

# Lawrence Berkeley National Laboratory

## Recent Work

### Title

LONG RANGE OBJECTIVES OF THE RADIATION LABORATORY UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA

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Long Range Objectives of the Radiation Laboratory  
University of California, Berkeley, California

*R. L. Thornton*

*November 30, 1955*

For the purposes of this summary, "long range" will be taken as referring to periods in excess of two or three years; i.e., to an extension beyond the period of current budget forecasts. Moreover, the work at the Livermore laboratory will be excluded with the exception of work on accelerators, which is closely related to the main stream of research at Berkeley. It is, of course, understood that, as at present, a fraction of the Berkeley effort is directed towards support of the Livermore work outside the limited fields indicated above and vice versa. Work in the biological fields is not included since it is felt that the intent of the request covers primarily the physical sciences.

Clearly the main objectives of the Laboratory will continue in the future as in the past and can be stated in a few words. Our efforts will be directed at accomplishing as much fundamental research as possible, particularly in the nuclear aspects of the physical sciences, and to utilize and develop our resources to the maximum extent. In the chemistry field, major emphasis will continue on the nuclear, chemical, and other properties of the heavier elements and on spallation reactions and nuclear properties in general. In nuclear physics, major effort will continue to be devoted to the high energy field. However, particularly at Livermore, an expansion of work at lower energies is already in progress, and valuable work is being done at the Crocker Laboratory and with the linear accelerator at Berkeley. Of comparable importance to the actual research accomplishments is the training of scientists and engineers. This involves work both at the graduate and post-doctoral levels, and successful careers of the men who have obtained part or all of their training at Berkeley is a great source of gratification to the Laboratory. In recent years we have also been able, because of the separation of our classified and unclassified research areas, to work much more effectively with foreign scientists and institutions. We feel strongly that this is of value not only to the scientific community but also to furthering good will towards the United States. We hope to continue to expand our work in this direction to the mutual benefit of all concerned.

## High Energy Nuclear Physics

The region of high energy physics will be defined for our present purposes as including work above the meson production threshold. It thus includes experiments involving the Bevatron, 184-inch cyclotron, and the synchrotron. The program involving the other accelerators, both in Berkeley and at Livermore, will be discussed later.

Major work will, of course, center about the Bevatron. Here it is of the greatest importance to push the work as rapidly as possible since the U. S. dominance of the high energy field is clearly diminishing. The central field of investigation for many years will certainly be concerned with the heavier unstable particles. The recent discovery of antiprotons makes it of major importance to understand the nature of their production and annihilation processes and the interactions which they make with nuclei. Presumably the antineutron will some day be discovered and similar problems will await investigation. The rarity with which these particles are produced, at least in our present experimental conditions, makes this a formidable and time-consuming task, and it will certainly occupy a substantial fraction of the Laboratory's efforts in the coming years. Many problems also must be studied involving the nature and properties of the other unstable

particles with masses both greater than and less than the nucleon mass. While these particles have been, in most cases, identified in cosmic ray studies, it seems certain from progress already made that major understanding must come from studies using the more numerous and controlled laboratory-produced particles. Here again, the almost bewildering array of particles is indicative of a long and systematic research endeavor, and the goal of the experiments will be somewhat similar to those listed for the antinucleons. In addition, work will be pressed on other problems in the high energy field; nucleon-nucleon scattering, nuclear reactions, and cross sections in general, etc. While, of course, graduate students will in many cases be associated with experiments on the Bevatron, the nature of the experiments is such that professional research teams may prove more effective. The improvement of the Bevatron research facilities to be undertaken in the present and next fiscal years, which involves additional experimental stations, external proton beams, etc., will permit an extended and more versatile research program. Modest increases in the scientific, operating, and service staffs will be called for.

It is expected that the 184-inch cyclotron will resume operations next summer at the 700 Mev proton level and with radically improved research facilities both for meson physics and for experiments involving external particle beams. This will enable us to extend and improve the experiments which have kept this machine profitably busy since the war. There is no dearth of suitable and significant experiments involving such fields as meson production and properties, detailed studies of nuclear reactions, cross-section measurements of all types, polarization experiments, etc. It may be expected that this machine will carry the major graduate student training load in the future, as it has in past years, and it is important that the Laboratory staff be sufficient to meet these needs, as well as those of the Bevatron and the other research activities.

Shortly a new injector system will be installed in the synchrotron which, it is expected, will substantially increase the intensity of the x-rays produced. The research program will continue on photo-meson experiments, photo-nuclear reactions, and other experiments involving the interaction of high energy electromagnetic radiation with matter. No essential change in the program level or goals is anticipated.

A major aspect of our future research program, and one of particular importance in this energy range, is the development of observational techniques. Improvements in this field have, in addition to their own intrinsic merits of improving experiments, the most important effect of markedly improving accelerator utilization efficiency. Accordingly we expect to increase substantially our efforts in this field. The recent spectacular success of the 10-inch hydrogen bubble chamber clearly indicates the wisdom of our efforts in this field and it will continue to be pressed hard. Under design at present is a 72-inch chamber which we feel confident will prove of the greatest value in Bevatron physics. The operation and effective use of these chambers will require expanded manpower allocations to this activity. Of importance to all visual observation methods (cloud chambers, bubble chambers, nuclear emulsions) is the matter of data recording, reduction, and analysis. It is certain that great improvements in these can be effected by increased use of mechanical devices, computers, etc. We expect to do considerable work in this direction. Improvements in counter techniques and equipment are continually needed and pay large dividends when they are achieved. Recent improvements in photomultiplier tubes, traveling wave amplifiers, faster oscillographs, etc., should be incorporated in improved counting systems as rapidly as possible. We have recently set up well-led electronic development groups, both aiming at immediate and at long-range problems, which have already

produced significant results. We hope to extend this effort in conjunction with other laboratories and industry in expectation that substantial improvements can be made if we are willing to work hard for them.

### Medium and Low Energy Nuclear Physics

Work in these fields involves the use of the 30 Mev linear accelerator and associated Van de Graaff, the 60-inch cyclotron, the heavy ion linac under construction at Berkeley, and the variable energy 90-inch cyclotron, the 500 Kev Cockroft-Walton accelerator, the high current linac (A-48 program), and the reactors at Livermore. Work proposed with the reactors will not be discussed here. The high current Livermore linear accelerator will be briefly considered as a separate topic later.

The work at Berkeley in these fields is expected to continue in the future at much the same level as in the past. However, the increased effort in the high energy fields will mean that proportionally a smaller fraction of the total effort will be expended here. Much work using these machines involves the Chemistry Division and will be discussed later. Work in physics involves detailed study of nuclear reactions, nuclear excitation, inelastic cross-section measurements, and the like. This field is a valuable training area for graduate students and most of the research work is done by them. Since this field is relatively static, it will not be discussed at length; however, a considerable amount of valuable fundamental research has come, and is expected to continue, from this field.

It is expected that a physics research program, in addition to the major interest of the nuclear chemists, will develop about the heavy ion linear accelerator. However, no specific plans are being made as yet, so it is presently impossible to anticipate their scope or significance.

Work with the 90-inch cyclotron at Livermore will mainly deal with the measurement of fast neutron cross sections such as total, elastic and inelastic,  $n-2n$  and fission reactions. In addition, various charged particle scattering and cross-section measurements will be undertaken. The energy range of interest is from about 1 to 14 Mev. The 500 kilovolt Cockroft-Walton accelerator will continue to be used to provide 14 Mev neutrons for elastic, inelastic, and other cross-section measurements.

### High Current Linear Accelerator

This program (also known as the A-48 program) will be discussed here since it is much more closely connected with the Berkeley work than that at Livermore, despite its location.

Present operation of the accelerator has demonstrated that high currents (1/4 amp and more) can be successfully handled in a machine of this type. Such currents permit radical changes in accelerator experimentation, and it will certainly take some years to explore their significance. As an example, a program of apparently major ultimate proportions has been proposed by DuMond of Cal Tech and Hans Mark of U.C. This involves the use of high precision spectrometers in the investigation of nuclear levels. This is particularly interesting in view of the success of recent theoretical models (Bohr-Mottelson) in predicting nuclear states and their character. It may be that, with more detailed experimental information, nuclear spectroscopy may approach the completeness of atomic spectroscopy with corresponding theoretical implications. This accelerator may well play a vital role in refining and determining the limitations of these theoretical advances.

With this uncertainty in ultimate goal, it is difficult to indicate the directions a long-range program should take. Clearly the machine should be powered to permit continuous high-current operation with deuterons and protons, and research facilities and operational funds provided to permit evaluation of its utility. Extension to higher energies is, of course, possible and is under study; however, firm proposals must await developments. Beyond doubt the success of this machine is a major contribution to accelerator technology; how this advance may best be exploited in the future is difficult to forecast at this time.

### Nuclear Chemistry

In contrast to the previous discussion which has been organized about accelerators and the associated research programs, our discussion of this division is in terms of scientific fields. In some respects these researches are more programmatic in character and hence lend themselves to more orderly treatment. Accordingly, on occasions a tabular listing of fields of investigation will be given.

#### A. Synthesis and Identification of New Elements

If a maximum half-life range of seconds to minutes is taken as the limit for chemical identification of a new element, the present predictions of nuclear instability toward alpha decay and spontaneous fission decay indicate that it will be possible to extend the periodic system to the neighborhood of elements 104-106. The technical difficulties in reaching this limit become increasingly difficult, but this laboratory will continue these studies to the extreme limit with advanced techniques.

It is possible that some properties of isotopes of elements beyond the limit of chemical detection may be measurable.

#### B. Extension of Decay Scheme Information for Isotopes in Entire Heavy Element Region

The number of known isotopes of the nine transuranium elements is now about 70. This number will be increased by additional experiments. More important, the detailed study of most of the radiations of these isotopes and other isotopes in the region above lead will be carried out using all modern instrumental techniques. These data will be used to test nuclear models such as the Mayer shell model, the Bohr-Mottelson unified model, or any other model which may be appropriate. Fission properties will be correlated and compared with theory.

#### C. Production of Larger Amounts of Transuranium Element Isotopes

To facilitate the new element studies discussed under Sec. A and the chemical studies to be discussed under Sec. D, it is necessary that larger quantities of certain transuranium element isotopes be available. These can be made by intensive neutron irradiation of sizeable amounts of plutonium or uranium. It will be part of our purpose to encourage the recovery of these isotopes in appropriate laboratories of the Commission and to undertake such operations within our own facilities when advisable for our own research needs.

#### D. Study of High Energy Nuclear Reactions by Nuclear Chemical Methods Using the Various Particle Accelerators of the Radiation Laboratory

1. Heavy Ion Linear Accelerator Studies. The production of heavy element isotopes and possibly new elements by bombardment of uranium and transuranium element targets with accelerated beams of nitrogen, oxygen, neon, and other heavy ions will be studied.

The fission reaction caused by heavy ion bombardment will be studied. Interesting reactions and reaction cross sections are expected in the bombardment of representative elements from all regions of the periodic chart.

2. 60-Inch Cyclotron Studies. Detailed study of reaction cross sections and excitation functions to determine competition between particle-induced fission reactions and others of the type (d,xn) (d,pxn), etc.

3. 184-Inch Cyclotron Studies. Spallation yields from the bombardment of representative target elements will be extended. The application of high sensitivity mass spectrographic techniques will greatly increase accuracy and also permit determination of stable products. Secondary reactions and other special studies will be made.

A high intensity meson beam should become available to allow detailed radiochemical study of meson reaction products in fission and spallation reactions.

4. Bevatron Studies. The study of representative fission and spallation reactions by the radiochemical method will be expanded. Where feasible, reactions involving mesons will be studied radiochemically. Cross sections for special products, such as tritium or beryllium, will be measured.

E. Study of the Physical and Chemical Properties of the  
Heavy Elements and the Rare Earth Elements

Work will continue on:

1. Chemical properties in aqueous solution.
2. Ion exchange and solvent extraction.
3. Thermodynamics of heavy elements in aqueous solution and in the solid state.
4. Absorption and emission spectra.
5. Atomic beam and microwave resonance experiments to determine:
  - a. Nuclear angular momentum
  - b. Nuclear quadrupole moments
  - c. Nuclear gyromagnetic ratios and other special nuclear properties.
6. X-ray crystallography.

F. Determination of Nuclear Spectroscopic States and Decay Schemes

All modern techniques will be used to study isotopes of interest obtained in the transuranium element studies or high energy reaction studies. Also other isotopes which can be made in the laboratory facilities and are deemed worthy of study will be investigated. The testing of nuclear theories will be a major goal of this effort. Techniques to be used include:

1. Alpha spectroscopy with precision magnetic spectrometers.
2. Gamma ray scintillation spectroscopy.



3. Beta ray spectroscopy using many instruments of advanced design.
4. Coincidence techniques to correlate  $(\alpha, \gamma)$ ,  $(\gamma, \gamma)$ ,  $(\beta, \gamma)$ ,  $(e^-, e^-)$  and other types of radiations with energy selection of both radiations.
5. Angular correlation techniques.

#### G. Instrument Development

A large activity in instrument development is required to support the program outlined in Sections A through F.

#### H. Chemical Engineering

A relatively modest program of study on basic problems in this field will be continued at the present level.

#### I. High Temperature Thermodynamics

A relatively modest program will be continued in the study of chemical systems at high temperatures. Considerable emphasis will be placed on chemical species present in the vapor phase in certain high temperature systems.

### High Energy Accelerator Study

The successive increases in maximum energy during the 25-year history of accelerators have been accompanied by a series of major discoveries and advances in particle physics. The antiproton is the latest example and one of the best because it had been sought for so long in cosmic rays. There are no signs of exhaustion along these lines; in fact, the occasional detection of very odd and unexplained cosmic-ray events provides virtual assurance that the advances will continue with still higher energies.

The effort and time required to build an accelerator in the multibev range are so great that it is obviously not desirable to advance into the high-energy region by small steps. From this time on, the increments of energy should be as large as it is technically possible to make. It is not known where the practical maximum is at the present time, but it is probably at least 150 Bev.

We would propose to carry out a study to delineate the problems which must be solved, to find tentative solutions of them, and to arrive at preliminary designs of such an accelerator.

A program of this kind will involve theoretical beam dynamics, magnetic materials and model measurements, control systems study, radiofrequency development, study of alignment and measurement methods, and, possibly, the building of an analogue model. The minor work we are doing at present on this program is a part-time effort by two or three men. We would hope in the future to expand this to a small group of about 8 people who could begin to seriously investigate the problems.

### Theoretical Physics

The work of the theoretical group is interrelated to almost all of the research activity of the Laboratory. It has three main functions: (1) to carry out original theoretical research, (2) to interact with experimentalists by pro-

posing, discussing, and analyzing experiments and by aiding where possible in the theoretical design of research equipment, and (3) to provide computational services for all activities which require them. In long-range planning, it is felt that the group need only expect a very moderate increase in size. This will be done, with the aim of improving the level of competence of the theoretical staff, by the occasional addition of an unusually competent theorist. The program outlined in this report will also require adding from time to time a theorist whose interests lie in the broad area of classical and applied theoretical physics. The present arrangement by which several of our post-doctoral theorists are relatively junior and spend a year or two at the Laboratory should be continued: A gradual increase in their number would be desirable. The number of theoretical graduate students working at the Laboratory has risen considerably and should also increase further. The rapidly increasing role of electronic computers has already radically changed the nature of the computing work load, and one must expect an ever-increasing volume of computation.

The principal topics of theoretical study will be those related to the experimental programs in physics and nuclear chemistry discussed herein.

### Organization

Scientific Personnel. A large part of the research program of the Laboratory is carried out by graduate students. At present they number about 55 in experimental physics and 40 in the Chemistry Division. This number will tend to increase with increasing enrollment at the University, but, particularly in physics, we could use and train effectively a substantially larger number. (In past years we have done so with more limited staff and facilities.) We expect to investigate means by which this may be accomplished.

It is not expected that a substantial increase in the permanent scientific staff will occur. However, the increased research facilities and the larger number of graduate students expected will call for a moderate increase.

We would expect to increase somewhat that portion of our scientific staff composed of recent Ph.D.'s and which is largely temporary in character. These men make important contributions to our research program, and such appointments are also valuable when considered as post-doctoral training.

Support Personnel. The reinforced program aimed at the fullest exploitation of our research facilities during coming years will call for increases in this category. This includes most importantly engineers and technicians who support the research program and carry the main burden of design and development. Some increase in shop effort for fabrication will also be required.

R. L. Thornton  
November 30, 1955