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ELECTROMAGNETIC RESEARCH DIVISION

QUARTERLY PROGRESS REPORT

Part II

for Period Ending December 31, 1951

AEC RESEARCH AND DEVELOPMENT REPORT

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Index No. ORNL-1270
This document contains 25 pages
This is copy 23 of 50, Series A

Subject Category: Technology-
Materials Testing Accelerator

ELECTROMAGNETIC RESEARCH DIVISION
Robert S. Livingston, Director

QUARTERLY PROGRESS REPORT, PART II
for Period Ending December 31, 1951

Edited by F. T. Howard

January 15, 1952

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

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Index No. ORNL-1270

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ABSTRACT*

The polonium 208 production rate has exceeded one curie per month, and approximately 2.9 curies have been produced during the quarter. Improved methods of cyclotron target fabrication have resulted in increased reliability of the bismuth-coated targets. Enclosed target handling facilities to prevent dispersal of alpha-active products are being installed.

In model magnet tests, a magnetic field pattern has been obtained which approaches the theoretical pattern of a Thomas-Type field designed for phase compensation.

Both flat and convex grid-type ion sources are being investigated for use in electromagnetic separation of lithium isotopes. The convex grids appear to provide better ion beam focus, but greater ion output is obtained from the flat grid system.

When, in thermal cycling tests of alpha-rolled uranium, the calculated stress is reduced by increasing the cycling rate from 30 to 2400 per minute the life of the test rod is greatly extended even at the same power input. Zirconium and thorium rods have also been tested.

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* Due to the restricted nature of the projects described herein, this Section II of the progress report should be abstracted by title only. Other work of the Electromagnetic Research Division has been reported in Quarterly Progress Report - Part I, ORNL-1269.

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CYCLOTRON PRODUCTION OF POLONIUM 208

In the continuation of the polonium 208 production program 2.865 curies have been produced during the past three months. The reliability of the bismuth coated targets used for this production has been greatly improved, and several alternate target fabrication methods have been investigated. The cyclotron beam energy has been accurately measured by several methods to aid in appraising the target yield data. To reduce the spread of alpha-active contamination about the cyclotron area and the building, enclosed target removal and processing facilities have been designed and are under construction.

Production Statistics

During the months of October, November, and December, 2.865 curies of Po 208 were produced in the 86-inch cyclotron. The reaction exploited is the Bi 209(p,2n)Po 208, which has a relative large yield for 20 Mev protons. During the previous quarter the total production amounted to 1.4 curies. The monthly production for the past six months is summarized in the bar graph, Figure 1. Most of the gain in production has been a result of improved cyclotron operation. The overall innage achieved with the machine for the three-month period was 59.4%. The innage approached 80% of the time allotted to bismuth target bombardment. During the period from October 1 to November 28, 120 hours per week were assigned to polonium production and since November 28, 144 hours per week have been available.

The specific production rate realized was 4.22 mc/mah, significantly better than the 3.39 mc/mah obtained for the months of July, August, and September. Measurements of beam pattern indicate that the orbital center of the proton beam is 1.8" below and 2.5" south of the center of the magnetic

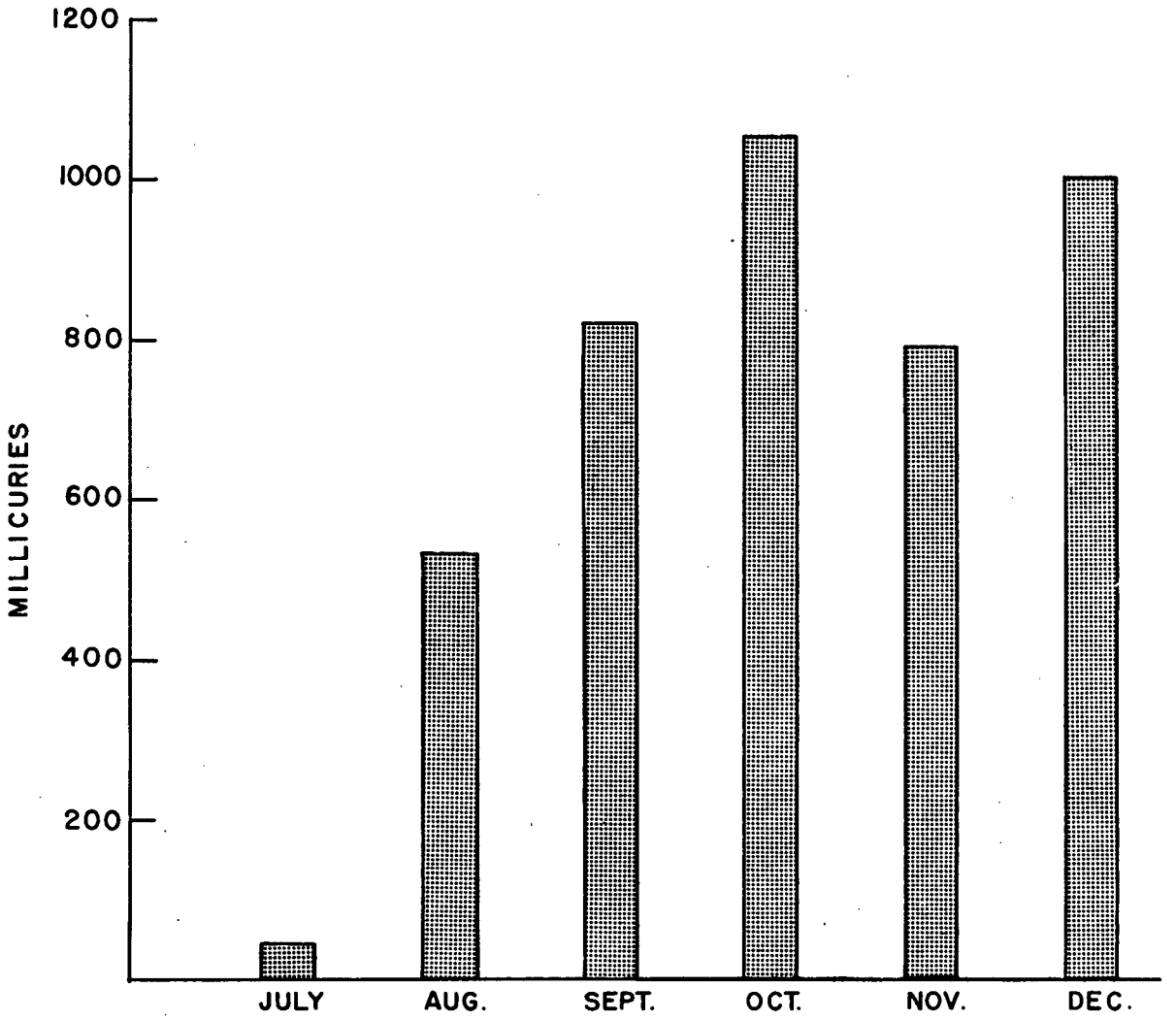

FIGURE I. PRODUCTION RATE

field. This accounts for the maximum beam energy being somewhat lower than would be expected from $H\rho$ considerations. Recent measurements from excitation functions for protons on copper give a beam energy of approximately 19 Mev. At this energy the specific yield of 4.22 mc/mah represents a yield efficiency of 72%, based upon a yield of 5.85 mc/mah predicted from the cross section measurements by Kelly.* A data summary for the targets run during October, November, and December is given in Table 1.

Bismuth Target Performance

The cyclotron targets used for the production of Po 208 present severe heat transfer problems. Because of the relatively small area of the beam pattern, the utilization of large currents requires that the heat flux be reduced by allowing the beam to strike the target at a small angle. The attainment of extremely high heat fluxes is severely limited by the melting point of bismuth (272°C); the surface temperature must be maintained well below this value to prevent evaporation of the bismuth surface and consequent loss of production.

The maximum current which may be utilized for the production of Po 208 is presently limited by the power dissipating capacity of the cyclotron targets rather than the output of the machine. At the beginning of each run a series of inspections at increasingly larger currents determine the maximum current which may be run on bismuth targets. Normally the current during the run is maintained at 10% below that which will just cause melting of the bismuth surface. During the past quarter an average of 530 μa at an energy of 19 Mev was obtained on bismuth targets. The best average obtained for any target was 690 μa.

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

Target No.*	Date	Average Beam (μa)	Bombardment Total (μah)	Assayed Yield (mc)	Specific Yield (mc/mah)	Cumulative Activity (mc)
73	10/2/51	550	33,420	135.5	4.05	1647
67	10/5	510	18,720	93.8	6.0	1741
72	10/8	501	28,260	109.0	3.86	1850
74	10/11	626	34,800	122.6	3.52	1972
76	10/12	420	410	2.3	5.38	1975
77	10/12	339	180	3.6	4.60	1978
75	10/15	638	28,420	92.4	3.25	2071
78	10/18	510	15,990	75.6	4.73	2152
79	10/22	459	32.798	145.8	4.44	2298
80	10/25	665	29,602	131.6	4.44	2430
81	10/29	632	36,130	141.0	3.91	2571
82	11/1	595	21,180	78.3	3.70	2649
83	11/5	551	28,540	149.5	5.24	2798
89	11/8	303	4,840	28.2	5.83	2827
86	11/12	544	29,170	170.2	5.83	2997
85	11/15	473	5,150	27.8	5.40	3025
88	11/18	431	10,290	32.2	3.13	3057
89	11/23	441	23,100	48.0	2.08	3105
91	11/25	506	12,720	64.0	5.03	3169
87	11/28	490	47,130	199.5	4.23	3368
92	12/4	691	60,890	231.6	3.79	3600
93	12/5	540	8,100	50.1	6.18	3650
94	12/12	620	41,497	199.5	4.81	3850
95	12/14	501	12,430	61.5	4.95	3911
96	12/16	615	26,820	91.9	3.43	4001
97	12/19	513	18,250	71.6	3.92	4075
99	12/26	408	12,610	51.3	4.07	4377
98	1/2/52	426	55,350	251.0	4.54	4326

*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

Occasional difficulty has been experienced because of small changes in the beam distribution which also account for the variations in target performance. The small grazing angle ($\sim 2°$) used in spreading the beam over the 10" length of the present targets makes for sensitivity to shifts in beam intensity distribution. Factors such as the dee voltage which affect the distribution are well understood. The elimination of any variation from this cause has been accomplished by accurate calibration of the dee voltmeters at the beginning of each run. Other causes of variation, such as the source position and whether or not it is grounded at the bottom, have not been so well controlled. The presence or absence of a good rf ground at the bottom of the source tube has a large effect upon the beam width. With the present ion source positioning arrangement there is no reliable criterion for determining whether the source is or is not grounded. During a major shutdown scheduled for January, a socket is to be installed to position and ground the end of the source tube.

Target Design

The standard target used during the past three months was the 6" by 10" grazing incidence type fabricated from flattened aluminum pipe; only slight modification of its design has been necessary. The number of strengthening pins welded through the target has been reduced from 12 to 9 to eliminate the center row which was in the region of most intense bombardment. Cavitation occurring on the downstream side of the pins reduced the heat transfer coefficient at those points, causing melted spots in the bismuth surface. The pin redistribution has eliminated the melting but has reduced the strength of the target appreciably. With the present design it is not possible to use water pressure in excess of 160 psi.

To provide greater mechanical strength, more uniform water channels, and a thinner aluminum backing between the bismuth coating and the water passages, several targets have been prepared by rifle drilling. The fabrication technique consists of rifle drilling a 6" by 10" aluminum plate with 3/16" holes spaced 1/32" apart across its width, Figure 2. After drilling, headers are welded on the ends in the same manner as for the flattened-tube type, and the surface is finished to leave 1/16" of aluminum between the surface of the target and the holes. The bismuth coating is applied in the same manner as for the flattened-tube target.

Two targets fabricated in this manner have been tested and found to be equally as good as the flattened-tube type in spite of the inadequate water flow through cooling passages. To achieve the same flow velocity as is obtained in the flattened-tube target, the total water flow rate must be tripled. Because of the high resistance of the target handling dolly, sufficient flow cannot be obtained to realize the potentialities of the rifle-drilled target. To give higher velocity in the cooling passages one of the rifle-drilled targets has been hot-rolled to produce approximately elliptical water passages 1/16" by 3/16" which gives a total passage area somewhat less than that of the present standard target. With this configuration, water velocities in excess of 30 ft/sec should be attainable. An undesirable feature of this target will be the poor heat transfer from the area between the elliptical holes.

Another grazing incidence target design which provides greater strength and superior heat transfer properties has been designated the slotted-plate type, Figure 3. The arrangement of the water cooling passages provides a significant increase in water cooling area over that available with either

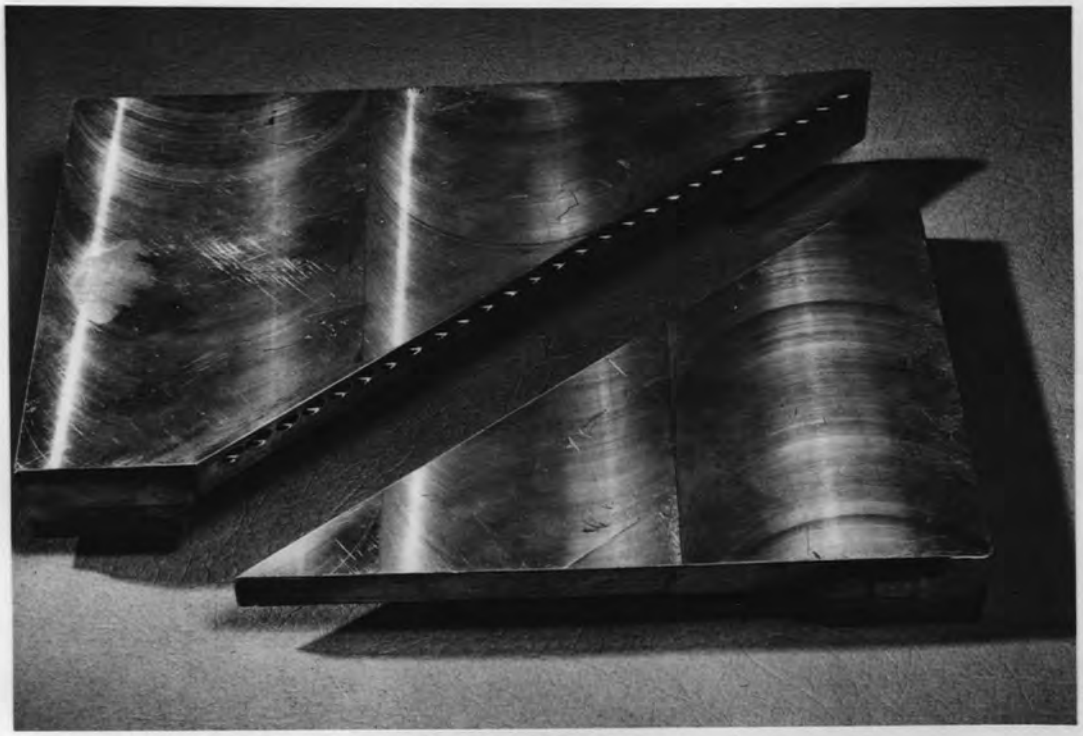

FIGURE 2 RIFLE-DRILLED TARGET

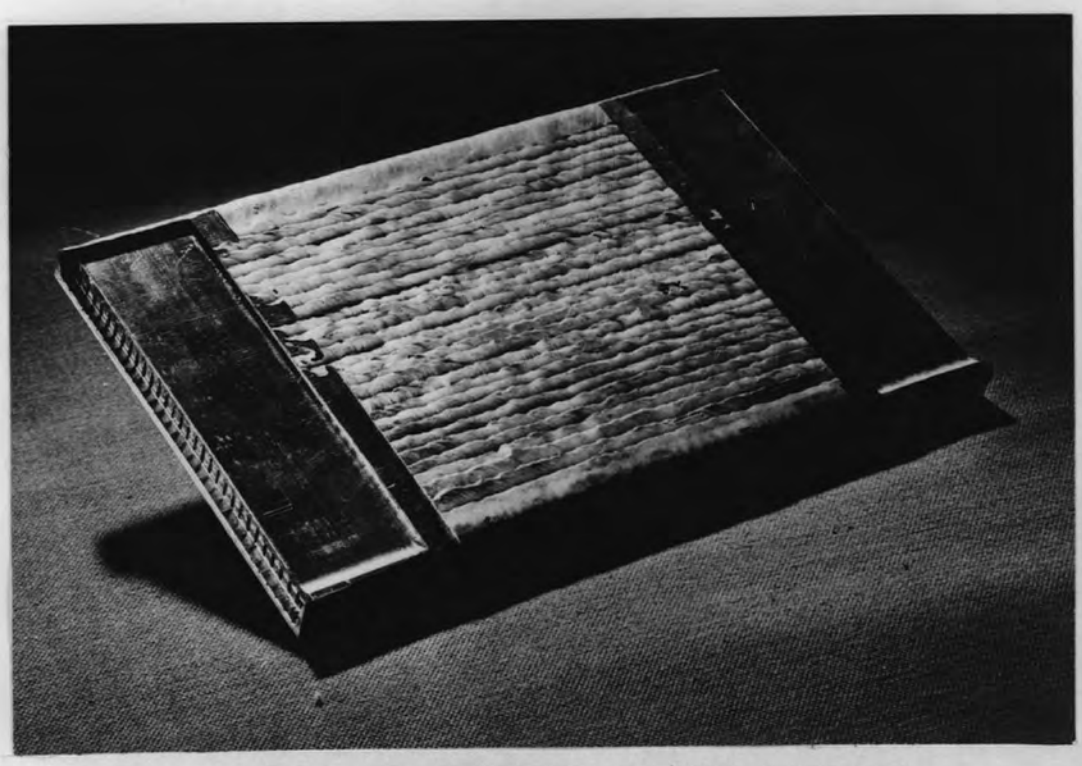

FIGURE 3 SLOTTED-PLATE TARGET

the flattened-tube or rifle-drilled target. A large number of narrow, 1/4" deep, water passages run the length of the target, the distance from the bismuth surface to the water passages being 3/32". The target is fabricated by milling the required number of slots of the desired width to a depth of 5/16" in a 1/2" by 6" by 10" plate of 2S aluminum. The slots are then closed to form 1/4" deep water passages by Heliarc welding to a depth of 1/16". No difficulty has been experienced in controlling the depth of the weld. Two targets of this type have been completed but have not been tested. The first has twenty-one 1/16" by 1/4" water passages, the second has thirty-three 3/64" by 1/4" passages.

Future Plans

During the major shutdown scheduled for early January a larger vacuum lock will be installed, thus making possible the use of targets as large as 15" by 15". The length of the standard grazing incidence target will be increased from 10" to 14". It is hoped that this increase in target length will permit a 20% increase in the allowable target current. An increase of 40% is not expected because of the greater precision of angular adjustment of the target required. With 14" long targets, even the target curvature will become the sensitive parameter in determining the degree of beam spread achieved.

As previously discussed, the target handling dolly is inadequate for supplying water flow in excess of that presently used, 30 gpm, because of the large pressure drop in the water supply system of the dolly. To overcome this a new unit is being constructed in which the pressure drop is reduced by a factor of ten. The area of all water passages has been increased by at least a factor of four and turbulence has been minimized where the flow direction changes. Another feature of this dolly will be the "quick-change" mechanism which fastens the target to the support tube. It will allow pressures as great as 300 psi to be used and will provide accurate alignment for rotating targets.

PHASE-COMPENSATED FIXED-FREQUENCY CYCLOTRON

The design of magnetic shims to provide a Thomas-type magnetic field for the 86-inch cyclotron is being developed from a 1/16 scale model magnet. Azimuthal variations in the magnetic field are produced by three "hills" radiating outward from the center of the shims. The contour of these model shims produce a field pattern approaching the pattern calculated to provide phase-compensation. A new vacuum tank to accommodate these shims in the 86-inch cyclotron is on order and a special liner is being designed. Actual conversion of the 86-inch cyclotron is held in abeyance while other proposals for evaluating the Thomas-type field are considered.

Magnetic Field

The bridge circuit* used for comparing the radial field with the central field in the 1/16 scale model has been altered to permit rapid direct plotting of the data. This was accomplished by adjusting the sensitivity of the galvanometer, the null indicator, so that millimeter deflections corresponded to per cent deviations from fixed ratios (0.1, 0.2--1.4, 1.5). By use of this technique, the model shims can be altered, with a burr cutter for example, and the result of such alterations determined in a comparatively short time. The present pattern of the magnetic field is compared with the theoretical field in Figure 4, which shows the effects of modifying the shim shape. In this particular case, the valleys (60°) of the shims near the center of the model were cut deeper and the hills (0°) of the shims were raised by soldering iron on the top of the shim surface. The experience gained in the operation indicated that further deepening of shim contour would not appreciably lower the field at 60°.

* Electromagnetic Research Division, ORNL, Progress Report, for period ending June, 1951, Y-795.

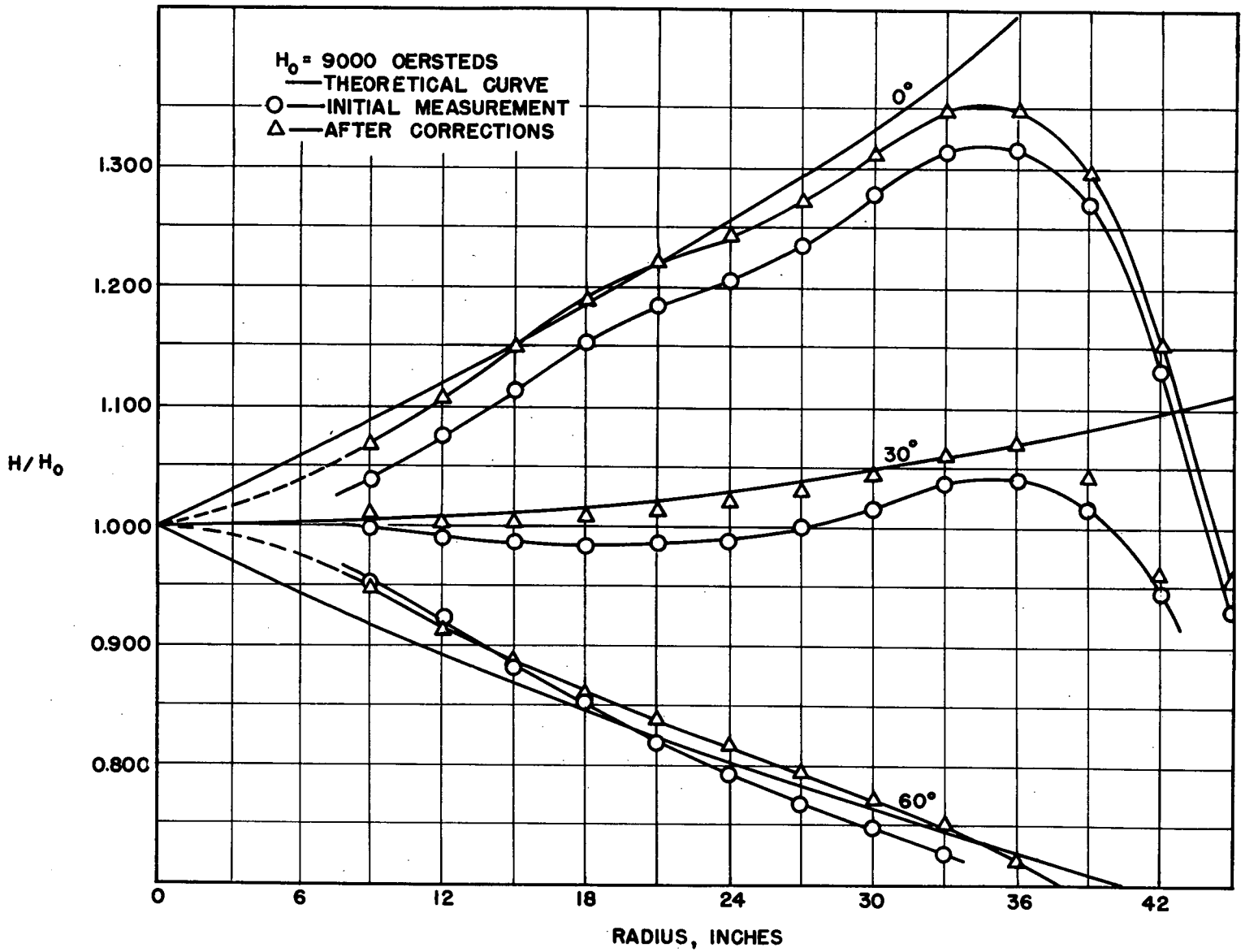

FIGURE 4 THOMAS-TYPE MAGNETIC FIELD FROM MODEL TESTS

It appears that for the final shim design the variations of the field in the vicinity of the center will deviate from the desired field over a region having dimensions of the order of the gap width of the magnet. This conclusion is borne out by a consideration of the solution of Laplaces' equation for such regions.

Liner

Calculations have shown that the copper liner must follow the contours of the inside surface of the shims to preserve adequate electrical clearance. This has imposed several severe mechanical problems since the liner is approximately twice as wide in the valleys as it is in the hills. It has been proposed to make the center section of the liner movable as illustrated in Figure 5, and to provide a mechanical joint which will not impede the rf current. A model of the device for locking the sections of the liner in place has been constructed and is being tested.

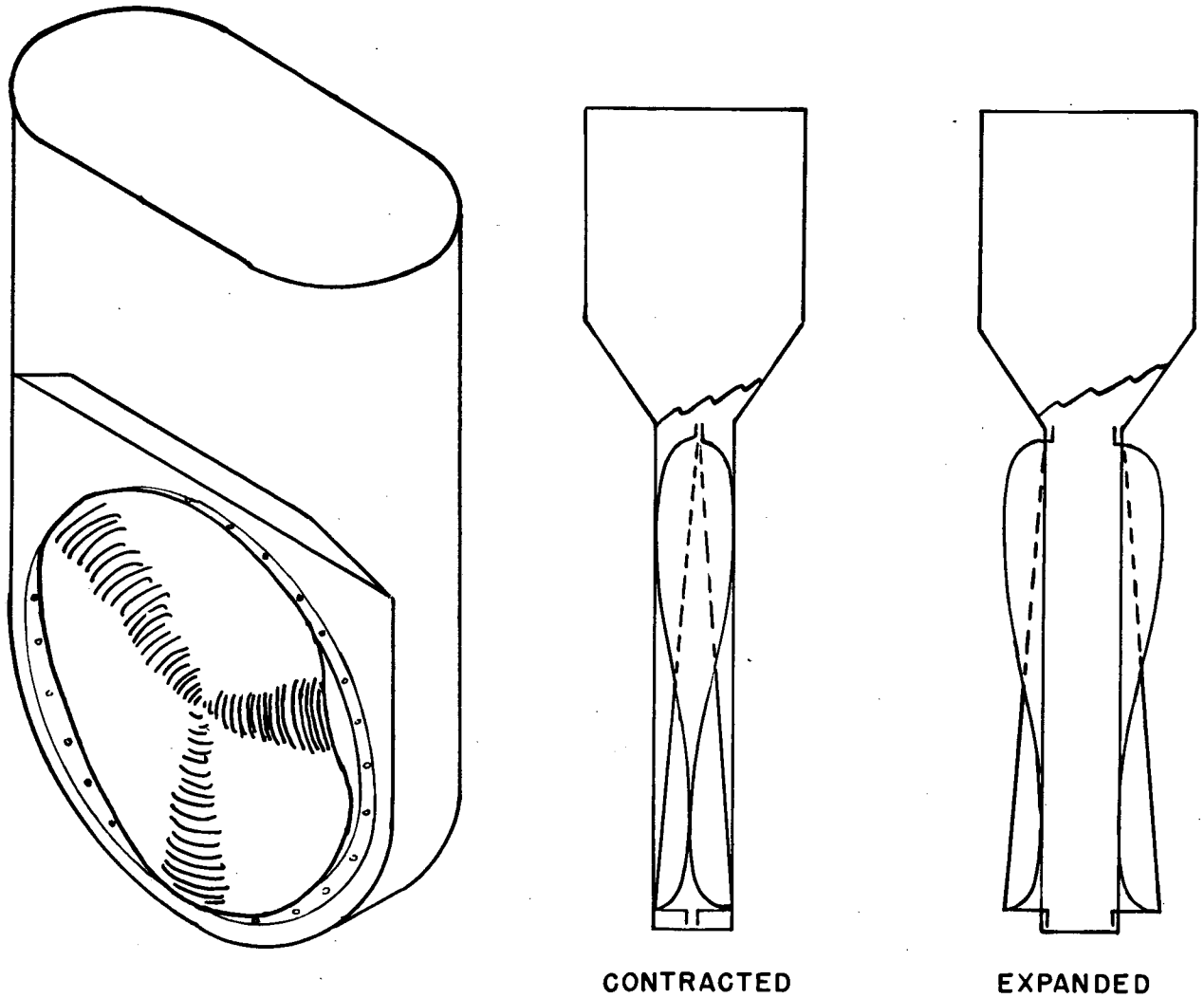

FIGURE 5 EXPANSIBLE LINER

ISOTOPE SEPARATION, LITHIUM

The light isotope program has increased in scope due to the integration of the program with the activities of a group in the Stable Isotopes Division. Grid structures and other equipment have been supplied to this group to facilitate their study of power regeneration collectors.

Both flat and convex grid-type ion sources have been tested with the flat grids continuing to give the highest ion output and the curved grids the best focus. Lithium ion currents of 1500 ma per square inch have been obtained.

Convex Grid Ion Sources

The good ion focus obtained with convex grids has led to intensive efforts to increase the output of this type of electrode system; the output has been only about one-half that obtained from flat grids. From geometric considerations* the focus obtainable from convex grids is superior to the focus from flat grids. Experimentally, the focus from convex grids appears excellent--- much better than indicated by assay data. For one test run the collected product assayed 42% Li 6, or an enrichment factor of 10. Since beam scanning data indicate better enrichment than assay data, it is possible that vaporized lithium escaping from the source is being deposited in the collector pockets; also, poor retention in the Li 7 pocket may increase the contamination of the Li 6 pocket. These problems are not fundamental and, with more attention to equipment design, should be rectified.

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* Electromagnetic Research Division, ORNL, Progress Report (Part II) for period ending September 1951, ORNL-1235.

TARGET TESTING

The resistance thermal cycler is being used to test alpha-rolled uranium rods for determination of the maximum allowable cyclic stresses, and to test various alternate target and associated materials.

Uranium Testing

In the "A" series of tests, reported previously,* it was found that large cracks developed in the uranium specimens after a few thousand cycles. The cycling rate was 30 per minute and the pulsed power 52.2 kw/in^3, which gave a calculated stress of 124,000 psi to the test sample. This series demonstrated that stress failure of uranium could be studied with the present apparatus but, since the calculated stress was greater than the elastic limit for uranium, a modification of experimental conditions was indicated.

The conditions were altered so that the calculated stress on the test rod would be 25,000 psi. This was accomplished by increasing the cycling rate to 2400 cycles per minute and increasing the pulse power input from 52 to 87 kw/in^3. The tests were made with an approximate sine wave power pulse which was "on" a nominal 8 1/3 milliseconds and "off" 16 2/3 milliseconds. The test specimens were alpha-rolled uranium with surfaces which showed only slight oxidation. During the runs a certain amount of rust, probably from the pump, became evident in the water, making reading difficult to obtain and eventually depositing on the sample. To clear the water, 0.05% oxalic acid by weight, was added to the coolant.

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*Electromagnetic Research Division, ORNL, Progress Report (Part II) for period ending September 1951, ORNL-1235.

In all of the tests of the "B" series small hairline cracks developed but only after several hundred thousand cycles; sample failure did not occur until the sample had been subjected to over a million cycles. Holes were drilled in one of the samples to insert a thermocouple and the peak power inpur was held constant during this run at 86.32 kw/in^3 (RMS). Temperatures were recorded hourly as follows: center temperature 370°C, 380°C, 365°C; surface temperature 94°C, 98°C, 98°C. The surface temperatures are probably not too reliable but it is felt that the readings are representative of average conditions. No "swing" was noticed in the readings since the time constants of the thermocouples were much greater than the 7.8 milliseconds "on" time. After the testing of four samples was completed, it was found that an error was involved in the power input due to the 40-cycle pulsing. The actual power input to the test sample was greater than indicated by $\sqrt{3}$. The test was consequently more severe than was intended. However, without the large temperature swing which occurred in the "A" series many more cycles could be applied to the test specimen, even though the average corrected power input was nearly the same. The run conditions for the "B" series are shown in Table II.

Zirconium and Thorium Testing

One sample each of zirconium and thorium has been tested in the resistance thermal cycler. Both specimens were of the dumbbell type with 0.030" holes drilled near the midpoint for center thermocouples and near the ends for voltmeter leads. The thorium rod was 1 1/8" shorter than standard, giving a smaller clamping area, but no difficulty was experienced in achieving sufficient power density. The conditions of the test were similar to those used in the "A" series on alpha-rolled uranium, reported previously. In the

Run No.	Surface Temp Limits °C	Center Temp Limits °C	Pulsing Rate (millisec.) On	Pulsing Rate (millisec.) Off	Pulse Power Input kw/in^3	Remarks
B-1	*	*	7.2	17.8	82 153	First cracks appeared at 640,000 cycles. After 10^6 cycles, power raised to 153.1 kw/in^3. Sample failed near fixed clamp after 1,470,000 cycles.
B-2	98-98	375-375	7.8	17.2	150	No swing was noticed in readings because of time constant in thermocouples. First crack appeared at 278,000 cycles. After 400,000 cycles, a large crack was noticed at one of the drilled holes. Sample failed at 746,000 cycles.
B-3	*	*	7.4	17.6	150	First cracks appeared at 264,000 cycles. Sample failed at 1.5 x 10^6 cycles in the fixed clamp.
B-4	*	*	7.4	17.6	140	First cracks appeared at 163,000 cycles. At 1.6 x 10^6 cycles "spines" were present on surface of specimen. The sample failed at 2,357,000 cycles.

* Samples not drilled for thermocouples.

TABLE II: TARGET TESTS SUMMARY, SERIES B

"A" series it was shown that stress failure occurred in alpha-rolled uranium after a few thousand cycles with a center temperature swing from 100°C to 500°C.

The cycling rate used for the tests on zirconium and thorium was thirty per minute with a 50% duty cycle. The water flow was 11 gpm, giving a mean velocity of 17.7 ft/sec. The maximum power density used for the zirconium rod was 87.5 kw/in^3. As a check on the current and voltage measurements the electrical conductivity of zirconium was calculated from the Brush recorder data giving the value 54 x 10^{-6} ohm-cm at 57°C, which agrees with the value 51 x 10^{-6} ohm-cm found in the literature. After the test the zirconium specimen was lightly tarnished and very slightly warped, but no evidence of failure was noticed. A summary of the test conditions is given below:

Center Temp. Limits	Surface Temp. Limits	Power Density (kw/in^3)	No. of Cycles	Avg. Resistance (ohms/4 1/2")
400 - 62°C	72 - 53°C	45.2	3058	3.07 x 10^{-3}
500 - 62°C	*	59.1	6072	3.22 x 10^{-3}
600 - 62°C	*	87.5	9102	3.33 x 10^{-3}

*Surface thermocouples cracked off early in run.

The thorium rod which was tested at a power density of 76.4 kw/in^3 failed after 8596 cycles. This occurred at a hole drilled through the rod for a center thermocouple. The rod exhibited short, narrow cracks radiating from all of the holes drilled in the test section. No other cracks were noticed but the rod was slightly corroded, particularly near the holes. The center thermocouple failed early in the test. Data taken as the power was being increased gave a center temperature of 300°C at 50 kw/in^3 during the pulse. It is estimated that the peak center temperature at 76.4 kw/cm^3 was 400°C to 450°C. Two additional tests of thorium will be made. The first of these will be run with thermocouples to correlate temperature swing and power density.

The second test will be made without thermocouples, thus eliminating the stress concentration caused by the holes.

Effect of Thermocouple Wire Gauge

Experiments were completed to determine the relative merits of 28 gauge and 32 gauge chromel-alumel thermocouple wire. For each size of wire a power input vs surface temperature curve was obtained for the midpoint of a stainless steel specimen. The curve for the 28 gauge wire was about 35°C below that for the 32 gauge, showing that the greater local cooling with the larger wire is sufficient to cause considerable error. This result, as well as the known higher response speed of the smaller wire, makes the use of 32 gauge wire desirable, in spite of the greater difficulty in making the thermocouples.

OPERATION SUMMARY

A summary of operations in Buildings 9204-3 and 9201-2 for the months of October, November, and December includes the following experimental runs:

Special Separations	16
Isotope Production	37
Electromagnetic Fundamentals	59
Electro-Nuclear Machines	51
Target Design	11
86-Inch Cyclotron	
Isotope Production	37
Nuclear Physics	74
Radiation Damage	48
Experimental Operation	3

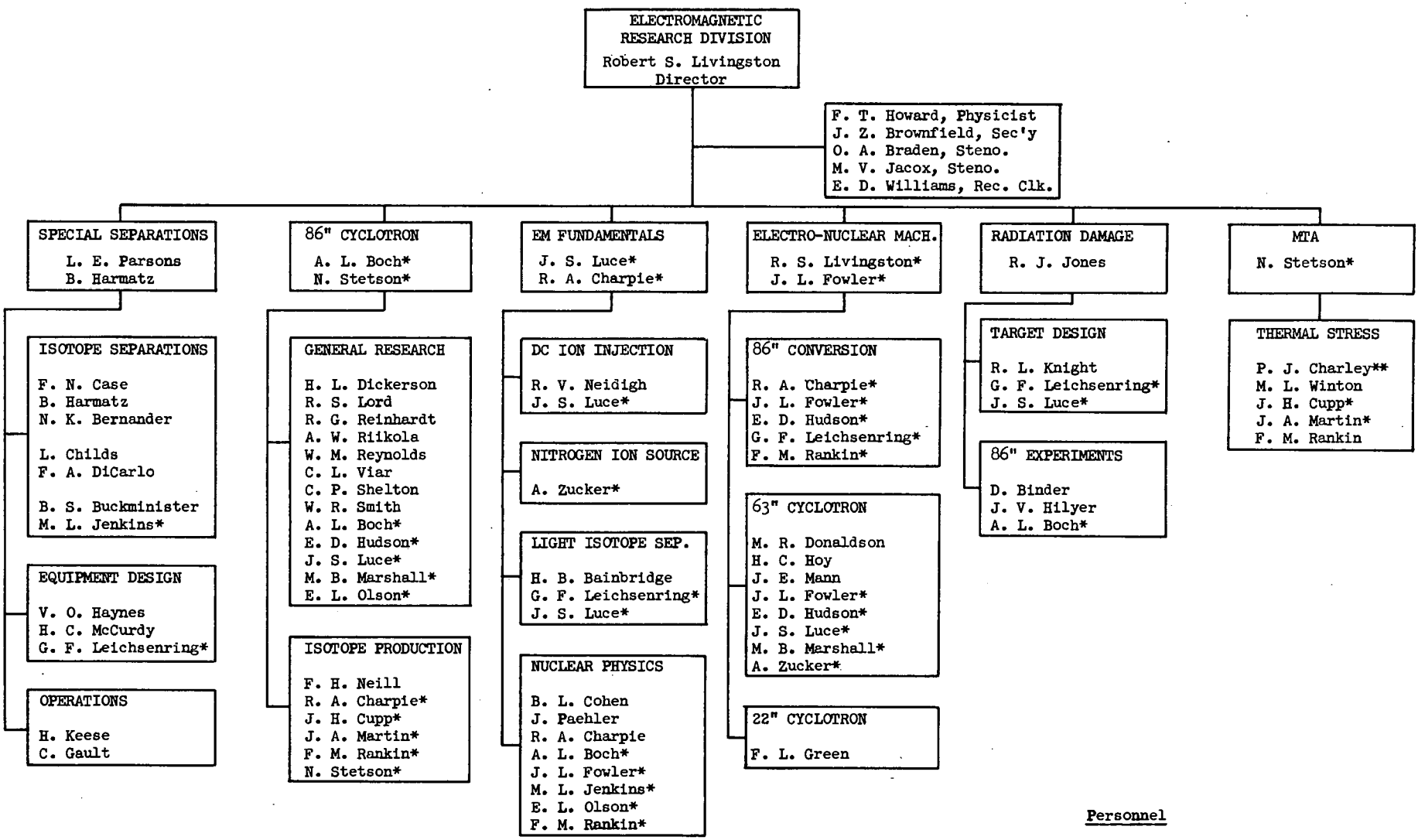
Distribution of shop time charged to each of the various projects is given in Table III.

Assignment of personnel to various projects is indicated by the personnel chart on page 25.

		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" Cyclotron Mechanical	570.4	6.3	170.5	17.2	720.0	26.0
34-243	86" 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	Electromagnetic Fundamentals	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" Cyclotron	1733.9	19.3	3.5	0.4	322.0	11.6
4900-178	Modification of 86" Cyclotron	-	-	-	-	98.2	3.5
4900-181	Alignment Rack for 86" Cyclo. Dees	5.0	0.1	-	-	-	-
4900-194	Vacuum Lock & Associated Equipment for 86" 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



Personnel

41 Monthly
11 Weekly
52 Total

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