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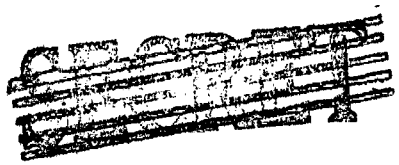

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Radiation Laboratory

BERKELEY, CALIFORNIA

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UNIVERSITY OF CALIFORNIA

Radiation Laboratory

Contract No. W-7405-eng-48

PROGRESS REPORT No. 72

March 15 to April 15, 1949

Berkeley, California

UNIVERSITY OF CALIFORNIA, RADIATION LABORATORY

March 15 to April 15, 1949

PROGRESS REPORT NO. 72

1. Bevatron

UNCLASSIFIED

The vacuum system for the one-quarter scale operating model has been completed and tested. It is possible to achieve a pressure of 2×10^{-6} mm Hg without the liquid air trap. The cyclotron vacuum system is tight including the dee and deflector stems. The injector cyclotron has produced a maximum circulating beam of 18 milliamperes and a deflected, unfocussed beam of 1.8 milliamperes at approximately one foot outside the tank. The assembly of the injecting deflector is complete and it is expected that an attempt will be made shortly to produce a beam in the complete model.

Work on the 18-inch cyclotron has consisted principally of testing the new oscillator to be used in the bevatron model injector cyclotron. No further attempts have been made to improve the focusing since it is felt that no more can be learned that will apply to the injector cyclotron in which the geometry will be quite different. A P.I.G. ion source was tried and gave a beam comparable to that obtained from the filament type source which has been used in most tests to date.

The bids for steel fabrication of the bevatron have been received and fan specifications have been issued for bids. Design work on the core and coils is continuing.

The theoretical group has been looking into the effect of a variation of accelerating voltage with radius. To prevent an increase in the phase oscillation amplitude by more than a factor of two or three, the fractional increase in accelerating voltage should not exceed half the fractional increase in radius. The effect of decrease in voltage with radius has not yet been calculated but it may increase the amplitude of betatron oscillations.

2. 184-inch Cyclotron Operation

UNCLASSIFIED

The cyclotron was used for research experiments ninety percent of the 499 hours that the crew was on duty.

New equipment for the deflection of protons was installed, and a proton beam was obtained in the cave.

3. 60-inch Cyclotron Operation

UNCLASSIFIED

The second model of the grounded deflector was tested during the latter part of the period. It proved to be less successful than the prior model. Attempts at re-design to allow more voltage on the deflector are being made. The operational efficiency over the rest of the time was in the order of 75 percent.

4. Synchrotron Operation UNCLASSIFIED

Additional study of the fluctuation in beam intensity has not yet revealed the reasons for the extremely variable performance. It is now suspected that occasional high intensity performance is due to a thinning down of the filament which results in increased emission, since the best performance with any injector seems to be obtained just before the filament burns out. The mechanism for aiming the injector has been installed. It has been found that there is an optimum position for each injector. An improvement has resulted in the average output of the machine but not in its peak performance. Experiments with injectors designed to have increased emission are still in progress and it is planned to try an injector which uses the high voltage pulse as a deflector to prevent electrons from hitting the back of the injector after their first revolution.

Some work has been done with a contractor which provides a current pulse starting at a time that can be selected by the operator through one of the octant coils. It is usually possible to improve the output by a factor of two with this device. Design work is proceeding on a new booster which will extend the period of betatron acceleration. It is hoped that with this device a larger fraction of the betatron beam will be accepted into a synchronous orbit and that by using the proper shaped pulse it may be possible to prevent the loss of some of the electrons during the betatron cycle which may be caused by the wide variation of voltage gained per turn which is now present.

Much of the original temporary construction has been replaced. The new bias winding has been installed but no bias is being used on the machine at the present time. All compensating resistors have been replaced and the present resistors are being operated within the rating.

Most of the past month has been devoted to runs using nuclear plates adjacent to a carbon target to obtain statistics on meson production. The technique of observation has been considerably improved by means of a beam collimator which reduces the background of the plates. A considerable time has been devoted to a study of transition thicknesses for various materials. The results of these procedures will be reported elsewhere.

5. Linear Accelerator and Van de Graaff Operation UNCLASSIFIED

On March 28, the linear accelerator and Van de Graaff were shut down for extensive changes in the building, and improvements in the machines.

The P. I. G. ion source was installed in the Van de Graaff. It should provide a substantial increase in beam current. A refrigerator is being given its final tests under 100 p.s.i. pressure and will later be installed in the high voltage shell when it is proved satisfactory.

The linear accelerator tank was opened for an inspection and cleaning of the drift tubes. Some silver plating is being done on places where polishing had removed it. Lead was installed in the tank to reduce the X-ray background in Building 10. The pulse lines are being rebuilt to double the pulse length and this, together with doubling the repetition rate, will give an increase of four in the duty cycle.

All the power supply equipment is being concentrated in the old amertran room, with a resultant increase in laboratory working space. The bombardment area is being enclosed by a concrete brick wall and has been greatly enlarged by taking over the men's locker facilities and wash room.

It is expected that the linear accelerator and Van de Graaff will be in operation again about April 27.

6. Experimental Physics

RESTRICTED

Film Program. The main effort has been on the range-energy relation of protons in emulsions. Experimental data at 39 Mev fall slightly below values extrapolated from the data of Lattes, Fowler and Cüer for protons of 13 Mev maximum.

Observations are being continued on electrons arising from meson decay. In eleven observed π^+-μ^+ decays where the entire μ remained in the emulsion, 3 definitely had high energy ϵ tracks originating at the end of the μ meson tracks. Sensitivity of the plates was too low to allow any conclusion to be drawn in all other cases as to whether there were electrons associated with the μ mesons, and background grains were too frequent to permit reliable estimates of ϵ energy by scattering. Further exposures with better shielding and more sensitive plates are being contemplated.

The synchrotron has been used to produce ϵ tracks of approximately minimum ionization in photographic plates, with the following results for representative emulsions:

Type	NT4A	NTB3	G5	G5
Emulsion No.	4595	401774	2999	3013
Grains per 14.3 μ	8.4	5.3	7.7	8.8

Plates for determining excitation curves of meson production by protons on carbon are being scanned. Very rough preliminary results give a factor of 10 drop in differential cross-section (for 11-14 Mev mesons) from 345 Mev to 240 Mev, and a factor of 100 from 345 Mev to 204 Mev.

The half life of the π^+ meson has been found to be the same, within the accuracy of the experiment, as Richardson's value for the half life of the π^- meson.

Cloud Chamber. A series of cloud chamber pictures have been taken in the neutron beam of the 184-inch cyclotron in an effort to detect slow mesons with a lower background. The yield of interesting events is negligible.

At the synchrotron the cloud chamber which is 85 feet away from the accelerator, has been located accurately in the center of the x-ray beam by passing the beam through an 1/8 inch hole in a lead collimator. The beam has approximately a two-inch diameter in the center of the chamber. A series of pictures of the showers produced in lead were taken with this arrangement.

A cloud chamber has also been placed in the deflected proton beam at the 184-inch cyclotron to discover if the background there will permit cloud chamber experiments. The first pictures indicate that further collimation of the beam is necessary.

Neutron Cross Section Measurements at 40 Mev. Using the 40 Mev average energy neutron beam resulting from the bombardment of a 1/2 inch Be target at 55 inches with deuterons in the 184-inch cyclotron, neutron total cross sections are being measured for as many elements as possible. The neutron detectors used are carbon discs activated by the $C^{12}(n,2n)C^{11}$ reaction which has a threshold at 20 Mev. The elements measured are:

H, D, Be, C, O, Al, Cu, Mo, Sn, Pb, U

Fission Chamber Measurements. The ratio of inelastic to total cross section has been measured for three different elements using bismuth fission chambers for the neutron beam emerging from the 184 inch cyclotron when 350 Mev protons are incident on a 2 inch Be target. The results are

El.	σ_i/σ_t
Al	.44 ± .03
Cu	.50 ± .02
Pb	.46 ± .03

The total cross section of hydrogen was measured using pentane-carbon difference. The value obtained is .037 ± .002 barns for the 270 Mev neutrons.

Mass Spectrograph. The magnetic field measuring device (germanium crystal) described in previous reports has been further modified. A definite temperature effect was corrected by mounting the crystal in a water-cooled copper block and filling the center with silicone oil.

New magnet current and high voltage metering and vernier circuits have been designed and are being built. A new leak and sample system have been designed in preparation for some runs with organic samples. As these will be a mixture of several different gases, the leak must give only molecular flow.

Samples of nickel 58 and 60 were analyzed but the results were not very accurate as there were large amounts of copper and zinc present. A normal butane sample was run in preparation for more organic samples.

Determination of Energy Distribution in Neutron Beam. Further experiments using magnetic energy discrimination to determine the distribution in energy of neutrons produced by 350 Mev protons in the 184 inch cyclotron continue to show a peak at about 270 Mev, with a half-width of about 100 Mev.

A study is being made of the relative merits of various experimental arrangements making use of the magnet, with the purpose of developing efficient techniques for studying the secondary particles produced in various elements by the 270 Mev neutron beam.

Experiments with the 300 Mev X-Ray Beam. (γ,n) reactions have been observed using the synchrotron x-ray beam on the elements carbon, copper, and molybdenum. An apparatus is being set up to measure the dependence of (γ,n) cross section on the maximum γ-ray energy in the range 100 to 300 Mev.

High Energy Gamma Rays from the 184-inch Cyclotron. By arranging the counters and magnetic field in the form of a 90° pair spectrometer (instead of the 180° type thus far used) it has been possible to find the peak of the gamma ray distribution for both 0° and 180° directions with respect to the proton beam. These energies at the maximum are about 120 mev and 70 mev for 0° and 180°, respectively. Two other angles of view have also been obtained, namely 47° and 133°. Energies at the maxima for these are 100-110 Mev, and 70-80 Mev, respectively. The yield as a function of angle suggests spherical symmetry in the coordinate system of the emitter.

Rough data have been obtained on an excitation function.

7. Theoretical Physics — UNCLASSIFIED

The meson production calculations give cross sections for the production of positive (negative) mesons by 300 Mev γ-rays on protons (neutrons) which indicate an excess of negative mesons predicted by pseudo-scalar theory (about 1.6:1) but about equal production of positive and negative on the basis of the scalar theory. The average cross sections are about 3×10^{-28} cm^2 per proton and 4.5×10^{-28} cm^2 per neutron.

Calculations are also being made on shower theory as applied to the synchrotron operation to obtain information about angular spread, density, and effects of ionization and shielding in showers.

8. Chemistry — CONFIDENTIAL

Part A

Neutron Deficient Isotopes of Polonium, Bismuth, and Lead. It has now been shown that Bi^{203} has a half-life of about 13 hours by observation of the growth of its daughter, 52-hour Pb^{203}. That Po^{203} decays with approximately 50-minute half-life to this Bi^{203} has been shown by milkings of bismuth from a mixture of polonium isotopes. This chain of mass 203 previously escaped detection because of confusion with 12-hour Bi^{204} which grows from 4-hour Po^{204}. The alpha activity of Po^{203} has not been resolved from the other activities present.

Alpha Half-life of U^{231}. An estimate of the alpha branching in the decay of 4-day U^{231} has been made by milking of Th^{227}. The principal mode of decay of U^{231} is by electron capture. The alpha branching observed corresponds to an alpha half-life of approximately 100 years for U^{231}.

Beta Spectrum of 64-Hour Re^{182}. The possibility of beta decay of Re^{182} is of interest because Os^{182} may be a stable isotope undetected in nature. An examination of the beta spectrum of the 64-hour Re^{182} has been made in cooperation with Helmholz and Hayward using a magnetic lens spectrometer. Conversion lines were

found corresponding to gamma energies of 350, 254, 165 and 130 kev. No evidence was found for a continuous beta spectrum.

Aqueous Oxidation Potential for the Am^{+3} - Am^{+4} Couple. From a measurement of the heat of solution of AmO_2 in 6M HNO_3 - 0.1 M HBF_4 to give $\Delta H = -30.4 \pm 2$ kcals for the reaction:

$$AmO_2 + 3H^+ \longrightarrow Am^{+3} + 3/2\ H_2O + 1/4\ O_2$$

It is estimated that the formal potential for the couple

$$Am^{+3} = Am^{+4} + e^-$$

is -2.6 ± 0.2 v, assuming that ΔS for the reactions are the same as for the corresponding plutonium species, and that the difference between the heat of formation of AmO_2 and Am^{+4} is the same as that between PuO_2 and Pu^{+4}.

A value of -3.1 ± 0.2 v is estimated for the Pr^{+3} - Pr^{+4} couple, from similar reasoning and a measured heat of solution of PrO_2 in 6M HNO_3 - 0.1M HBF_4 to give $\Delta H = -42.5 \pm 2$ kcals.

Thermal Decomposition of AmO_2. The thermal decomposition of AmO_2 has been carried out in the range $AmO_2 \longrightarrow AmO_{1.85}$. From measurements of the oxygen pressure in equilibrium with the oxide the ΔH per mole of O_2 has been computed as 21 kcals.

In the course of these measurements the quantity of O_2 absorbed by Am_2O_3 at 500° C was determined. The composition of the higher oxide corresponds to $AmO_{1.98 \pm 0.02}$.

Chemistry UNCLASSIFIED

Part B

Synthetic and Experimental Chemistry. The condensation of methyl iodide with acetaldehyde has been carried out in hexyl ether to give a satisfactory yield of isopropyl alcohol. This compound has been converted to isopropyl bromide by reaction with phosphorus tribromide and will be condensed with acetamidomalonic ester to give valine-γ-C^{14}.

The conversion of α-bromopropionic acid to give zinc lactate has been studied on a 15 mmole scale. Over 80 percent yield of lactic acid can be obtained. Since the preparation of α-bromopropionic acid has previously been studied in the synthesis of alanine, it is hoped that it will shortly be possible to make this compound labeled in any one of the three positions.

A high activity preparation of codeine-methoxy-C^{14} been made. About 50 percent yield based on carbon dioxide was obtained on a 15 mmole run and material of approximately 1 μc/mg. specific activity was prepared.

Carboxyl-labeled fumaric acid was converted to carboxyl-labeled d,l-tartaric acid by oxidation with sodium perchlorate in the presence of osmic acid. The paper chromatographic coordinates of this acid were determined.

The use of lithium aluminum hydride with other solvents than carbitols is being studied because some splitting of ethers by this reagent seems to take place.

In addition, the synthetic preparation of the following compounds is being studied: alanine-3-C^{14}, leucine-β-C^{14}, isobutyl bromide-1-C^{14}, oxalacetic acid-methylene-C^{14}, fumaric acid-C^{14}, succinic acid-C^{14}, Demerol-N-methyl-C^{14}, glucose-1-C^{14} and mannose-1-C^{14}.

Biological Chemistry. Work on the study of the rate in mice of metabolic oxidation to $C^{14}O_2$ of simple labeled organic compounds is continuing. In addition, some Warburg experiments with liver slices are being performed with the same type of compounds. A program has been started to study the exact nature of the compounds into which these simple molecules are metabolized.

A health hazard question that has not been answered and one of long standing concerns the rate of exchange of radio barium carbonate in the lungs with carbon dioxide of the air or body system. A series of short-term experiments has been instituted to try to determine just how rapidly this takes place with barium carbonate injected as a colloidal suspension in the vein or as a dust slurry in the lungs or in the muscles.

Photosynthetic Chemistry. Barley and geranium leaves have been subjected to short periods of photosynthesis with labeled carbon dioxide. The products formed by these plants are, in general, the same as those for the algae Scenedesmus and Chlorella. The major radioactive product of 2-second photosynthesis by barley and 4-second photosynthesis by geranium is phosphoglyceric acid. Longer periods of photosynthesis produce the same intermediates in the synthesis of sucrose as in the algae.

In geranium appreciable amounts of the two-carbon acids, glycine and glycolic acid appear. This suggests that the alternative path of regeneration of a C_2 acceptor molecule of the algae is functioning.

In barley the same two-carbon acids are found and, in addition, at least two new compounds. Free glyceric acid has been identified in the radiograms (radioautographs of paper chromatograms).

Experiments to determine the effect of malonate inhibition on photosynthesis show that the formation of malic acid in 90-second periods of photosynthesis with Scenedesmus is reduced by 80 percent or more when the algae cells are suspended in a pH 4.5 malonate buffer (5.0 mg./ml.) for three hours prior to the period of photosynthesis. Degradation of alanine from the same experiments shows that about 40 percent of the radioactivity is in the alpha- and beta-carbon atoms and 60 percent in the carboxyl-carbon atom in both malonate-inhibited and non-inhibited 90-second photosynthesis. It is felt that the two-, three- and four-carbon acid cycle which has been proposed for the reduction of carbon dioxide in photosynthesis is in operation during the malonate inhibited experiments and that malic acid is not, therefore, a member of this cycle.

It has been found that no hydrolysis of glucose-1-phosphate occurs during chromatographing in either phenol or a mixture of butanol and acetic acid. When glucose-1-phosphate and fructose-6-phosphate were chromatographed in phenol or a

mixture of acetic acid and butanol, the positions of the two compounds were overlapping in both solvents.

Work is continuing on the separation of ortho-phosphate and hexose monophosphate by use of Dow A-1 resin.

Preliminary experiments have been done to determine the rates of incorporation of radioactive amino acids into proteins.

Chemistry SECRET

Part C. Project 48B

Metals and High Temperature Thermodynamics. Work is in progress on the following problems.

1. Refractory studies.
2. Thermodynamics of CN and N_2.
3. Absorption coefficients of CN and C_2.
4. Thermodynamics of molybdenum halides and oxides.
5. Thermodynamics of gaseous aluminum oxides.
6. Low melting metal systems.
7. Structure of solids and gas-solid surface interactions.

Basic Chemistry. Solvent Extraction. The following problems are under investigation.

1. The exchange of iodine atoms between iodate ion and iodine.
2. The chelate complex of lanthanum with TTA.

Engineering Development of Plutonium Separation. The following subjects are being investigated.

1. Solvent extraction using chelate process.
2. Pilot-scale synthesis of TTA is now completed.
3. Mechanisms of TTA synthesis are being investigated.

Ore Reduction.

1. A micro titration method for U(VI) is being developed.
2. A method for determining the oxidation state of uranium using the dropping mercury electrode is being investigated.
3. A photovolt Model 500 Fluorimeter has been used for fluorimetric analysis of uranium but the lower limit of this method is not low enough for our purpose. A photomultiplier is under construction and it is hoped to be able to analyze as little as 5×10^{-10} g uranium. A Photovolt Model 512 Fluorimeter has been ordered for use in conjuction with this work.

9. Medical Physics UNCLASSIFIED

Part A

Tracer Studies. The metabolism of praseodymium in rats has been completed. This material was administered as carrier-free material, complexed with oxalate, complexed with citrate, with added carrier, and with neodymium carrier. Distribution in the animals follows a typical pattern of the lanthanide rare earth series, this being primarily liver and skeletal deposition.

Radioautographic Studies. Radioautographic studies with praseodymium in bone, and plutonium in scar tissue are continuing. Work is in progress on special NTB emulsions in the study of plutonium distribution in the costochondral junction.

Decontamination Studies. Studies of the effect of zirconium citrate therapy and of endocrine factors in bone metabolism are being continued. The pituitary growth hormone was found to cause increased growth at the epiphyseal disc even in rachitic animals, but there was significant effect on the deposition of radiostrontium. Metabolic studies with radiofluorine and radiocalcium are being initiated.

Radiochemistry. Two Oak Ridge shipments of Y^{91} were checked by column separation and were found to contain a single activity. The peak activity corresponded to the carrier peak as determined by spectrographic analysis. Twenty samples of 0.5 mc each were prepared for injection.

A satisfactory method has been developed for separating At^{211} from organic material. Preliminary data have been obtained on the distribution of At in the rat 18 hours after injection. Thyroid uptake was found to be $\sim$4.5 percent. Four hundred microcuries of carrier-free radio-arsenic were separated from a germanium target using a distillation method previously reported.

Medical Physics UNCLASSIFIED

Part B

Radioiron Study in the Blood of Normal and Polycythemic Rats. Two groups of adult female rats were used. Group I consisted of 5 normal control animals and Group II 4 polycythemic animals produced by daily intraperitoneal injection of 0.12 milligrams of cobalt and 0.2 milligrams of iron. The rate of disappearance of a tracer dose of Fe^{55} and Fe^{59} from the plasma, the amount of tracer present in the red cells at daily intervals up to 8 days, and the plasma iron was determined in both groups. The blood volume of the polycythemic animal was determined on the last day of the experiment.

The average half time for the disappearance from the plasma of a tracer dose was 109 minutes in the normals, and 99 minutes in the polycythemic animals. The average serum iron was 3.4 gamma per cubic centimeter in normal rats and 3.8 gamma per cubic centimeter in the polycthemic animals. The maximum uptake of the tracer iron by the red cells was 30 percent in the normals and 37 percent in the polycythemics. The mean half of the red cell of the normal was 95 days and that of the polycythemic red blood cells was found to be 96 days, as calculated from the rate of turnover of iron in the red cells.

Tissue Radiation Dose Study. Direct measurement of ionization produced in tissue by radiations from radioactive isotopes was found to be the only reliable method for ascertaining the dose delivered to very small organs such as those in mice and rats, and in thin tissue layers in man. In such cases, where the linear dimensions of an organ are comparable to the range of beta particles, dose calculations are unreliable unless a large empirical correction can be inserted to take into account the radiation which is not absorbed in the tissue under consideration. It is found, however, that the necessary correction can be made if an empirical curve can be established which represents the ion density (ions/cc) as a function of the distance in tissue from a point source for each radioactive isotope. Since data of this kind is not available it is necessary to undertake such measurements in order to evaluate the results of extensive experiments on mice and other laboratory animals in which radioactive isotopes were used.

For this purpose direct measurements of ionization were undertaken using a point source, and a cavity ionization chamber which can be placed at arbitrary distances from the source in a tissue-like medium. Two experimental arrangements are now in use. The first consists of solid material (polystyrene) in which the source and chamber are inserted, and the second consists of tissue-like gas surrounding the source and chamber; the latter arrangement is necessary to extend the measurements down to very low energy beta particles. With these arrangements, the ionization curve can be measured over the range of tissue thickness from about 0.1 mg per cm^2 to 10 gm per cm^2. Thus far the ionization curve of I^{131} has been measured in the solid absorber. Further measurements on I^{131} and other biologically important isotopes are to be continued.

10. Health Physics and Chemistry UNCLASSIFIED

A Bi fission counter has been used as a survey instrument for detecting the number of very high energy neutrons emerging through the 10 ft. concrete shielding. The counting rates range between 0.5 and 2 counts/hr. By comparison with the counting rate of the same instrument in the approximately-known flux of the neutron beam, it is concluded that one count per hour denotes a flux density of about 1 neutron/cm^2sec over 50 Mev.

The projects currently in progress in the Research and Development group of the Health Chemistry Section during the period March 15, 1949 to April 15, in addition to the routine work of monitoring, decontamination, and disposal are as follows:

1. Work in preparation for the arrival of a special slug from Hanford during May is 60 percent complete; the slug opener is complete and the completion of the chemistry unit is well under way.

2. Universal pipettor for microchemistry was used in model form on a special job.

3. Four 4 foot screwdriver was created for use on active objects, especially targets.

4. Special equipment was assembled and used in work on a Hanford shipment.

5. A special stirrer for use in Dr. Gofman's box for the safe processing of radio-yttrium and strontium was completed.

6. A hood for electrodeposition work by Dr. Tobias and Dunn was completed.

7. A two-speed, high capacity blower was installed in a Berkeley box in preparation for special alpha work.

8. Four Berkeley boxes were completed and delivered.

LMB/4-27-49
Information Division

SUMMARY OF RESEARCH ACTIVITIES

March 15 to April 15, 1949

60-inch Cyclotron — UNCLASSIFIED

1. Development of ion sources for carbon and oxygen ion beams.

   Counter equipment about ready to start evaluation of cones.

2. General studies aimed at increasing power output. (E.g., the replacement of dees, dee supports and grounding spiders with new design.)

   Temporarily suspended.

3. Application of studies of magnetic shimming to reducing the dee and deflector voltage requirements and to increasing the energy.

   184 inch model tests indicate that 1-1/2 inch improvement can be affected by increasing pole face diameter from 60 inch to 72 inch.

4. Improvement of handling equipment for targets and ion source to reduce the exposure of personnel.

   Three test models of target assemblies are now being tested. These provided clamped vacuum seals replacing screw connections.

5. Application of remote control to filament depth and other adjustments.

   Still in fabrication stage.

6. Development of hydraulic motor for remote control of adjustments inside the vacuum.

   Temporarily suspended.

7. Other developments.

   Impetus has been placed on grounded type deflector to replace present voltage variety. Two models have been tested to date.

184-inch Cyclotron — UNCLASSIFIED

1. Installation of new, higher-power magnet generator.

   Motor not yet delivered.

2. Development of improved beam monitoring equipment.

   Under construction.

184-inch Cyclotron (Continued) UNCLASSIFIED

3. Design and construction of improved targets and target handling equipment to meet continuing experimental requirements.

   Some parts completed; other parts still under development and construction.

4. Other developments.

   Improved electrostatic deflector being devised. Bayonet lock completed for the foil head on jiffy probe. Allows quick removal of radioactive targets.

300 Mev Synchrotron UNCLASSIFIED

1. Studies of influence of operating parameters on synchrotron output.

   Additional study is being made to determine the causes of the fluctuations in beam intensity.

2. Operational studies, related to bevatron problems, such as studies of effect on beam current of (a) magnetic field variations, (b) vacuum chamber cross sectional area, (c) beam scattering; study of catching conditions for pulling ions into synchronous orbit.

   No work during this month.

3. Search for mesons using 300 Mev X-rays.

   A study is being made of meson produced in photographic emusions by 300 Mev x-rays. The technique of observations has been considerably improved by means of a beam collimator which reduces the background on the plates.

4. The determination of absorption coefficients of various materials for high energy x-rays.

   Measurements are in progress.

5. Study of nuclear reactions produced by high energy electrons and x-rays.

   (n,γ) reactions with high energy x-rays have been observed in C, Cu, and Mo.

6. Other developments.

   A mechanism for aiming the injector has been installed. Design work is proceeding on a booster to extend the period of betatron acceleration.

Linear Accelerator and Van de Graaff — UNCLASSIFIED

1. General replacement of temporary construction and changes indicated by operational experience.

   Extensive changes were made during this period to improve the operation of the machines and to make more space for experimental equipment.

2. Redesign and replacement of component parts of Van de Graaff generator as required in light of continuing operation.

   A refrigerator is being given final tests at 100 p.s.i. pressure and will be installed in the high voltage shell of the Van de Graaff, if it proves successful.

3. Development of ion sources for Van de Graaff generator and bevatron.

   A P.I.G. type ion source has been installed in the Van de Graaff to increase the out-put.

4. Use of 32 Mev proton beam for proton-proton scattering and other experiments exploring the fundamental properties of nucleons.

   All experimental work has been at a halt while the repairs and modifications are being made.

Bevatron — UNCLASSIFIED

1. Operational studies using low-power one-quarter scale operating model.

   Vacuum system completed and tested. Obtained a pressure of 2×10^{-6} mm Hg, untrapped. Injector cyclotron has produced maximum circulating beam of 18 milliamperes and deflected, unfocussed beam of 1.8 milliamperes at approximately 1 foot outside tank. Expect to be ready to try for beam by April 23.

2. Erection of crane and magnet. Construct and install magnet coils, vacuum system, controls and accessory equipment.

   Fan specifications issued for bids. Steel plate fabrication bids received. Design work on core and coils continuing.

3. Developments of an injection system.

   Development test concluded. Crew has been transferred to quarter-scale injector operations.

PHYSICS RESEARCH

General

UNCLASSIFIED

1. Range measurements for fast particles.

   No work during the month.

Fundamental Properties of Nucleons.

UNCLASSIFIED

1. Neutron-proton scattering.

   Experiments are continuing.

2. Proton-proton scattering.

   Much effort has been spent in this experiment with counter techniques in the cave. Serious difficulties have been encountered which are being studied.

   A run was made with a cloud chamber in the deflected 350 Mev proton beam to determine the amount of background for a p-p scattering experiment. An investigation of the angular momentum above $\ell=2$ for p-p scattering at 32 Mev shows negligible effects for any physically reasonable potential. On completion of measurements, detailed phase shift analysis will be attempted.

3. Scattering of protons and neutrons on deuterons.

   Bombardment of deuterons by 90 Mev neutrons should produce a sharp forward deuteron peak (as from carbon). Calculations on the protons ejected from inelastic n-d collisions have begun.

4. Other scattering experiments.

   The study of charged particles emitted from nuclei under neutron bombardment continues.

5. Life time of the neutron.

   No progress during the period of this report.

6. Production of mesons by 390 Mev alpha particles, 350 Mev protons, and 300 Mev X-rays.

   Extensive cloud chamber experiments have been done to detect low energy mesons produced by neutrons.

   Average cross sections for meson production by γ-rays on protons or neutrons are about 3×10^{-28} cm^2 per proton and 4.5×10^{-28} cm^2 per neutron. Calculations on production by 350 Mev protons are being extended to other meson theories than scalar.

Fundamental Properties of Nucleons. (Continued) UNCLASSIFIED

7. Other experiments.

Study of the high-energy γ-rays from the 184 inch cyclotron continues actively.

Nuclear Reactions. UNCLASSIFIED

1. Types of reactions produced by particles and X-rays at various energies.

(γ,n) reactions have been observed using the synchrotron x-rays on the elements C, Cu, and Mo. An attempt is being made to understand theoretically the results of York and Powell on the interaction of 90 Mev neutrons with carbon by a more detailed nuclear model.

2. Energy dependence of reactions.

An apparatus is being set up to measure the dependence of (γ,n) cross section on the maximum γ-ray energy in the range 100-300 Mev.

3. Study of radioactive isotopes formed and their decay properties.

A new isomer of Co^{58} has been observed. It is formed by Mn (γ,n), CO(n,2n), Ni(n,p). It decays to the well known 72 day Co^{58} with the emission of highly converted 23 Kev γ-rays. The half life is 9.3 hours.

4. Total cross sections for neutrons and charged particles for various elements.

Studies continue on total cross sections at neutron energies of 40 Mev and at 270 Mev. An attempt is being made to fit neutron cross sections at 45 Mev and 275 Mev theoretically.

5. Study of the characteristics of fission and fission product yields produced by high energy particles.

Some excitation functions of U and Th fission have been measured with the 60-inch cyclotron.

6. Other Experiments.

Some measurements of the fluorescent yield in At have been started.

Instrumentation UNCLASSIFIED

1. Instrumentation in support of cloud chamber development.

   Measurements have been made of the timing interval in the fast timer circuits in an attempt to discover why they do not remain constant.

2. Development of ionization chambers and Lindemann or vibrating reed electrometers for specific purposes, such as hydrogen 3 analysis for use in medical physics.

   Ionization chamber methods are in use in an attempt to evaluate dosage delivered by radioisotopes in tissue.

3. Continuing development of solid counters, and studies of suitable materials, including naphthaline, anthracene, etc.

   Applications to medical physics of γ counting by scintillation counters is under study.

4. General development of electronic counting equipment.

   Work continues on the development and construction of electronic equipment for special laboratory use.

5. Development of gas-filled counters in various forms to meet specific research requirements, such as n-ϕ scattering, neutral meson detection, etc.

   Various counters for special uses are in process of construction.

6. Development of radiation survey instruments.

   Fast-neutron survey instruments are being developed.

7. Applications of Nier spectrometer and development of low-mass sprectrometer.

   Program begun on studying chemical effects of radiation.

8. Instrumentation in support of chemistry program, including special mass-spectrograph for assigning mass numbers, x-ray spectrograph, beta-ray spectrograph, spontaneous fission counters and special counters for measurements in accelerator beams.

   Various phases of the instrument development in support of the chemistry and health chemistry programs are being actively pursued.

Electromagnetic Isotope Separation — SECRET

1. Design and construction of experimental units.

   Inactive.

2. Development of rf source units.

   Inactive.

3. Investigation into neutralization of space charge, including rf photoelectric and thermionic emission methods.

   Inactive.

Nuclear Chemistry. — CONFIDENTIAL

1. Preparation and properties of all neutron-deficient isotopes that can be reached with the 60-inch and 184-inch cyclotrons.

   Evidence has been found for Po^{203} and Bi^{203}. Work is in progress on a large number of other elements.

2. Determination of cross sections for the many spallation reactions at high energies.

   Work is continuing on yield of products of spallation of copper with 350 Mev protons for comparison with results with deuterons and helium ions.

3. Characteristics of bismuth, lead, and other element fission. Theory for the process.

   Fission of tantalum is being studied.

4. Extension of fissionability measurements below tantalum into the rare earth elements.

   No progress.

5. Characterization of fission of uranium and thorium induced by high energy particles.

   The relative yields of some products from fission of uranium with 350 Mev protons have been determined, and additional measurements are underway.

6. Identification of the interesting new bismuth alpha-emitters.

   Milking experiments are in progress to better determine the mass assignments of the light bismuth isotopes.

Nuclear Chemistry (Continued) CONFIDENTIAL

7. Attempt preparation of elements 97 and 98.

No progress.

8. Preparation of larger amounts of americium 241 and curium 242 for chemical and nuclear studies.

No progress.

9. Preparation of those isotopes of americium and curium (also neptunium and plutonium) which have not yet been prepared, and the determination of their properties, including spontaneous fission rate and slow neutron fissionability.

Pu^{235} has been better characterized.

10. Determination of amounts and properties of transplutonium isotopes produced by the intense neutron irradiation of plutonium and americium.

Experiments are being made with the mass spectrograph to try to adapt it to the isotopic analysis of bombarded plutonium and americium.

11. Chemical identification of the products from nuclear reactions with 350 Mev protons.

Protons are being utilized in problems 1, 2, 3, 5, and 16.

12. Study of meson reactions by chemical means.

No progress.

13. Development of chemical analysis techniques utilizing radioactive tracers.

No progress.

Chemistry of Heavy Elements. CONFIDENTIAL

1. Microchemical studies of curium in pure form to determine its chemical properties.

No progress.

2. Further studies of americium including its oxidation states and other basic chemical and metallurgical properties.

The Am^{+3}-Am^{+4} oxidation potential in acid solution has been estimated from thermal data.

Chemistry of Heavy Elements. (Continued) CONFIDENTIAL

3. Chemistry of protoactinium and neptunium and other elements about which little is known. Studies of their metallurgy.

No progress.

4. Chemical properties of the rare earth elements for comparison with the actinide elements.

Work continues on possible lower oxidation states, on hydrolysis of $LaCl_3$, and on oxide equilibria.

5. Methods of separating americium, curium, and higher elements from each other and from the rare earths.

No progress.

6. X-ray diffraction determination of crystal structure of compounds of neptunium, americium, and curium.

No progress.

7. Thermochemical studies of compounds and metals of heavy elements.

Thermal data have yielded estimates of the Pr^{+3}-Pr^{+4} and Am^{+3}-Am^{+4} oxidation potentials.

8. Investigation of the chemistry of astatine (element 85) on a tracer scale. Formation and study of new isotopes of astatine.

Work is in progress to try to identify the light isotopes of astatine by milking the corresponding polonium and bismuth daughters.

9. Other experiments.

The lower halides of thorium are being investigated by chemical studies and by x-ray diffraction.

High Temperature and Pile Chemistry. SECRET

1. Metals and high temperature thermodynamics.

Work is in progress on refractory studies, thermodynamics of CN and N_2, absorption coefficients of CN and C_2, thermodynamics of molybdenum halides and oxides, thermodynamics of gaseous aluminum oxides, low melting metal systems, and the structure of solids and gas-solid surface interactions.

2. Basic chemistry. Solvent extraction.

Investigations are continuing on the exchange of iodine atoms between iodate ion and iodine, and on the chelate complex of lanthanum with TTA.

High Temperature and Pile Chemistry — SECRET

3. Engineering development of plutonium separation.

The pilot scale synthesis of TTA is complete and the mechanisms of TTA synthesis are being investigated.

4. Ore reduction.

A micro titration method for U(VI) is being developed and a method for determining the oxidation state of uranium using the dropping mercury electrode is being investigated.

Plant and Equipment — UNCLASSIFIED

1. Completion of bevatron building; continuation of bevatron construction.

Work has been progressing slowly on the 48 inch drain line. Although the weather has been dry the past month, the inaccessibility of this location makes progress difficult. Also, there has been difficulty with ground water and it has been found necessary to call in a consultant to make a survey. These delays have, of course, held up the grading work. Architects are preparing final working drawings for foundation and building. The 1/4 Scale Model Bevatron is essentially complete in so far as construction work is concerned. Design of the full-scale bevatron is continuing. Steel has been ordered for a 2-1/2° full-scale section of the magnet for testing purposes.

2. Complete equipping of Central Research Laboratory Building.

Work is progressing on the pouring of the third floor walls and overhead. Electrical, heating and plumbing contracts are proceeding on the first and second floor levels.

3. Construction of Animal House and Cafeteria.

A site has been selected for the cafeteria and the architects, Hertzka and Knowles, are proceeding with the design. The animal house is being delayed pending finishing of design of the cafeteria.

4. Construction of Shops - plumbing, electrical, sheetmetal and salvage.

Final working drawings for the first building are nearing completion. The second shop building will not be started until next fiscal year.

5. Miscellaneous Small Construction.

Storage Facilities. Grading has progressed to the point where it is held up by the bevatron grading job. Further progress will be impossible until the 48 inch pipe line is completed on the bevatron job.

Plant and Equipment. (Continued) UNCLASSIFIED

5. Miscellaneous Small Construction. (Continued)

Paint Shop. This project is essentially complete.

Alterations to Laboratory Buildings. Work is in progress in the Old Radiation Laboratory and Donner Laboratory.

Power Distribution. Material for this job is being delivered.

Fire Protection. Work has been progressing on this project and the electrical portion is nearing completion; however, the pipe is just being delivered for the water mains and it is anticipated that they will be installed during the next few months.

Parking Lot. Rough grading is approximately 50 percent complete.

Connecting Road. Clearing is nearing completion, rough grading is just starting.

University of California Hospital Radiological Laboratory - Architects' studies are being made and instrument bids are being scrutinized.

MEDICAL RESEARCH

Biological and Medical Studies at Crocker Laboratory UNCLASSIFIED

1. Evaluation of the metabolic properties of fissionable elements, fission products, and other materials of project interest.

The metabolism of praseodymium in rats has been completed.

2. Decontamination studies.

Studies of the effect of zirconium citrate therapy and of endocrine factors in bone metabolism are being continued. Metabolic studies with radio-fluorine and radio-calcium are being initiated.

3. Radioautographic studies.

Radioautographic studies with praseodymium in bone, and plutonium in scar tissue are continuing. Work is in progress on special NTB emulsions in the study of plutonium distribution in the costochondral junction.

Biological and Medical Studies at Crocker Laboratory (Continued) UNCLASSIFIED

4. Radiochemistry.

Column separations were done on two Oak Ridge shipments of Y^{91}. Carrier-free radio-arsenic was separated from a germanium target. A satisfactory method has been developed for separating At^{211} from organic material. Preliminary data have been obtained on the distribution of At in the rat.

Medical Research at Donner Laboratory UNCLASSIFIED

1. Selective tissue irradiation involving radioactive colloids of phosphorus, yttrium, zirconium, lanthanum and uranium.

Methods of lymphatic infiltration are being investigated.

2. Biological effects of fission.

No new results.

3. Biological effects of high energy neutrons.

Hematological studies on 184 inch cyclotron personnel and on mice irradiated with high energy neutrons are being conducted.

4. Use of large animals in long range studies of item (3) with particular interest centered in carcinogenic and longevity aspects.

Facilities for care of large animals not yet available.

5. Biological effects of high energy particles (other than neutrons - see item (3) above).

This work is being continued.

6. Biological effects of radiation on nucleoprotein metabolism and protein metabolism.

Main current efforts are on purification of nucleic acids.

7. Effects of radiation on the reticuloendothelial system and related effects with regard to immunity mechanisms.

Transferred to Naval Radiation Laboratory at Hunter's Point (Dr. Victor Bond). This may be resumed later.

Medical Research at Donner Laboratory (Continued) UNCLASSIFIED

8. Microchemical assay of tissue components by induced radioactivity.

   The work is being continued.

9. Study of the mechanism of radiation injury and possible prophylactic and therapeutic management of such injury.

   No new results.

10. Study of metabolism measured by the utilization of simple organic compounds labelled with radioactive carbon.

    Current studies are with radio-methionine, and radio-valerate.

11. Study of genetic effects of radiation.

    The work is being continued.

12. Radiation effects on micro-organisms and studies on the nature of radiosensitivity and radioresistance.

    Reported in A. E. C. report dated April, 1949.

13. Effects of specific irradiation of liver, spleen, bone marrow, and lymphatic tissue on the circulating plasma proteins.

    Studies are still mainly centered on description of normal plasma protein fractions with ultra centrifuge and electrophoresis apparatus.

14. Metabolic studies on normal and leukemic cells.

    Methods are being worked out for the analysis of significant constituents of suspensions of normal and leukemic cells undergoing metabolism.

15. Physical chemistry. Physical and chemical methods in dealing with large molecules in biological systems.

    The work is being continued.

Cancer and Medical Research at U. C. Hospital (48-C) UNCLASSIFIED

1. Effects of external irradiation of the whole body.

   9 blood counts done on patients treated before or during 1946.

2. Hematological effects of irradiating the body from within. P^{32} and I^{131} work.

   9 blood counts done on patients treated with P^{32} prior to May 24, 1948. 13 blood counts done on patients treated with I^{131}; of these 13, one is a new patient.

Cancer and Medical Research at U. C. Hospital (48C). Continued) UNCLASSIFIED

3. Studies of the metabolism of I^{131} together with tests of its usefulness as a diagnostic and therapeutic agent.

   25 iodine uptake studies and 7 patients given therapy; 3 surgical cases with autographs made from the tissues; continuation of statistical reorganization.

4. Study of skin reaction to radiation from x-rays, gamma-rays, beta-particles, alpha-particles, and neutrons.

   No work being done under this title.

5. Investigations in (4) extended to plants and animals.

   No work being done under this title.

6. Investigations into the cause and cure of radiation sickness.

   No work being done under this title.

7. Other experiments.

   A study was done of the proportions of non-protein bound to protein bound iodine from a series of blood specimens taken from a patient following a test dose of I^{131}.

Organic and Biological Chemistry. UNCLASSIFIED

1. Use of carbon 14 in study of organic reaction mechanisms and physical-chemical phenomena, such as the mechanisms of molecular rearrangements, cracking of hydrocarbons, ets.

   Work has continued on free radical mechanism of peroxide decomposition.

2. Production for shipment of various carbon 14 labelled compounds, such as methyl-labelled sodium acetate, methylene and carboxyl-labelled glycine, carbonyl-labelled sodium pyruvate and glucose.

   Product of a 20 mc. run of glycine-2-C^{14} has been sent to Oak Ridge. A hot run of codeine-methoxy-C^{14} will be started for distribution.

3. Production for experimental use of compounds and as phenylalanine (either beta or ring labelled), complicated amino acids, drugs, hormones, carcinogens, etc.

   The synthetic preparation of the following compounds is being studied: alanine-3-C^{14}, leucine-β-C^{14}, valine- -C^{14}, isobutyl bromide-C^{14}, oxalacetic acid-C^{14}, fumaric acid-C^{14}, tartaric acid-C^{14}, succinic acid-C^{14}, lactic acid-1-C^{14}, lactic acid-2-C^{14}, Demerol-N-methyl-C^{14}, glucose-1-C^{14}, mannose-1-C^{14}, valine-α-C^{14} and leucine-α-C^{14}.

Organic and Biological Chemistry (Continued) UNCLASSIFIED

4. Studies of the mode of action and distribution of the compounds in (3) above in animal and plant metabolism.

   The metabolism of propionic acid-C^{14} in tissue slices is being studied in Warburg experiments. The metabolic products will also be determined. The rate of metabolism in mice to $C^{14}O_2$ of simple labeled organic compounds is also being studied.

5. Isolation of the intermediates of photosynthesis and study of the mechanism of this process.

   The process of photosynthesis in higher plants, barley and geranium leaves, has been studied. The products are similar to those found in algae. The inhibition of photosynthesis by malonate has been determined. Malic acid formation is inhibited.

Health Physics UNCLASSIFIED

1. Dosimetry in high energy neutron beams; evaluation of energy absorption coefficients for hydrogen, carbon and oxygen; application to tissue.

   No progress to report.

2. Study of ranges and relative numbers of ionizing secondaries from materials irradiated with high energy neutrons.

   Work is continuing.

3. Controlled exposure of animals in neutron beam.

   Program in progress under Medical Physics.

4. Applications of new types of counters to dosimetry.

   The program of adapting scintillation counting methods to biological problems is continuing.

5. Extension of health protection program, involving use of film badges and pocket chambers by all personnel.

   Film badges are now being used by all Laboratory personnel.

6. Other developments and studies.

   Shielding, and radiation field outside shielding under continuing study.

Health Chemistry UNCLASSIFIED

1. Shielding - materials, stopping power, geometry.

   Continued study of the appropriate material and design to be used in containers with maximum efficiency in shielding, especially for economy of shipping weight. Further shielding to eliminate "shine" from the straight-type wall cave from heavy gamma emitters has been put in place.

2. Problems in optics for caves and dry boxes, involving mirrors, lenses and liquids.

   Present techniques being put to practical use; further development to be undertaken at first opportunity.

3. Plutonium slug design for use in piles.

   No further work being done on this at present.

4. Instruments including G. M. tubes, tongs, and particle detecting rings.

   No developments at present.

5. Decontamination of the air expelled from an area such as the "hot cave".

   Design development and tests of filters being continued.

6. Surface decontamination for working areas; studies of decontamination technique for large equipment, and development of special equipment for this purpose.

   Decontamination annex awaiting construction.

7. Design of special target holders for active material.

   An improved interceptor target holder for the Crocker 60 inch cyclotron has been completed and successfully put into use. Special target holder with emphasis on speed of removal of target for detection of short-lived isotopes ready for test.

8. Continuing improvement in dry-box design, construction and associated mechanical equipment for remotely handling and performing specialized manipulations with active materials.

   Work on the above activities constitutes a major portion of the time spent by the Research and Development group; any further statement on the progress therein is beyond the scope of these comments.

9. Receival, storage, monitoring and waste disposal of all radioactive material in Laboratory, and health monitoring for exposure to such activity.

   Continuous attacks on these problems being made, details of which would require too lengthy a description to be suitable for this report.

RESTRICTED

APPROXIMATE DISTRIBUTION OF EFFORT

PROGRAM	SUBDIVISION	MAN-MONTHS EFFORT	COMMENTS
184-inch Cyclotron	Operation	10.8	
60-inch Cyclotron	Operation	-	Non-Project
Synchrotron	R.f. System	.5	
	General	.3	
	Injection	2.5	
	Miscellaneous	1.0	
	Magnet Tests and Operation	6.4	
Linear Accelerator	Linear Accelerator - General	1.8	
	Van de Graaff - General	2.5	
	Development	5.9	
Bevatron	Injector	1.5	
	Magnet	3.3	
	1/4 Scale Model	2.3	
	Miscellaneous	.2	
Experimental Physics	Cloud Chamber	4.8	
	Film Program	7.0	
	Ionization Chamber and Crystal Counter	1.8	
	Neutron-proton Scattering	1.1	
	Proton-Proton Scattering	2.6	
	Meson Range and Decay Measurement	1.7	
	Absolute Cross Section Measurements	3.1	
	Neutron Half Life	.5	
	General Physics Research	8.4	
	Magnetic Measuring Equipment	.3	
	Instruments for General Use	2.1	
	Meson Experiments with Synchrotron	1.0	
	Scintillation Counters - Research Experiments	1.1	
	Nier Spectrometer	1.5	
	Low Mass Spectrograph	.2	
Theoretical Physics	Bevatron	1.5	
	Cyclotron	.8	
	General Physics Research	12.0	

PROGRAM	SUBDIVISION	MAN MONTHS EFFORT		COMMENTS
Chemistry, Part A	Chemistry of Transuranic Elements	5.8		
	Nuclear Properties of Transuranium Elements	4.0		
	Transmutation with the 184-inch Cyclotron	7.5		
	Analytical and Service	15.2		
Chemistry, Part B	Synthetic and Experimental Chemistry	7.0		
	Biological Chemistry	4.6		
	Photosynthetic Chemistry	5.9		
Chemistry, Part C	Metals and High Temperature Thermodynamics	3.0		
	Basic Chemistry, including Metal Chelates	1.0		
	Engineering Development of Plutonium Separation	2.0		
	Ore Reduction	3.5		
Medical Physics, Part A, Div. I	Metabolism of Fission Products	11.0		
	Decontamination Studies	7.0		
	Radiochemistry	2.0		
	Radioautography	2.0		
Medical Physics, Part B, Div. II	Tumor Metabolism	1.7	1.7	Consultant Man-Months
	Special X-ray Studies, Radioactive Measurements, etc.	3.9	3.2	
	Radioactive Carbon Studies	1.0	.1	
	Fundamental Medical Research	2.9	2.7	
	Hematology	.4	1.4	
	Medical Work with the 184-inch Cyclotron	2.6	1.1	
	Fly Genetics	2.0	.3	
	60-inch Cyclotron Bombardments	.4	-	
	Physical Chemistry	3.4	-	
	Specific Irradiation	2.5	.2	
Health Physics and Chemistry	Monitoring, Disposal, Salvage, Decontamination, etc.	6.2		
	Research and Development	17.8		
	Film Badge Program	4.6