2:00 PM)	11
6/28/51	" " " " " (4:00 PM)	2
6/29/51	General area by alignment dock	2
6/29/51	General area in cyclotron pit	1
7/1/51	Installation of dees and liner	734
7/2/51	General pit area	110

As expected, the airborne contamination increased following large scale agitation of air as large pieces of equipment were moved and decreased as primary sources of polonium were decontaminated. The largest amount of airborne contamination seemed to be associated with the dees but even this was relatively low after the initial removal operation.

Contamination of Dees. On July 2, 1951 measurements of the alpha activity on the surface of the dees were made with an ionization chamber. To determine how much of the contamination was easily removable, a series of smears was taken on both the liner and the dees. The results of the measurements are shown in the following table. The activity is indicated in d/min for each smear. It must be remembered that smear measurements cannot be accepted as precise, but do indicate the relative ease of removal of the surface contamination.

Location	Dee and Liner Smears 10^4 d/min
Outer west side north dee	7.5
Outer west side south dee	5
Outer east side north dee	2.5
Outer west side south dee	3
Inside bottom lip north dee	5
Inside bottom lip south dee	35
Inside liner top west side	0.1
Inside liner top east side	0.2
Inside liner top north side	0.07
Inside liner top south side	0.3
Inside liner top bottom south side	2
Inside liner top bottom north side	0.1

Clothing Contamination. Spot checks for alpha contamination were made on the protective clothing worn by persons working with contaminated material from the cyclotron. The measurements were made with the AC Poppy proportional counter which has a probe area of 35 cm^2. The values shown in the following table were the highest found for the particular type of clothing.

Article	10^4 d/m-35 cm^2
Gloves	3
Shirts	0.5
Trousers	0.3
Caps	0.1
Shoes	0.05
Shoe covers	1

Area Surveys. Surveys were made in the mechanical area, lunch room, and in the dee storage area to check for alpha contamination. No significant activity was found except on the blotting paper used in the mechanical area to absorb the wash solution draining from the liner.

Pump Oil Analysis. The oil from the diffusion pumps and the finishing Kinney pumps were analyzed for alpha contamination with results as below:

	$\mu c/cm^3$
Finishing Kinney	6.5×10^{-7}
Diffusion	8.3×10^{-5}

Reduction of Contamination

After the above experience with the alpha contamination associated with cyclotron maintenance several improvements were incorporated. It was clearly shown that air movement across highly contaminated surfaces must be eliminated if airborne contamination was to be controlled. It was observed that alpha contamination of measurable amount was present after about 50,000 μah of bombardment. With the higher currents and increased innage time now obtainable, the number of microampere-hours of service for a set of dees before removal may increase a hundred-fold. Thus, facilities for reducing contamination spread by at least the same factor were indicated.

To prevent the flow of the air from the pit area the blower system was converted so as to maintain the pit under a slight negative pressure. The air from the pit now passes through Chemical Warfare Services filters and is exhausted to the atmosphere through a stack. These steps have been effective in preventing spread of airborne contamination throughout the building.

Provision is being made for handling the dees upon removal from the cyclotron without exposing them to the air in the room. This will be accomplished by surrounding the dees and liner with large plastic bags as they are removed by means of the overhead crane. It will then be possible to transfer the dees in the bags without contaminating the air in the building.

To provide for a proper storage and decontamination area, two air-tight rooms are being built, one serving as a repair and storage area and the other as a decontamination area. The former is being installed around the present dee and liner jig rack. Both of the rooms will be equipped with controlled air systems. The decontamination room will have a change room and a tank below the floor level for disposal of wash solutions.

Target Changing. Recently it has been noticed that high levels of airborne contamination are present during and immediately following the target removal operation. To determine if this contamination was present at times other than during target removal the following air samples were taken at the time of the operation and later.

Date	Area	d/min-m^3
9/11/51	Pulling target	300
9/11/51	General area after pulling target	150
9/12/51	General area 31 hours after target removal	9

These results indicate that the airborne contamination exceeds the MPL during target removal only. Respirators are being worn by all personnel involved in this operation.

As larger currents and longer bombardment times were obtained it was expected that the above levels of air contamination would increase. This effect is shown in the following table.

Date	Area	d/min-m^3
9/27/51	Removing targets (operational)	1,300
9/27/51	Removing target (general area)	900
10/2/51	General area at start of target removal	10,000
10/2/51	General area after target is placed in carry box	2,000

On September 29 and 30 it was necessary to open the tank to air to correct a short in the dee system. The following samples are indicative of the contamination produced by this operation.

Date	Area	d/min-m^3
9/29/51	Above open tank	73,000
9/29/51	Over north end with top open	22,000
9/30/51	4 feet from open side port	27,000
9/30/51	Between cement shield and tank	13,000
10/2/51	By west end of cement barrier	1,400

The increased activity of the cyclotron targets and the results of the tank opening operation have made it necessary to consider systems for containing the alpha contamination and preventing its further spread through the building. It is planned to confine the contamination in the pit area by building a change room adjacent to the present cyclotron maze. This room will provide change facilities for regular work clothes and for clothes worn in the pit area. Shower facilities for personnel and decontamination sinks for small parts will complete the installation. No contaminated material will be allowed to enter the "clean" end of the change house unless it is properly contained in a package suitable for preventing the escape of alpha-active material.

PHASE-COMPENSATED FIXED FREQUENCY CYCLOTRON

The use of the Thomas-type* magnetic field with azimuthal variations to obtain phase compensation in the fixed frequency cyclotron is being investigated. A 1/16 scale model of the 86-inch magnet is being used in developing the design of magnetic shims required to produce the desired magnetic field configuration.

Magnetic Field of Model Magnet

The Thomas-type magnetic shims for the 1/16 scale model magnet are assembled from 1/16" sheets of steel. In building up the shims from these plates, difficulty encountered with the accurate layout of the shim contours has been solved by adoption of a photographic process which reduces errors by a factor of four. The contours (four times enlarged) are laid out with thin lines on tracing cloth, the drawing is reduced photographically, and a 1/16 scale negative is prepared. The shim stock, drilled to fit on dowel pins, is coated with photographic emulsion and the print of the negative is obtained on the surface of the steel. The shim steel is then cut with a band saw, sanded to the contour lines, and stacked on dowel pins to form the shims.

The magnetic field, as measured on successive models, is approaching the theoretical field. A set of shims has been tested which is within 4% of the theoretical field, up to a radius corresponding to 33 inches full scale. Since the measurements show that the 1/16" shim steps used in the model introduce variation in the field of the order of 2%, shims with 1/32" steps are being designed. This new 1/32" shim stock represents 1/2" steps in the full scale design; it is planned to use 1/4" stock for the full scale shims.

* Thomas, L. H., Phys Rev 54, 581 (1938).

Full Scale Magnetic Field Measurements

A method of exploring the full scale magnetic field has been devised. At any radius, the theoretical field is a constant plus a part which varies as the angle, θ.*

$$H = H_o \left[1 + \frac{A\omega r}{c} \cos 3\theta + \frac{B\omega^2 r^2}{c^2} \right]$$

Thus, if a search coil with its axis perpendicular to the field is moved about the center at a given radius in the theoretical magnetic field, the flux change observed will vary sinusoidally with three times the angle. Now if a reference coil at the center of the magnet, in a uniform field, is geared to the search coil so as to rotate three times to one revolution of the search coil, the flux change observed from the reference coil will vary in the same way as that from the search coil. Therefore, if the two coils are in the correct phase relative to each other, and a predetermined fraction of the signal of the reference coil is bucked against that of the search coil, the difference signal recorded on a fluxmeter represents the difference between the actual magnetic field and the desired one. With apparatus operating on this principle, one should be able to explore the magnetic field in a few hours. The instrumentation for this type of measurement is being designed.

As a check on this method as well as a means of determining the absolute magnetic field, it is planned to use a modification of proton resonance equipment for establishing the absolute magnetic field where it is more nearly flat ($3\theta = 0, \pi/2, \pi, 3\pi/2$). The necessary equipment for making this measurement has been ordered.

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* Progress Report, Y-795, p. 30.

Vacuum Tank and Liner

Fabrication of a vacuum tank to accommodate the Thomas-type shims in the 86-inch cyclotron has been delayed by the shortage of stainless steel; delivery is now promised for April, 1952. A water-cooled copper liner is being designed to fit the contours of the shims and to be removable by remote controls.

ISOTOPE SEPARATION, LITHIUM

One of the factors limiting the output of the calutron as used in the electromagnetic process is that isotope separation depends upon the emergence of ions from a narrow source. The combined effects of natural focusing at 180° and magnetic focusing produces for each isotope an image of this source at the collector position. The images must be sufficiently distinct to permit the desired degree of resolution. Production from the calutron appears to be limited by the number of focusable ions that can be obtained through this narrow source.

For a high production rate, a wide ion source aperture would be desirable. The use of such a source, stabilized by grid structures, has been investigated for the separation of uranium and thallium isotopes.* Large ion currents were obtained but resolution of isotopes was unsatisfactory. Investigation of this type of ion source was then continued on a reduced scale. The application of potentials to side screens adjacent to the path of the ion beam was found to improve the resolution somewhat.** In further investigations of the resolution of isotopes for high current densities lithium has been used because of the more favorable mass ratio of the two isotopes.

Focal Patterns of Ion Beams

The anticipated focal patterns of ion beams can be determined graphically. All ions of the same mass and energy move in orbits of the same radius in crossing a uniform magnetic field. The center of each orbit is, however, determined by the direction in which the ion was accelerated. In the sketches

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* Progress Report for period ending June 30, 1950, Y-637.

**Progress Report for period ending October 1, 1950, Y-676.

in Figure 4 the paths of ions leaving the ion source at the normal angle, 90°, are shown as solid lines. Ions diverging from the normal are shown by dotted lines; the example here is for ±6° divergence. In order to simplify the diagram the focal pattern is shown for a single isotope.

Calutron Ion Source. Where all ions appear to emerge from a focal line at the source the divergent ions are rather well focused at the 180° position. Ions diverging as much as ±12° have been focused satisfactorily. The total throughput appears to be limited, however, by the number of ions which can be obtained through the narrow source.

Flat Grid Ion Source. When the ion source is widened and stabilized by thin transverse grids, a much enlarged, flat source is obtained. As a result of natural focusing all ions leaving this surface at the normal angle should be sharply focused at the 90° position. Further, they should be focused to repeat the pattern of the source at the 180° position. Ions divergent at the source greatly diffuse the focus at 90° but are almost entirely focused within the pattern at 180°.

Isotope separation may then be considered either at 90°, where the foci are separated by Δr, or at 180° where the distance is $2\ \Delta r$. If divergence can be greatly reduced a sharper focus can be expected at the 90° position; when the radius is reduced, angular divergence becomes less important but the distance between isotopes is also less. While the focus is wider at the 180° position the distance separating any two isotopes would be twice that at the 90° position. Distinct focal patterns for the isotopes can be obtained at 180° only when the width of the source is less than the difference in beam diameters for the two isotopes, $2\ \Delta r$. This method might be applied successfully to lighter elements having relatively large mass ratios.

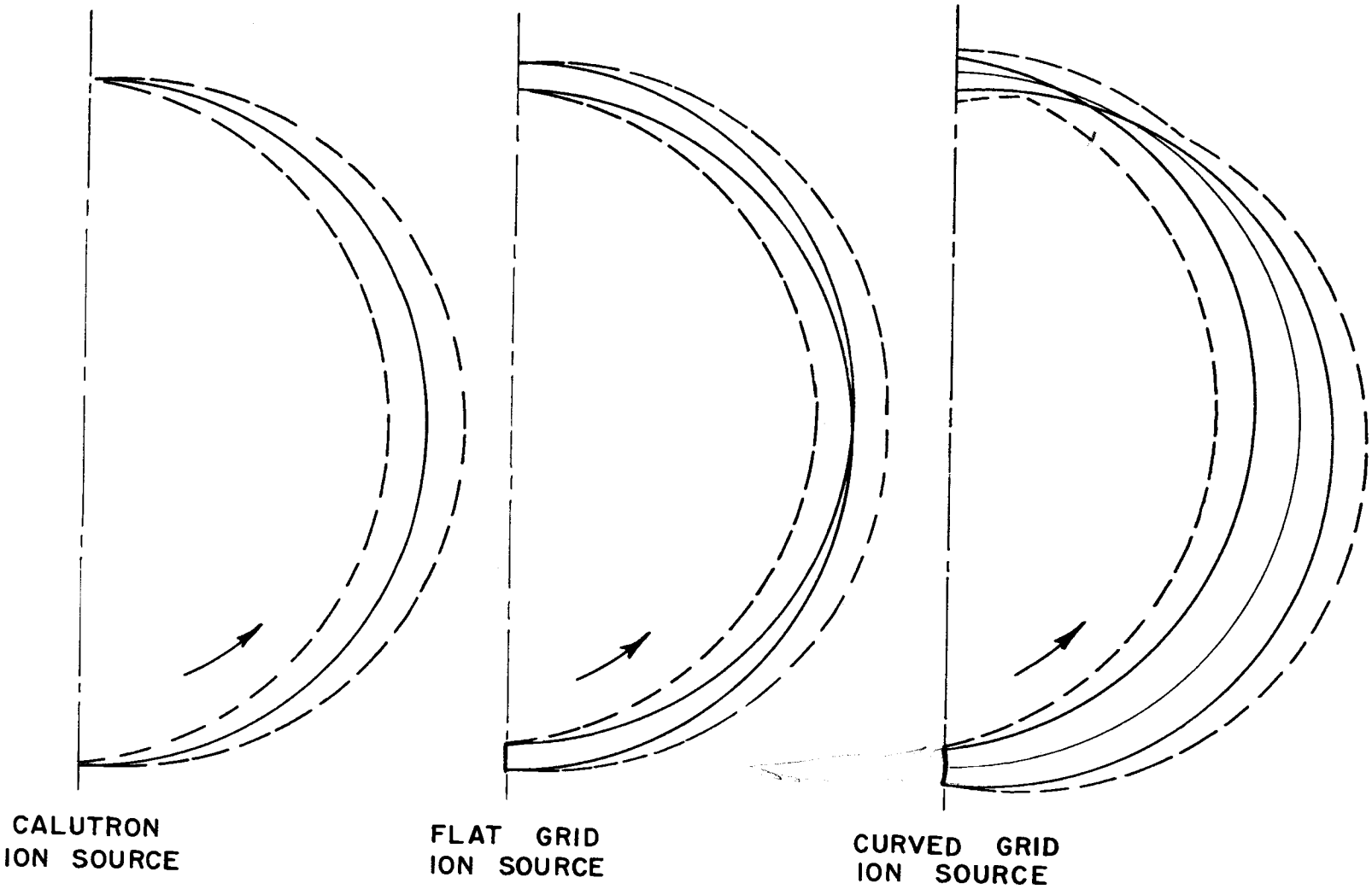


FIGURE 4. BEAM PATTERNS FOR A SINGLE ISOTOPE

Curved Grid Ion Source. When curved grids are used in the ion source so that ions are accelerated from a cylindrical surface the natural focus of ions leaving this surface at the normal angle is moved towards the 180° position, the actual position being determined by the curvature of the grids. In this case the focus of the normal ions tends to coincide with the focus of the divergent ions. If a good focus can actually be obtained near the 180° position, advantage could be taken of the greater distance between the focal patterns of the isotopes.

Experimental Results

Lithium is being used in the investigation of grid-type ion sources to determine the optimum grid geometry, magnetic field, and accelerating voltage and to determine possible ion output and isotope separation. A number of test runs have been made with flat grids. Transverse grid openings 0.062" have given the best results. Curved grids are being fabricated for future tests. The largest output and best beam focus both appear to occur at about 3500 oersteds for 15-20 kv acceleration. While the magnetic field has not been determined carefully, it is in the proper range. This test was conducted without side screens which may affect the results.

Output. The highest output obtained to date is 1200 ma of Li^+ ions from one square inch of source area. While this is certainly not the ultimate limit it is probably a practical limit for present operations. An output of one ampere per square inch is now being used for estimates.

Isotope Separation. No separated isotopes have been collected yet. Resolution of isotopes has been judged by observing the patterns in the beam and on the target plates. Isotopic separation appears good at the 90° position for flat grids. Equipment is now being fabricated for the collection of separated lithium isotopes for mass analysis.

TARGET TESTING

The equipment for thermal cycling test rods by means of pulsed electrical power has been moved and reinstalled in Building 9204-3. The target testing program was then continued with emphasis on thermal cycling of alpha-rolled uranium.

Resistance Heating

The primary interest in the testing program is centered about the behavior of uranium under rapid thermal cycling at high power densities and high surface heat transfer rates. For this reason the tests using the new installation have been limited to the use of water cooling to attain the necessary high heat transfer rates.

In the first test an average power density of 8 kw/in^2 was obtained in a 1/4" alpha-rolled uranium rod, with a 1:5 duty cycle and pulsed 8 cycles per second. A record of the center and surface temperatures was secured with 28 gage chromel-alumel thermocouples and a Brush recorder. In spite of the excellent frequency response characteristic of the recorder it is suspected that the temperature swings measured are somewhat low, particularly in the case of the center temperature. The center thermocouple is imbedded in dental cement of relatively low thermal conductivity and therefore has a low response speed. The sample melted and failed near its midpoint after 100,000 cycles. No evidence of growth during the test could be noted. Inspection of the surface after the test revealed a number of longitudinal cracks which passed through the holes drilled for the thermocouples. The surface of the specimen was heavily corroded and apparently coated with iron oxide from the cooling water used.

The type of failure produced in the above test is quite different from results of previous tests with helium cooling, which demonstrated that slow cycling of alpha-rolled uranium with low thermal gradients produced growth in the direction of the rod axis (direction of rolling). The cycling rates obtained in these tests were 1-3 cycles per minute with temperature swings from 100°C to 500°C.

In an attempt to duplicate the center temperature swing obtained with helium cooling, 100°C to 500°C, the cycling rate was reduced to one second "on" and one second "off". The effect of changing the cycling rate was to hasten greatly the sample failures. The longest sample life for this series was 9300 cycles with a pulse power density of 50 kw/in^3. The last two runs were made without thermocouples to eliminate the stress concentration produced by the holes, the required power level having been previously determined. In every case failure was preceded by longitudinal fissures which appeared after only a few hundred cycles. A summary of these tests is given in Table II.

It is apparent that the type of damage produced with high-gradient cycling is quite different from that produced with low- or zero-gradient cycling and that a different mechanism is involved. It is assumed that growth is restrained because the surface of the rod does not attain the temperatures at which large growth rates have been obtained. The fissures are produced by fatigue failure caused by the high cyclic thermal stresses produced as a result of the large thermal gradient. Preliminary calculations indicate that stresses well above the elastic limit of alpha-rolled uranium ($10\text{-}15 \times 10^3$ psi at room temperature) are produced. In further tests an attempt will be made to determine the maximum allowable cyclic stress for this application.

Run No.	Surface Temp Limits °C	Center Temp Limits °C	Pulsing Rate (Sec) On	Pulsing Rate (Sec) Off	Pulse Power Input kw/in^2	Remarks
A-0	100-120	320-323	0.025	0.100	40.0	Sample failed after 100,000 cycles. Numerous longitudinal cracks in surface.
A-2	127-50	466-102	1	1	41.6*	Several thermocouple holes, 2 drill rod inclusions. Initial crack after 450 cycles. Sample failed after 1500 cycles. Numerous deep fissures, very jagged.
A-4	106-50	486-112	1	1	--	First crack 5100 cycles. Open circuit after 6900 cycles. Noted that resistance of sample gradually increases.
A-9	--	500-100	1	1	52.2	No holes in specimen. Surface roughening after about 1 1/2 hours. First crack after 3600 cycles. Failure 4350 cycles. Resistance of sample (start of pulse) = 1.24×10^{-3} ohms. Resistance at end of pulse 2.03×10^{-3} ohms. Indicated average temperature rise of entire sample 228°C (using $\alpha = 2.8 \times 10^{-3}$ ohms/°C).
A-6	--	500-100	1	1	52.2	No holes in specimen. First crack after 5400 cycles. First crack was well located so moving pictures were taken of it. Power was raised after 7500 cycles to hasten cracking for pictures. Complete failure at 9300 cycles.

* Meter reading in doubt.

TABLE II: TARGET TESTS SUMMARY

Bombardment Heating

Two Zr-U-Zr sandwiches, 1" by 4", prepared by the ORNL Metallurgy Division, were heated with protons from a calutron-type ion source. One specimen was representative of a poor bond and one was representative of the best bond obtained. The test plates were bombarded with a proton beam for 14 hours at a heat flux of 1 kw/in^2. The sample with the excellent bond appeared to be unchanged after bombardment while there appeared to be separation of the uranium from the zirconium at the edges of the poor bond. Both plates have been returned to the Metallurgy Division for metallographic examination.

OPERATION SUMMARY

A summary of operations in Buildings 9204-3 and 9201-2 for the months of July, August, and September includes the following experimental runs:

Special Separations	27
U 236 Program	2
86-Inch Cyclotron	101
Electromagnetic Fundamentals	46
Electro-Nuclear Machines	51
Radiation Damage	35
Target Design	6

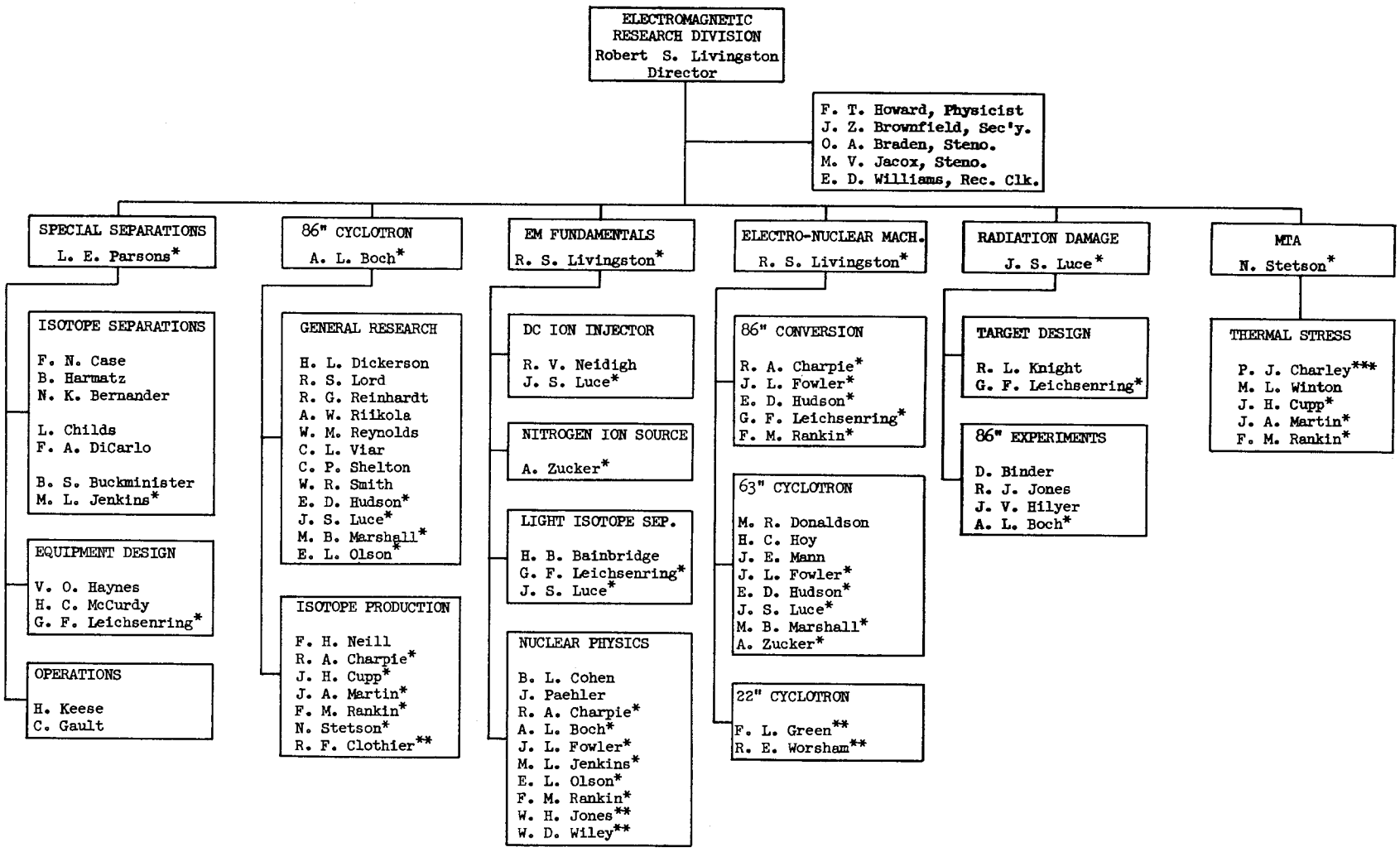
Distribution of shop time charged to each of the various projects is given in Table III.

Assignment of personnel to various projects is indicated by the personnel chart, page 32.

		Mechanical Service		Machine Shop - Carbon		Machine Shop - Metal	
		Hours	% Used	Hours	% Used	Hours	% Used
33-238	Special Separations	80.0	0.9	129.0	13.1	-	-
33-240	U 236 Separation	85.5	1.0	64.5	6.5	2.0	0.1
		165.5	1.9	193.5	19.6	2.0	0.1
34-242	86-Inch Cyclotron Mechanical	570.4	6.3	170.5	17.2	720.0	26.0
34-243	86-Inch Special Targets	2132.0	23.8	1.0	0.1	20.0	0.7
		2702.4	30.1	171.5	17.3	740.0	26.7
36	Fundamental Electromagnetic Research	736.5	8.2	224.5	22.7	288.0	10.4
37	Electro-Nuclear Machines	191.0	2.1	8.0	0.8	27.0	1.0
38	Radiation Damage Research	1053.5	11.7	32.0	3.2	372.0	13.4
3550-366-2	MTA Target	486.4	5.4	-	-	68.0	2.4
4900-132	Plutonium Laboratory Facilities	1668.4	18.6	337.0	34.1	66.0	2.4
4900-161	The 63-Inch Cyclotron	1733.9	19.3	3.5	0.4	322.0	11.6
4900-178	Modification of 86-Inch Cyclotron	-	-	-	-	98.2	3.5
4900-181	Alignment Rack for 86-Inch Cyclotron Dees	5.0	0.1	-	-	-	-
4900-194	Vacuum Lock & Associated Equipment for 86-Inch Cyclotron	212.5	2.4	19.0	1.9	790.8	28.5
43204-1	Building Maintenance Service	14.0	0.2	-	-	-	-
	Total	8969.1		989.0		2774.0	

TABLE III: TIME DISTRIBUTION - MECHANICAL AND MACHINE SHOPS

October 1 through December 31, 1951



* Dual Capacity
** Research Participants
*** CRD Personnel
R. L. Quinn on loan to Protective Equipment Evaluation Program

Personnel

40 Monthly
11 Weekly
51 Total

September, 1951