

Los Alamos National Laboratory

LA-UR-92-1467

***The Relevance of the Los Alamos Meson Physics
Facility (LAMPF) to National Goals***

A White Paper

The Los Alamos Fellows

April 20, 1992

Contents

Summary	1
Introduction	3
University Relations and Education.....	5
Intellectual Vitality at the Los Alamos National Laboratory.....	7
Nuclear and Particle Physics.....	8
LAMPF and the Nuclear Weapons Program at Los Alamos	10
Links to the Academic Community and the Graduate/Postgraduate Talent Pool.....	12
Condensed-Matter Research at the Manuel Lujan Jr. Neutron Scattering Center (LANSCE)	13
LANSCE and Structural Biology.....	15
Radioisotope Research, Development, Production, and Distribution at LAMPF	18
LAMPF as Key to Development and Demonstration of Accelerator-Driven, Intense-Neutron-Source Technology	20
Background	20
LAMPF's Role	21
Capabilities of an Upgraded LAMPF for APT/ATW/APP	22
Capabilities of an Upgraded LAMPF in Other Areas	23
Conclusions	24
Acknowledgments.....	25
Appendix A	
Academic Institutions and National Laboratories at LAMPF	27
Industrial Laboratories Represented at LAMPF.....	29
Hospitals Represented at LAMPF	29
Appendix B	
Contributions of LAMPF to Nuclear Weapons Development	30
Measurement of Cross Sections	30
Weapons-Related Research from LANSCE.....	30
Future Capabilities and Opportunities.....	31
Appendix C	
Applications of LANSCE Technology	32
Metal Matrix Composites	32
Polymers	33
Antigen Sites	34
Appendix D	
LAMPF-Produced Radioisotopes	35

Appendix E

Nuclear Medicine Research Activities	38
Biomedical Generators	38
New Agents for Accelerator-Based Radiopharmaceuticals	38
Myasthenia Gravis Research	38
Imaging Agents for Lymph Nodes and Therapy for Lymphoma	39
Early Detection and Treatment of Lung Cancer	39
Positron-Emission Tomography (PET) and ⁶⁸Ge	39
Forecast Growth of PET	40

The Relevance of the Los Alamos Meson Physics Facility (LAMPF) to National Goals

SUMMARY

The President's FY 93 Budget indicates that the Department of Energy (DOE) proposes to close the Los Alamos Meson Physics Facility (LAMPF) in FY94 for budgetary reasons. LAMPF is integrated into the Los Alamos National Laboratory (LANL) and the national infrastructure, and its closure would preclude future contributions to the Laboratory and the Nation. The LANL Fellows, who are senior scientists with no administrative responsibilities, and who represent all of the scientific disciplines and the programs at the Laboratory, have carried out a study of the impact of losing these contributions. This report documents their findings, which may be summarized as follows:

- *LAMPF is a unique facility that addresses a wide range of national scientific and technical goals.*

LAMPF is a complex of experimental nuclear facilities driven by the world's highest intensity (1 mA) 800-MeV proton linear accelerator. This high intensity makes possible its simultaneous use for: the production of secondary particle beams (i.e., pions, muons, neutrinos, electrons, and neutrons), the production of essential radioisotopes, radiation damage studies, the Proton Storage Ring (PSR), the Los Alamos Neutron Scattering Center (LANSCE) and the Weapons Neutron Research (WNR) facility. LAMPF provides particle beams and experimental facilities for basic research at the leading edge of nuclear and particle physics, atomic physics, condensed matter physics and material science, astrophysics, and medical science, and for applied research in the broad fields of national defense, energy, material science, medicine, and radiation damage. LAMPF is also a major producer of radioisotopes for medical and commercial uses. This broad spectrum of experimental capabilities and applications, concentrated within one multi-disciplinary, multi-program national laboratory, makes LAMPF unique. The high intensity of the primary beam allows interesting, new capabilities to be added at a relatively modest cost without having to duplicate the existing capital investment, estimated at a replacement cost of approximately \$1 billion.

- *LAMPF makes strong contributions to the Nation's science and technology base and to the education and training of its scientists and engineers.*

The research carried out at LAMPF has resulted in more than 1400 refereed publications in the open literature that describe scientific and technical advances. LAMPF facilities are used by scientists from more than 300

institutions, including universities, industry, and national laboratories. Approximately 50 commercial institutions and several hospitals and medical institutions have conducted research at LAMPF. This facility is readily available and widely used as a national resource. Its role in education and training has been very important; numerous undergraduate students (171), graduate students (250), and post-doctoral fellows (112) have worked at LAMPF and entered the Nation's scientific work force. Two hundred and twenty-six Ph.D. degrees have been awarded based on research done at LAMPF. During last year alone, approximately 700 scientists from 40 countries visited or worked at LAMPF. This pool of scientific and technical talent becomes part of the network that helps to maintain the Nation's science and technology base at a high level.

- *LAMPF provides important benefits to all LANL programs.*

The research, development, and testing involved in LANL's national defense programs require highly qualified scientists and engineers who have access to the rapidly expanding data base and the latest technologies. Acquiring and maintaining these broad skills is a difficult task made more challenging by the classified nature of much of the weapons program. The Laboratory must insure that it can carry out its many other technical responsibilities in areas as diverse as helping to modernize the DOE weapons complex, to develop and improve energy sources, the development of environmental technologies, nuclear safeguards and surveillance, and technology transfer to industry. LAMPF has always contributed to the Laboratory in a major way in these areas. Without LAMPF's contribution to the Laboratory's scientific reputation, the Laboratory's ability to recruit the best scientists and engineers would be damaged. Without LAMPF's ties to other institutions, the Laboratory would suffer a loss in the timeliness, quantity, and quality of the technical information and scientific resources available to it. This would damage the Laboratory's ability to exploit new ideas and technical opportunities in a competitive manner. Finally, without LAMPF, the Laboratory would lack important nuclear facilities that can be applied to solve the DOE's emerging programmatic needs and the urgent technical problems facing the Nation.

INTRODUCTION

The closing of the Los Alamos Meson Physics Facility, LAMPF, by September 30, 1994, is being seriously considered by the United States Department of Energy. This is a consequence of a DOE decision that the Continuous Electron Beam Accelerator Facility (CEBAF) and the Relativistic Heavy Ion Collider (RHIC) *must* be funded. The budgetary constraints are such that there are insufficient funds allocated to the DOE Office of Energy Research, the principal funding agency of LAMPF, CEBAF, and RHIC, to support all three activities. This white paper sets forth, and documents, the concerns that the Los Alamos Fellows have, should the phase-out of LAMPF occur in 1994 with its attendant consequences for Los Alamos and the Nation.

The Fellows, which includes the smaller group of Senior Fellows, are technical staff members of the Laboratory who have been honored with this title in recognition of their sustained scientific and technical accomplishments, scientific leadership, and standing in the international scientific community. They embrace all major scientific disciplines at the Laboratory and comprise about 3% of the Laboratory's technical staff. In view of the central role that LAMPF has had in the research and development agenda at Los Alamos National Laboratory, the Fellows have taken on the task of presenting an overview of LAMPF's influence on the Laboratory in meeting a wide range of national goals.

LAMPF is a high-intensity, 800-MeV proton accelerator. It produces secondary beams of other types of particles: pions, neutrinos, protons, neutrons, and muons. These beams are used for a broad range of research and practical activities. LAMPF is central to the intellectual life of the Laboratory and its relation to the university community. To replace LAMPF would cost approximately \$1 billion; its operating costs are approximately \$50 million per year.

Our goal in this report is to provide information that can be useful to others in **making** their own assessment of LAMPF. Not all of the Fellows are experts in **nuclear physics**, nor in other technical areas on which LAMPF activities bear; hence, we have relied on colleagues who are knowledgeable in the relevant disciplines (see the Acknowledgments) to provide detailed technical information. We hope to show that the influence of LAMPF at the Laboratory goes far beyond its achievements in nuclear physics.

LAMPF's capabilities cover a remarkable spectrum ranging from basic research at the leading edge of nuclear, particle, atomic, and condensed-matter physics, materials science, astrophysics, structural biology, nuclear medicine,

and nuclear chemistry to applied problems in national defense and energy. We will show how these capabilities bear on a variety of problems already identified as requiring national commitment, such as energy, waste management, industrial competitiveness, nuclear proliferation, and health and the associated advancement of basic biological knowledge. We believe it would be a serious mistake to weaken the capability of the Laboratory to respond to these commitments by closing LAMPF, which, as a basic research facility with a uniquely broad interface with scientific, educational, and engineering communities, is a central component of this capability.

We shall not address, except in a short résumé, the issue of the importance of LAMPF in nuclear physics, since this has been set forth in detail elsewhere.* We would, however, like to cite the succinct summary given in a letter to the Director of the DOE Office of Energy Research, dated August 7, 1989, from Nobel Laureate Hans Bethe, who was Theoretical Division Leader at Los Alamos during World War II and has been a yearly visitor since then. He writes as follows:

Anyone who knows me will tell you that I seldom use strong language. But I must repeat that closing down LAMPF in the foreseeable future would be a disaster. A disaster for world nuclear physics because LAMPF is unique and not duplicated in other countries; a disaster, particularly, for American medium-energy nuclear physics which is now leading in the field, and which would be relegated to a low position. And a disaster for the Los Alamos Laboratory, leading in matters of national security, and its relations with the Nation's universities.

It is still so that LAMPF proton, pion, muon, neutron, and neutrino beam intensities remain second to none, worldwide. So also do the extraordinarily large number of beam channels. Nor will this situation change when CEBAF, the RHIC, and KAON, in Canada, come on line some years from now. In fact, LAMPF will complement both CEBAF and RHIC, neither of which will have the capabilities of LAMPF, especially with regard to practical applications*.

It is the purpose of this report to document the scientific activities of LAMPF that substantiate its role at Los Alamos. We set forth these points in some detail in the following sections (nuclear physics is only briefly summarized, since this

* For a detailed account of research with meson factories, see *The Meson Factories* by Torleif E. O. Ericson, Vernon W. Hughes, and Darragh E. Nagle. Berkeley: University of California Press, 1991. See also *Research at LAMPF*, LA-UR-92-926, February, 1992. A report to the Nuclear Sciences Advisory Committee, Los Alamos National Laboratory.

subject has been reviewed recently by several DOE-appointed committees). We shall address the following topics:

Nuclear and Particle Physics (brief summary)

LAMPF and the Nuclear Weapons Program at Los Alamos

Condensed-Matter Research at the Manuel Lujan Jr. Neutron Scattering Center

LANSCE and Structural Biology

Radioisotope Research, Development, Production, and Distribution at LAMPF

LAMPF as Key to Development and Demonstration of Accelerator-Driven Intense-Neutron-Source Technology

Conclusions

Before turning to these technical issues, as a group greatly concerned with the broader societal and intellectual aspects of scientific activities, we would like to address the role of LAMPF in education and the vitality of the Laboratory as a whole. In our opinion, these positive influences are also a significant consideration in the overall evaluation of LAMPF. We give these views in the first two sections:

University Relations and Education

Intellectual Vitality at the Los Alamos National Laboratory

UNIVERSITY RELATIONS AND EDUCATION

Education has become a key concern of Americans, who correctly recognize the connection between educational excellence and national well-being. We have in this country a substantial number of world-renowned scientific institutions that contribute significantly to fundamental and applied research and education. Scientists from these institutions come to LAMPF, including the Los Alamos Neutron Scattering Center (LANSCE) and the Weapons Neutron Research Facility (WNR), to carry out research in nuclear and particle physics, materials science, atomic physics, and biology. Students, as well as faculty members, participate in this work and exchange ideas and perspectives with Los Alamos staff.

One measure of LAMPF's educational success is the large number of students who have passed through its doors. Between 1987 and 1991, 171 undergraduate students, 250 graduate students, and 112 postdoctoral scholars have pursued study and research at the facility. In a typical year, LAMPF provides a setting in which more than 700 visiting scientists and students can discuss experiments, conduct research, and share information and ideas. These

interactions have had impressive results. Between 1970 and the present, 241 Ph.D. dissertations were published as Laboratory reports. Of this number, 226 came from LAMPF. This amounts to an average of one LAMPF Ph.D. each month. (In reality, the total may be up to 30% higher because many dissertations are not registered with the Laboratory.) More than 1400 scientific papers have been published in refereed journals based on work conducted at the facility.

LAMPF was authorized by the Congress to be an open scientific facility. One positive scientific tradition is the free and open *international* exchange of scientific information and ideas. LAMPF is a proud contributor to this tradition. Scientists and students from more than 40 countries have used the facility. Particularly significant is the fact that the international visitors are not only from the technologically advanced, developed world, but also from less-developed countries, such as Mexico, where greater interaction with cutting-edge science is sorely needed. At last count, researchers from more than 300 international scientific and technical institutions have worked at LAMPF, including such prestigious groups as the Academy of Sciences of the USSR, the Max Planck Institute, the Royal Institute of Technology of Sweden, and the Japan Atomic Energy Research Institute.

LAMPF's role in connecting academia more closely to industry is also significant. Learning is shared with the private sector just as it is with university scientists. Researchers from more than 50 private concerns have spent time at the facility, including groups from the Arco Oil and Gas Company, Hughes Research Laboratory, and Westinghouse Electric Corporation. In addition, collaborators from medical facilities, such as the Yale New Haven Hospital, Chicago Medical School, and the University of New Mexico Cancer Research/Treatment Center, have used LAMPF to identify new opportunities for improving national health care.

These are just a few examples of the exceptional contribution LAMPF makes to education. Appendix A lists the numerous institutions that have been associated with the facility's educational activities. We invite you to take a few moments to examine this impressive assemblage; it is, perhaps, the most eloquent expression of LAMPF's significance available anywhere.

B. F. Skinner once wrote that "education is what survives when what has been learnt has been forgotten." He is correct to point out that education is first and foremost a process. It is perhaps a more important process today than it was when Skinner penned his remarks three decades ago. Study after study has shown that the national economic return from investment in education is far greater than that from most other forms of investment. At this important juncture, it is especially necessary that we nurture the very few renowned

scientific institutions we have that contribute to fundamental and applied research and education. For this reason, if for no other, LAMPF deserves both our continued support and our gratitude.

INTELLECTUAL VITALITY AT THE LOS ALAMOS NATIONAL LABORATORY

LAMPF is regarded as a center of scientific excellence, not only because of the tangible results it contributes to the understanding of nuclear physics, elementary particle physics, atomic physics, biology, and materials science, but also because of its intellectual vitality. Intellectual vitality is about *people*; it develops and grows through their creativity, dedication, interactions, and communications. Ultimately, it is about how these are integrated to create an atmosphere where innovative ideas blossom. In its absence, scientific output is mundane; where it is nurtured, as at LAMPF, science excels.

Part of the reason for intellectual vitality at LAMPF is that its scientists play a catalytic role as a crucial link between the university community and the exacting demands of a Laboratory committed to national defense and security; this is a necessary link for the continuity of the conceptual basis of science with this mission. It is partly because they are probing, both theoretically and experimentally, a region of physical law—the quantum domain—where the rules of nature are elusive and not fully understood. Opportunity for, and the excitement of, discovery of the subtle rules governing nature's most fundamental behavior are powerful stimuli that drive the intellectually curious to pursue careers in science.

This intellectual vitality extends far beyond LAMPF as a machine. In various ways, both subtle and concrete, its secondary effects pervade the Laboratory.

An easily quantified benefit to the Laboratory derives from the large influx of highly qualified personnel attracted to LAMPF and LAMPF's effect on the recruitment of first-rate scientists. The Laboratory's ability to recruit first-rate talent is the main component of its effectiveness in helping to attain national goals. Some 300 scientists and engineers who have come to LAMPF have stayed at Los Alamos in Laboratory postdoctoral and staff positions; others have found out about science in other parts of the Laboratory and have become consultants. These individuals are often attracted to fields other than those of their own specialization, and provide a cross-fertilization into programmatic areas.

This influence on recruitment extends beyond the people directly associated with LAMPF and comes from the aura that is provided by the presence of a

strong scientific program, which attracts good people who would not come otherwise. The possibility of attending seminars and associating with researchers in exciting, cutting-edge areas of research is a great attraction. These benefits, which derive as well from other basic science facilities at Los Alamos, are directly responsible for the renowned intellectual vibrancy of the Laboratory. The "pride of association" stretches across the Laboratory and is an important quality of its staff.

As a specific illustration, an increasingly important role in this intellectual vitality is played by LANSCE, a recently commissioned national user facility that is accessible, free of charge, to scientists from universities, federal laboratories, and industry for non-proprietary research that supports DOE missions. Last year, for example, more than 200 scientists submitted experimental proposals to LANSCE, which oversubscribed the available beam time. Almost all of the groups that carried out experiments included one or more graduate students or postdoctoral fellows, with about 40% of the visiting experimenters falling into one of these two categories. During its summer run cycles, LANSCE attracts a number (usually about 20) of graduates and undergraduates who work on various aspects of materials science, physics, chemistry, biology, and computer science under the guidance of LANSCE staff members.

Finally, let us note that there are also benefits from the additional population base of highly trained scientists and engineers who come to LAMPF, some of whom may later decide to start their own consulting firms or join high-tech industry. Many who are trained at LAMPF later leave to take scientific positions in universities and government, so LAMPF is an important player in the intellectual vitality of the Nation.

We conclude that the contribution of a strong scientific facility such as LAMPF extends far beyond the science that it does and the support it provides to the users groups throughout the Nation.

NUCLEAR AND PARTICLE PHYSICS

LAMPF is a multidisciplinary laboratory for basic and applied research. Its multiplicity of high-intensity beams makes it a scientific instrument, unique in the world, providing the fields of nuclear and elementary particle physics with a microscope to explore nuclei and fundamental interactions among the basic constituents of matter. The main LAMPF accelerator shares its high-intensity beams with other facilities, and in this way it supports research activity encompassing, in addition to nuclear physics and elementary particle physics, atomic and molecular physics, astrophysics, condensed-matter physics, and

nuclear chemistry. Studies of radiation damage to materials and to electronics components are also carried out, and a number of important radioisotopes for commercial and research use are uniquely produced at LAMPF. To build a facility today with the capability of LAMPF would cost \$500 million, not including LANSCE (Los Alamos Neutron Scattering Center) and WNR (Weapons Neutron Research Facility).

The scientific case for LAMPF as a facility for basic research in nuclear and particle physics rests on the precision measurements that it is able to make with its high-intensity beams, the breadth and depth of issues that can be addressed with its beams of pions, nucleons, muons, and neutrinos, and its record of high-quality research. LAMPF has become one of the most productive basic-research facilities in nuclear and particle physics as a result of the vast array of beams and experimental areas. Its record of high-quality research is manifest in approximately 1400 scientific papers in refereed journals, which are based upon the completion of about 700 experiments since its commissioning in 1972. More than 200 Ph.D. theses have come from research at LAMPF.

While LAMPF's past record of accomplishment is strong, it still has a vigorous scientific program with many future users and programs. LAMPF is a national user facility with an 800-member users group representing over 100 American and foreign universities. Each year about 30 experiments receive beam, and approximately 400 scientists visit the facility to plan, carry out, and analyze these experiments. At present, there are 92 approved experiments awaiting beam time, resulting in long queues in the beam channels. With the talent in local staff and the users group, and with the variety of beams and the investment in equipment that it now has, LAMPF is poised to be responsive to the changing research emphasis within nuclear physics over the next five years and, with modest upgrades, to changes over the next several decades. The present program and future plans were recently presented to a Nuclear Science Advisory Committee (NSAC) reviewing the scientific programs of the major DOE facilities.

Below, we list some experiments currently under way that place LAMPF on the cutting edge of current research in nuclear and particle physics. These experiments, and the additions to the facility that are envisioned for the next decade, some of which lead the LAMPF program into new directions, are consistent with the central goals of nuclear physics for the decade of the '90s, as recently laid out by the 1989 NSAC Long-Range Plan.

- Parity and time-reversal tests in compound nuclei to test fundamental symmetries in nuclei.

- Measurement of the electric dipole moment of the neutron as a critical test of time-reversal invariance.
- Polarized muonic ^3He to measure the weak-hadronic form factor.
- Measurements on muonium to test quantum electrodynamics.
- Measurement of the decay of the muon to electron and gamma as a test of nonconservation of the family classification of particles.
- Measurement of the rho parameter in muon decay as a precision test of the Standard Model of the electroweak interaction.
- Neutrino-proton scattering to measure the quark structure function of the proton.
- Neutrino oscillations to test family nonconservation and missing mass in the universe.
- Pion production in pion-induced reactions to test the mechanism of chiral symmetry breaking.
- Pion double charge exchange to probe short-range strong-interaction dynamics in nuclei.
- Nucleon charge exchange to probe the spin-isospin response of the nucleus.
- Parity nonconservation in atomic cesium as a precision test of the Standard Model.

LAMPF AND THE NUCLEAR WEAPONS PROGRAM AT LOS ALAMOS

LAMPF is a vital asset, both to applied nuclear technology and to basic nuclear science. In its early years, in fact, the facility was motivated and some of its initial development was funded by both of these communities. (In the early to mid-1960s, administration and funding were consolidated in the Division of Physical Research in accordance with the proviso that the basic science mission of DOE includes underpinning the physics and materials science for DOE's applied programs.)

We view LAMPF as a complex that includes the accelerator and its integral experimental areas, plus the Proton Storage Ring (PSR), the Los Alamos

Neutron Scattering Center (LANSCE), and the Weapons Neutron Research Facility (WNR), all of which rely on LAMPF beam. This LAMPF complex is critically important to the Los Alamos nuclear weapons design and test community. Its value derives from three perspectives: direct ongoing contributions to Nuclear Weapons Research, Development, and Testing (RD&T); unique capabilities with the potential to address emerging needs of significance to the weapons mission; and indirect, but very important, benefits, including a role as the major experimental facility at Los Alamos that links the Laboratory to the academic community and the graduate/postgraduate talent pool.

We take a broad view of the role of the Nuclear Weapons Program as the backdrop to these comments. The program has a primary responsibility for stewardship of the nuclear stockpile, with current emphasis on safety and security. As the stockpile is reduced along the lines of recent Presidential initiatives, Los Alamos-designed weapons will constitute an increasing fraction of this stockpile (to more than 80%). With a mandate to reduce reliance on underground testing, there will be a premium on improving predictive capabilities for weapon design and on making increasingly efficient use of underground testing resources. The aging of weapon systems makes understanding of weapon materials behavior important.

Currently, most of the direct contribution of LAMPF to the weapons program is through neutron measurements of nuclear and materials phenomena. These capabilities are largely provided by the unique capabilities of the PSR/WNR/LANSCE facilities, which have been partly or fully supported by the Nuclear Weapons Program.

Clearly, nuclear expertise is one vital element of the weapons program, both in the technical base and in the testing of new and stockpiled weapons. The unique capabilities of WNR and LANSCE support predictive capability by providing nuclear data for design calculations and simulation codes, nuclear data for the development and interpretation of test diagnostics, and direct absolute calibration of detectors and spectrometers. In addition, WNR has been used to measure the response of stockpiled warheads to neutron radiation; this is important both for weapons survivability and verification.

Improved availability or accuracy of cross sections and calibrations are important elements of improving the predictive capability of design calculations and of evaluating the implications of integral underground experiments. Surprisingly, in a number of cases of interest there are few or no experimental measurements, and the accepted "evaluated" cross sections may have significant uncertainties. Specific examples of this are given in Appendix B.

The materials science capabilities at LANSCE are also contributing to the scientific base of the weapons program. The close coupling of LAMPF/LANSCE to the nuclear materials and high-explosives expertise at Los Alamos enhances the potential utility of this facility for extended research programs on such materials. LANSCE has now achieved dependable operational status. Its primary mission is to support the national materials science community. Nevertheless, LANSCE has already provided the beginnings of some valuable basic research related to the Nuclear Weapons Program. Programs such as these contribute to larger thrusts in nuclear materials, fundamental science of high explosives and explosives safety, and advanced engineering materials. See Appendix B for further discussion of these contributions.

Another opportunity to contribute to the future weapons program is the extrapolation of the demonstrated capabilities of WNR to a new capability for a single-pulse neutron-burst facility. By adding a neutron-multiplying assembly to a WNR-like target and by upgrading the PSR, we could produce a burst of more than 10^{15} neutrons/cm² in a few microseconds. This burst facility could be cost-effective for vulnerability and weapons-effect studies, for assessing neutron-induced gamma production and materials effects due to intense neutron irradiation, and for visualizing dynamical systems (such as explosive-driven assemblies) by neutron radiography and diffraction. This capability is now undergoing conceptual development and initial assessment.

In addition to ongoing contributions from WNR and LANSCE, the capabilities of the LAMPF complex provide the potential for a number of important new contributions relevant to the future weapons program. In a number of cases, these capabilities are unique in the United States or the world. In addition, proximity of LAMPF to the Laboratory's nuclear materials and processing capability provides additional potential. These capabilities and opportunities are outlined in Appendix B.

Links to the Academic Community and the Graduate/Postgraduate Talent Pool

Given the proposed stockpile reduction and the lack of ongoing production, the research and development base of the nuclear weapons program at Los Alamos will be an increasingly important factor in underpinning deterrence. One of the major reasons for the success of the Nuclear Weapons Program at Los Alamos is the strong and diverse technical base resident at the Laboratory. National laboratories such as Los Alamos and Lawrence Livermore, which have a primary mission as weapons design laboratories, cannot function in isolation from the broad unclassified technical community. There is great value,

therefore, to a major experimental facility, such as LAMPF or Livermore's NOVA, as visible centerpieces of experimental science and technology development that are attractive to the larger scientific and technical community.

A continuing issue at Los Alamos is how to hire the best physicists and other technical professionals from top educational institutions into the weapons program and then to continue to provide them with challenging careers. As a major experimental facility of international stature relating to nuclear and particle physics and materials science, the LAMPF complex has introduced many excellent experimental and theoretical scientists to Los Alamos, and has brought many of them here as students, postdoctoral appointees, or collaborators. LAMPF has thus been one important ingredient in the success of the Laboratory's recruiting programs.

LAMPF has also been a vehicle for Los Alamos to retain a high level of technical expertise in fast instrumentation and particle detection. It provides an opportunity for physicists, who are heavily engaged in nuclear particle detection for interpretation of underground nuclear tests, to perform research, to retain their legitimacy in the academic community, and to stay at the leading edge technically. This continual cross-fertilization has helped retain the kind of physicists that have enabled the Los Alamos National Laboratory to achieve its record of technical innovation in underground nuclear experiments.

CONDENSED-MATTER RESEARCH AT THE MANUEL LUJAN JR. NEUTRON SCATTERING CENTER (LANSCE)

LANSCE uses pulsed beams of neutrons to study the structures of solids and liquids, and to provide unique information that is important in fields as diverse as materials science, engineering, physics, chemistry, and structural biology. The importance of neutrons as a structural probe is rooted in their physical interaction with matter:

- Neutrons are highly penetrating, allowing the structure of bulk specimens to be examined.
- Neutrons are sensitive to both atomic and magnetic structures.
- Neutrons are able to measure the energies of atomic vibrations and so probe the forces that hold matter together.
- Neutrons can discriminate between different isotopic species, a fact that makes them a powerful probe of hydrogenous materials such as biological and/or synthetic polymers.

At LANSCE, neutrons are produced by a process known as spallation—this occurs when an energetic beam of protons from LAMPF is allowed to impinge on a tungsten target. This method offers several technical and environmental advantages over the competing technology based on nuclear reactors:

- Because the beams are pulsed they can be used more economically—a reactor must produce 100 times more neutrons than a spallation source to achieve results similar to those obtained from neutron scattering.
- The spectroscopic techniques made available by pulsed beams allow the structures of materials to be probed simultaneously over a large range of length and time scales, a feature that is particularly important for the study of the complex materials that are the bread and butter of materials scientists and biologists.
- There is no inventory of uranium or fission products at spallation sources to pose security risks or increase the Nation's inventory of hazardous nuclear waste.
- Spallation sources have low residual radioactivity and are easy to shut down rapidly, making them inherently safer than reactors.
- Finally, spallation technology offers an attractive option for improving existing neutron sources because, in contrast to reactor technology, it is far from the inherent limit of its performance.

In large measure, our understanding of materials is based on a knowledge of their structure. Such structural determinations are often made, and sometimes can *only* be made, by neutron scattering. For example:

- A knowledge of the structure of ceramic high-temperature superconductors, first obtained by neutron scattering, has led to an understanding of the importance of “sheets” of copper atoms in the superconducting process.
- Neutron-scattering experiments that probe structural and magnetic fluctuations in these materials are gradually improving our understanding of the excitations that may be responsible for the electron pairing that gives rise to the superconductivity.
- Neutron-scattering experiments have revealed the organization of magnetic moments in materials that have high coercivity and large remanent magnetism, even at elevated temperatures. So-called hard

magnets of this type are used in electric motors where their properties are crucial to performance.

- A technique known as contrast-matching has allowed scientists to use neutron scattering to determine the conformation (arrangement) of molecules in polymers—a feat akin to identifying the arrangement of a single strand of spaghetti in a plate full of it. From such information comes an understanding of why some polymers are stronger or more ductile than others.

There are several motivations for studying the structure of materials. From the point of view of the research physicist or chemist, such information adds to the base of fundamental knowledge, the accrual of which is an end in itself. More pragmatically, materials scientists aim to use such knowledge to design new materials with desirable properties—composite materials that maintain their strength at high temperatures or batteries that store more energy, for example. In the field of structural biology, the conventional wisdom is that an understanding of the structure of biopolymers is likely to provide vital clues about the function of such molecules.

Neutron scattering at LANSCE covers a broad spectrum of topics. Several examples are presented in Appendix C to indicate how this work contributes strongly to programs of national importance, such as nondestructive testing of materials and the measurement of properties of polymers. The applications to structural biology are of such significance that we devote the next section to this subject.

LANSCE AND STRUCTURAL BIOLOGY

Studies of the structures of biological molecules at LANSCE form a natural complement to work on the human genome. The latter emphasizes the sequence of bases that make up a particular chromosome, whereas structural biology concentrates on the structure and conformation of larger macromolecular units.

Neutron scattering is playing an increasingly important role in advancing our state of knowledge about biological structure and function at the molecular level. Biomolecular systems that carry out the basic life processes are complex, interactive, multicomponent systems that operate in a wide variety of environments, including membranes and densely packed aqueous suspensions and solutions. For example, genetic information (that is passed on from generation to generation and contains the coded DNA sequences that allow a cell to manufacture its protein constituents) is packaged in complex assemblies of DNA and protein molecules that lie inside the densely packed cell nucleus.

The processes by which the DNA sequence is reproduced, or translated into a form that the cell can read and use as a template to build its proteins, involve interactions with other proteins and carefully orchestrated structural rearrangements at many different levels. To understand these processes it is crucial to obtain structural information on the individual components of complex assemblies.

The ability to probe the structures of biomolecules depends on having radiation with wavelengths on the order of, or smaller than, the objects we wish to study. Neutrons, x-rays, and electrons are therefore all useful for studying biomolecular structures. Neutron scattering, however, provides us with the unique capability of being able to study the individual components of complex biomolecular systems in different functional states using the technique of contrast variation or solvent matching. Macromolecules in solution will scatter neutrons, x-rays, or electrons, and the variation in intensity of the scattering as a function of scattering angle gives information on the structure of the macromolecule. The intensity of the scattering signal for any component is proportional to the difference in the scattering density of the component and that of the solvent. This is the "contrast" factor. The contrast of biomolecules in solution for neutrons can be readily manipulated by substituting deuterium for hydrogen, either in the solvent or in the biomolecule. This effect arises from the fact that neutrons are neutral particles that are scattered by the nuclei in a molecule, and hence the neutron-scattering properties of isotopes of the same element can vary radically.

For all the elements commonly found in biological systems, except hydrogen, neutron-scattering-length densities are similar in magnitude and are positive. Hydrogen has a negative neutron scattering-length density (indicating a phase change for the scattered neutron arising from a resonance effect), which is about half the magnitude of that for the other elements. The scattering density for a component is simply the sum of the scattering densities for each atom in the particle divided by the volume of the component. Thus differences in the mean hydrogen content of a particle result in different mean neutron-scattering densities. This is the basis for the differences in mean neutron-scattering densities for the major constituents of biomolecular systems. Polynucleotides like DNA, polypeptides like proteins, and the lipid molecules that make up biological membranes each have quite different mean neutron-scattering-length densities. In addition to these intrinsic differences, it turns out that the neutron-scattering-length densities of each of these constituents lie between the neutron-scattering-length densities for pure H₂O and pure D₂O. Thus, by adjusting the D₂O content of a solvent, one can match the neutron-scattering-length density of any of these constituents with that of the solvent and observe the scattering from what remains. Thus, for a complex of DNA and protein one can

characterize the structure of the DNA and that of the protein separately. This capability is crucial to sorting out the details of the molecular interactions and conformational transitions that are basic to understanding dynamic biochemical processes such as replication, transcription, and biochemical regulation.

The neutron-scattering properties of the elements in biomolecules also give special advantages for high-resolution neutron protein crystallographic studies of biomolecules. Neutron protein crystallography can give information on the precise locations of hydrogen atoms in biological macromolecules, thus providing crucial information on the role of solvent in biomolecular structure as well as the role of specific hydrogen atoms in catalytic processes, for example. This type of information cannot be obtained using x-ray or electron crystallography.

While neutrons provide us with special capabilities for biological structure determination they have one disadvantage—they are produced in sufficient quantities for neutron-scattering experiments only by nuclear reactors or by spallation sources that are driven by high-intensity accelerators. High-intensity neutron beams are crucial for biological studies, since biological systems are inherently weak scatterers of neutrons, and they are difficult to prepare in large quantities in pure form. The Los Alamos spallation neutron source is currently the highest-intensity spallation neutron source in the United States, and it provides the potential for upgrades that would allow us to maintain international leadership in pulsed-neutron technology and applications worldwide. Neutron spallation sources provide neutrons in short bursts, or pulses, hence important advantages in instrumentation can be gained over the steady-state neutron source of a reactor by using time-of-flight methods to do energy or wavelength analysis of the neutrons used in any experiment. This attribute is particularly valuable in instrumentation used for studying biomolecules in solution with contrast variation. Because one can use a broad range of wavelengths in the experiment, it is possible to measure objects with dimensions over a very wide range (tens to thousands of angstroms) with a single instrument arrangement. This means that one can study everything from small individual proteins, or protein complexes, through the larger protein complexes or DNA/protein complexes to the plant viruses and even to the large animal viruses. One can also use the pulsed structure of a spallation neutron source to gain advantages for neutron crystallography using Laue diffraction techniques.

At the present time LANSCE provides neutron beams that can be utilized for studying biomolecular structures. There is currently a small-angle neutron spectrometer (LQD) that is a national user facility designed to serve a spectrum of disciplines including materials science, polymer science, and structural biology. The use of the LQD for studying antigens is described in Appendix C.

This spectrometer has proven a valuable resource for medium-resolution studies of biomolecular assemblies in different functional states, though at the present time this facility is seriously oversubscribed. There are plans under way to build a second low-Q diffractometer and a neutron crystallography station at LANSCE that would be national user facilities for structural biology.

The loss of these facilities, were LAMPF and consequently LANSCE to be closed down, would be felt widely in the structural biology community at a time when there is a terrible shortage of neutron-scattering facilities for neutron users in the United States in all disciplines. We would not only be losing a unique and valuable resource for today, but our potential to push these techniques to their technological limits will be lost.

RADIOISOTOPE RESEARCH, DEVELOPMENT, PRODUCTION, AND DISTRIBUTION AT LAMPF

The Medical Radioisotopes Research and Production Programs at Los Alamos 1) make use of the excess beam of 800-MeV protons from the LAMPF accelerator to produce radioisotopes of demonstrated or potential value in nuclear medicine and/or biomedical research and 2) provide these radioisotopes to the nuclear medicine, biomedical, and other research communities. With the intense beam current of LAMPF, we can produce quantities of radioisotopes that cannot be produced anywhere else in the world. In fact, we have demonstrated production of more than 30 radioisotopes at LAMPF and are the sole United States supplier of approximately 15 of these.

Research activities continue to focus on the development of new radioisotopes. Production activities are directed at providing radioisotopes in various stages of development, from strictly research radioisotopes to radioisotopes used in commercial products. In FY 1991, Isotope and Nuclear Chemistry (INC) Division personnel made over 120 shipments of 17 curies (Ci) of 15 radioisotopes to more than 50 organizations worldwide. These organizations include universities, hospitals, government research institutions, radiopharmaceutical manufacturers, and other commercial entities; the research communities served include nuclear medicine, biomedical research, environmental science, materials science, and physical science.

The Medical Radioisotopes Research and Production Programs serve a vital function for the nuclear medicine and other research communities as a national resource for radioisotopes for use in medicine and other applications. While there are a few facilities that can produce some of these radioisotopes in limited quantities, there are none, other than LAMPF, that can provide the quantities required for many of the commercial applications.

The Isotope Production Facility (IPF) at LAMPF consists of an automated insertion and retrieval system at the LAMPF beam stop that allows us to insert target materials, including metals, alloys, and salts, into the proton beam. There are currently nine target stringers that can be inserted and irradiated simultaneously. Targets and irradiation schedules are determined by the requirements of our commercial customers and the nuclear-medicine research community. Other requirements for radioisotopes are satisfied on a best-effort basis. After irradiation, the targets are highly radioactive (>100 000 Rem); therefore, they are remotely removed from the LAMPF beam stop area, transported to the hot cell facility at the Radiochemistry Site (TA-48), and processed for the radioisotope products.

We give below several important examples of commercial radioisotopes and research radioisotopes from our portfolio of 30 products. See Appendix D for the description of additional LAMPF-produced radioisotopes and for a table of customers.

^{68}Ge . This LAMPF-produced radioisotope is the parent of ^{68}Ga , which is a positron emitter. A $^{68}\text{Ge}/^{68}\text{Ga}$ biomedical generator is available, and radiopharmaceutical development work using this generator as the source of ^{68}Ga is a nuclear-medicine research area. However, the major use for this radioisotope is for calibration and absorption correction sources for clinical positron-emission-tomography (PET) scanners. PET is currently the fastest-growing nuclear-medicine diagnostic tool, with 100 centers already operating and another 100 projected by 1995. This represents a total capital investment of approximately \$1000 million, and most of this equipment cannot operate without the ^{68}Ge calibration sources. The Department of Energy is currently the only supplier of this important nuclear-medicine radioisotope.

^{67}Cu . This LAMPF-produced radioisotope has nuclear properties that make it an extremely attractive candidate for radiopharmaceuticals for both diagnostic and therapeutic applications. Research activities include applications of this radioisotope for studies of copper metabolism, investigations of autoimmune diseases such as myasthenia gravis, and early detection and treatment of lung cancer, as well as diagnosis and treatment of lymphoma and colon cancer. For these applications, high-specific-activity material is required. Reactor-produced material does not satisfy this requirement; only accelerator-produced material can be made with adequate specific activity. These promising approaches to cancer detection and treatment and other biomedical research will disappear without the LAMPF-produced material. DOE is the only supplier of high-specific-activity ^{67}Cu for these areas of research.

²⁶Al. This radioisotope is used for understanding the role of aluminum in Alzheimer's Disease. LAMPF is the only source of this radioisotope.

LAMPF also is the sole or major producer of the following radioisotopes: ³²Si, which is the only long-lived radioisotope of silicon used for environmental research; ⁴⁴Ti, which is the parent for ⁴⁴Sc, a positron emitter that could form the basis of yet another generator for PET; and ¹⁴⁸Gd, which is used as a low-energy alpha source for physics experiments (e.g., on board Galileo).

The nuclear-medicine research efforts in the Isotope and Nuclear Chemistry (INC) Division involve investigations of new radioisotopes and biomedical generators, radiopharmaceutical development and labeling, and *in vivo* animal studies to demonstrate the utility of new agents discovered in this program. Research directed at new radioisotope development involves conceptualization of an isotope and applications, development of the targeting and irradiation schedules to maximize isotope yields, investigations of separations chemistry required to isolate and purify the isotope of interest, and experiments to explore applications. The biomedical generator development contributes to the availability of short-lived research radionuclides, PET agents, and therapeutic radioisotopes. The labeling efforts focus on development of radiopharmaceuticals with selectivity for receptors, diseased tissues or organs, including radiolabeled covalent and chelate complexes, radiolabeled chelate complexes attached to monoclonal antibodies or other small biomolecules (peptides or nucleotides), or directly radiolabeled monoclonal antibodies or small biomolecules. Biological evaluations of radiopharmaceuticals range from biodistribution studies in cells and tissues to *in vivo* animal studies. Many noted clinical research centers (e.g., the Mayo Clinic, the Johns Hopkins University, the National Cancer Institute) collaborate with Los Alamos to evaluate the potential of pharmaceuticals incorporating LAMPF-produced radioisotopes. These activities are summarized in Appendix E.

LAMPF AS KEY TO DEVELOPMENT AND DEMONSTRATION OF ACCELERATOR-DRIVEN, INTENSE-NEUTRON-SOURCE TECHNOLOGY

Background

The Laboratory's initiative in the new technology area of Accelerator-Driven, Intense Neutron Source Technology (ADINS) can have a key impact on important national applications as well as future technology directions for the Laboratory. ADINS includes the following:

- Accelerator transmutation of nuclear waste (ATW) aimed at destruction of long-lived radionuclides in high-level nuclear waste (HLW). Applications include defense waste cleanup at Hanford and as a potential key component of commercial HLW management strategies.
- Materials production (includes accelerator production of tritium [APT] and accelerator production of ^{238}Pu [APP]).
- Long-term, nuclear-energy production in a system that uses no enriched fuels, destroys essentially all of its long-lived HLW, and offers safety features of accelerator drive.
- An intense neutron source for basic research in materials science. Similar technology could drive a short-pulse burst facility for weapons effects.

LAMPF's Role

Beam-stop experiments as well as those performed at WNR/LANSCE would include the following types of data measurements, scaled integrated tests, and component demonstrations.

1. Supporting Data—Key Measurements.
 - (a) Determination of the neutron production per proton for targets having geometries appropriate for APT/ATW and similar systems.
 - (b) Spallation product yield and decay power. For both APT and ATW, knowledge of radioactive products produced in the spallation target is fundamental to arguments concerning operational advantages that are environmentally attractive. For example, long-lived radionuclide production is important for ATW overall system material balance; production of volatiles would be important for APT radiation source-term quantification.
 - (c) Measurement of nuclear transmutation cross sections for fission products. An important example is that of ^{137}Cs (30-year half-life) for which factors of 10 differences exist in current data. This information is key to determining whether ATW can handle radionuclides with half-lives less than 30 years. If it can, then times for remaining waste management may be less than 100 years, instead of several centuries.
 - (d) Determination of fission cross sections on unstable nuclei such as ^{238}Np ($t_{1/2} = 2$ days). Fission of this unstable species is key to the

two-step transmutation of nonfissile actinides in an intense thermal neutron flux.

- LAMPF/LANSCE are the only national facilities where such data can be obtained, particularly for unstable target species.

2. Scaled Integral Tests. The LAMPF beam stop provides a facility that is crucial to beginning tests/demonstrations of APT, ATW, APP, Scaled APT systems that include neutron spallation target, D₂O blanket, a flowing ³He loop, and perhaps on-line tritium extraction could be demonstrated. Similarly, a ²³⁸Pu demonstration (APP) would consist of target, blanket, and a neptunium oxide slurry. Chemical separations also could be demonstrated if fission-product contamination were small. Tests using LAMPF would produce significant quantities of ²³⁸Pu (tens to hundreds of grams). Finally, similar ATW system components could be tested with an additional component being a flowing technetium loop for which continuous extraction of the transmutation by-product, ruthenium, would be demonstrated. A key technology issue that would be addressed is the impact of the radiation environment (i.e., radiolysis) on the chemical separations. One deficiency is the neutron flux level (~10¹⁴ n/cm²/sec), which is too low to demonstrate two-step actinide burn.

- The LAMPF beam stop provides a unique facility that can replicate, at a scaled level, the environment of an ATW/APT/APP system.

3. Component Demonstrations. The LAMPF beam (1 mA over a few-square-centimeters area) directly simulates power densities on ATW/APT neutron targets as well as beam entrance windows. Damage data for candidate materials can be obtained at the LAMPF beam stop, in addition to the scaled integrated system tests indicated above. A different type of component demonstration could take place at the WNR facility, where close to full-scale mockups could be exposed to low-proton-current conditions to measure integral material-production values (tritons per proton, for example).

- The combination of LAMPF/LANSCE is unique to produce demonstrations of key APT/ATW/APP components.

Capabilities of an Upgraded LAMPF for APT/ATW/APP

LAMPF, upgraded in power by an order of magnitude, would take the integral system and component demonstrations described above from an initial proof-of-principle to a next level of pre-pilot-scale demonstration.

A principal area for technological verification is neutron spallation target performance. (Much high-power accelerator technology development has occurred because of SDI. This development has not been replicated in the target area.) The target performance (heat load handling, materials lifetime, spallation production buildup, ...) would be demonstrated using this upgraded facility at power densities comparable to ATW (few megawatts/m³).

The most likely route for such an upgrade would be through replacement of the low-energy (<100 MeV) end of LAMPF with modern neutral particle beam (NPB) components (ion source, radio-frequency quadrupole,* modern drift-tube linac). The beam structure could include a beam operating at around 10% duty factor with a peak current of order 100 mA. The proton charge per bunch would be within a factor of 2 of the present LAMPF beam structure (0.5×10^8 protons/bunch).

To retain LAMPF's simultaneous acceleration of H⁺ and H⁻, two low-energy beam lines could be utilized (ion source, RFQ, DTL) that would be combined at higher energy. This system would provide a realistic demonstration of funneling. Integrated system operation would be demonstrated at higher levels than can be performed using the current LAMPF. For example, on-line or semibatch processing of materials could involve material quantities on the order of hundreds of grams per year.

Capabilities of an Upgraded LAMPF in Other Areas

The upgraded LAMPF described above would provide an intense neutron spallation source whose performance would be comparable to that associated with the United States Advanced Neutron Source (ANS). ANS is projected to cost at least \$1 billion and would utilize a fast burn-up reactor core design. Core lifetimes would be 10 days, with 4 days required to replace the fuel elements. The upgraded LAMPF facility would have a higher performance than an 800-MeV, 6-mA spallation source under study by the Europeans.

Such a source could also drive a short-burst subcritical assembly that would exceed current Sandia fast-burst facilities for weapons effects testing. It would also exceed performance levels (flux and pulse widths) associated with new proposals put forth by Sandia.

Finally, a 10-mA, 50- to 60-MeV beam extracted from LAMPF and directed onto a flowing lithium target could be a powerful fusion materials effects facility.

* The first radio-frequency quadrupole sections were built at Los Alamos.

- LAMPF, upgraded to 10 megawatts of beam power, is required for APT/ATW/... development and can serve as a focus for a multidisciplinary technology thrust for the Laboratory in the future.

CONCLUSIONS

LAMPF is unique among nuclear physics facilities because it is embedded in a multidisciplinary laboratory and impacts on a number of critical national concerns in both basic and applied research.

Several years ago, a DOE review committee, chaired by Erich Vogt, Director of the Canadian meson factory (TRIUMF), identified LAMPF as the flagship of U.S. nuclear science. It has not been superseded thus far. It remains the world's largest, highest-beam-power, most versatile proton-accelerator-based facility with multiple beam lines and satellite facilities (LANSCE and WNR), which also have multiple beam channels. In terms of the hadronic component of nuclear physics, the number of experiments that can be simultaneously accommodated, and the potential for immediate and long-term practical applications, we see no challenge to LAMPF on the horizon.

LAMPF, including LANSCE and WNR, represents a very major investment (replacement value would exceed \$0.5 billion). It is paying handsome dividends by permitting research and applications in major scientific areas that impact directly on our national well-being in defense, education, energy, and health, the avoidance of technological surprise, and in helping to maintain the vitality of a major national laboratory devoted to a broad range of national security issues.

Large as is the total cost of LAMPF, that investment is less than the total sales of medical accelerators that have already been built using LAMPF-developed technology. But perhaps more important is the fact that these medical x-ray machines have improved the treatment for many tens of thousands of cancer patients each year. We continue to anticipate comparable, and even greater, dividends from future applications of LAMPF capabilities that are not duplicated by any existing or planned facility. These are likely to occur in biology and medicine, materials research, nuclear-waste transmutation, and tritium production. Success in any one of these areas can translate into enormous national benefits and monetary savings. The intellectual contributions of LAMPF are not quantifiable, but are of transparent importance to whatever scenario is projected for the future of the Laboratory. It is our considered judgment that the scrapping of LAMPF, in the time frame under consideration by DOE, will very quickly be seen as a disaster, in the short term, and would forfeit opportunities and leadership in a number of critical areas far into the future.

For the future, modest upgrades of LAMPF can maintain its world-class status in fundamental research and education. An upgrade of spallation neutron capabilities to serve materials science and biophysics requirements is, by far, the most cost-effective way for the United States to remain competitive, by way of neutron probes, in these important arenas. It appears that the European Community will now adopt the spallation neutron source option for the future.

The utilization of LAMPF as the injector for a next-generation neutron source would provide major savings in time and money compared to the construction of a new reactor. In the meantime the U.S. would have a world-class neutron source to pursue problems of national interest.

ACKNOWLEDGMENTS

The technical sections of this document were drafted by scientists in the appropriate field. The Fellows wish to thank the following individuals for contributing this factual information:

J. David Bowman, Nuclear and Particle Physics Group (MP-4)

Robert Burman, Nuclear and Particle Physics Group (MP-4)

Harry Dreicer, Associate Director at Large

Robert Glasser, Center for National Security Studies

**Philip Goldstone, Office of the Associate Director for Nuclear Weapons
Technology**

John Immele, Associate Director, Nuclear Weapons Technology

Mikkel Johnson, Medium-Energy Physics Division Office

O'Dean Judd, Office of the Associate Director for Defense

**Warren Miller, Associate Director for University Relations and Fundamental
Research**

Eugene Peterson, Nuclear and Radiochemistry Group (INC-11)

Roger Pynn, Director, Los Alamos Neutron Scattering Center

Jill Trehwella, Biochemistry/Biophysics Group (LS-2)

Geoffrey West, Elementary Particles and Field Theory Group (T-8)

The LANL Fellows Ad Hoc Review and Editorial Committee is composed of:

J. D. Bowman

J. L. Friar

M. B. Johnson

J. D. Louck

M. R. Raju (Chairman)

H. Robertson

L. Rosen

G. B. West

J. B. Wilhelmy

W. H. Woodruff

The Committee wishes to acknowledge the assistance of John Allred and Beverly Talley in the production of this document.

APPENDIX A

Academic Institutions and National Laboratories at LAMPF

Abilene Christian University	Fermi National Accelerator Laboratory
Albany Medical College	Florida International University
American University	Florida State University
Applied Research Labs	Fordham University
Argonne National Laboratory	Franklin & Marshall College
Arizona State University	George Mason University
Associated Western Universities, Inc.	George Washington University
Boston University	Georgia Institute of Technology
Brigham Young University	Geoscience Research Institute
Brookhaven National Laboratory	Hampton University
Brooklyn College	Harvard University
Brown University	Idaho State University
California Institute of Technology	Indiana University
California State College, Long Beach	Iowa State University
California State Polytechnic, Pomona	James Madison University
California State Polytechnic, San Luis Obispo	Johns Hopkins University
California State University, Los Angeles	Kansas State University
California State University, Northridge	Kent State University
California State University, Sacramento	LaRue County High School
Carnegie-Mellon University	Lehigh University
Case Western Reserve University	Lewis and Clark College
Catholic University of America	Lincoln University
Central Washington University	Linfield College
City College of New York	Louisiana State University
City University of New York	Massachusetts Institute of Technology
Clarkson University	Memphis State University
College of William and Mary	Michigan State University
Colorado College	Michigan Tech University
Cornell University	Mississippi State University
Duke University	New Mexico Institute of Mining/Technology
Earlham College	New Mexico State University
East Texas State University	New Mexico Technical Institute
Eastern New Mexico University	New York University
Eastern Tennessee State University	Norfolk State University
Elmhurst College	North Carolina State University
Embry-Riddle Aeronautical University	Northern Arizona University
	Northern Illinois University
	Northwestern University

Oak Ridge National Laboratory	University of Central Arkansas
Oberlin College	University of Chicago
Ohio State University	University of Cincinnati
Ohio University	University of Colorado
Old Dominion University	University of Connecticut
Oregon State University	University of Denver
Oswego High School	University of Florida
Pennsylvania State University	University of Georgia
Princeton University	University of Houston
Purdue University	University of Idaho
Reed College	University of Illinois, Chicago
Rensselaer Polytechnic Institute	University of Illinois, Urbana-Champaign
Rice University	University of Iowa
Rutgers University	University of Kansas
Saginaw Valley State University	University of Kentucky
San Jose State University	University of Louisville
Sierra Engineering	University of Maryland
Southern University	University of Massachusetts
St. Mary's College	University of Massachusetts Medical Center
Stanford Linear Accelerator Center	University of Michigan
Stanford University	University of Michigan Medical Center
State University of New York	University of Minnesota
State University of New York, Stony Brook	University of Mississippi
Syracuse University	University of Missouri
Temple University	University of Montana
Texas A&M University	University of Nebraska, Lincoln
Texas Tech University	University of New Hampshire
Thomas More College	University of New Mexico
United States Air Force Academy	University of Notre Dame
United States Naval Academy	University of Oklahoma
Universidad de Puerto Rico	University of Oregon
University of Arizona	University of Pennsylvania
University of Arkansas	University of Pittsburgh
University of Arkansas for Medical Science	University of Rochester
University of California, Berkeley	University of South Carolina
University of California, Davis	University of Southern California
University of California, Irvine	University of Tennessee
University of California, Los Angeles	University of Texas, Austin
University of California, Riverside	University of Texas, El Paso
University of California, San Diego	University of Utah
University of California, Santa Barbara	University of Virginia
University of California, Santa Cruz	University of Washington

University of Wisconsin
University of Wyoming
Utah State University
Valparaiso University
Virginia Polytechnic Institute
Virginia State University
Virginia Tech
W.A.M.D.I
Washington State University
West Virginia University
Western Michigan University
Western Washington University

**Industrial Laboratories
Represented at LAMPF**

American Magnetics, Inc.
Arco Oil and Gas Company
AT&T Bell Laboratories, Murray Hill
Battelle Pacific Northwest Laboratory
Columbia Scientific Industries
Cryomag Services, Inc.
E. I. DuPont de Nemours
Eaton Semiconductor Equipment
EG/G, Idaho, Inc.
EG/G, Los Alamos, Inc.
GEO Magazine
Hamamatsu Corp.
Harshaw Chemical Company
Hemmes/Southwest Co.
Hughes Research Laboratory
Idaho National Engineering
Laboratory
INEL
INTA
Jomar Systems, Inc.
Koch Process Systems, Inc.
Lockheed Missile & Space Co.
Lujan Software Services, Inc.
Matra Data Vision
Merrick & Co.
Micron Semiconductor
Mitsubishi International Corp.
New England Nuclear Corporation

Nova Electronics and Software
Nuclear Shielding Supplies &
Services
NUS Corporation
Oxford Instruments
Oxford Instruments North America,
Inc.
Phillips Scientific
RDM International, Inc.
Rockwell International
Salem Technical Services
Santa Fe Energy Research
Santa Fe Institute
SBE, Inc.
Science Applications International
Corp.
Scientific Systems International
Sheedy Drayage & Rigging Co.
Southwest Research Institute
Summa Medical Corporation
Tektronix Federal Systems, Inc.
Thorne E.M.I. Electron Tubes, Inc.
TRW Systems Group
Wang NMR, Inc.
Westinghouse Electric Corporation

Hospitals Represented at LAMPF

University of New Mexico Cancer
Research/Treatment Center
College of Physicians & Surgeons,
Columbia University
Johns Hopkins University
Maine Medical Center
Medical Radiology Associates, PA
Ochsner Clinic
St. Mary's Medical Center
The Chicago Medical School
University of Colorado Medical
Center
University of Kansas Medical Center
University of New Mexico School of
Medicine
Yale New Haven Hospital

APPENDIX B

CONTRIBUTIONS OF LAMPF TO NUCLEAR WEAPONS DEVELOPMENT

Measurement of Cross Sections

Examples of recent and planned experiments for improving accuracy of cross sections and calibrations for increasing the predictive capability of design calculations and evaluating the implications of integral underground experiments include the following:

- Measurement of neutron-induced fission cross sections, fragment angular distributions, and neutron and gamma-ray multiplicities and spectra in uranium, plutonium, and other actinides. In some cases, the fast-neutron cross sections were found to be different from previous evaluations by ~15% and more.
- Measurement of (neutron,gamma) cross sections in light nuclei.
- Accurate absolute calibration of fully integrated detector systems (detector, cables, oscilloscopes) to be deployed at Nevada Test Site.
- Measurement of the neutron cross section of ^{88}Y , a radiochemical diagnostic. Recent Russian information suggests this cross section may be significantly different from the currently accepted value.
- High-energy gamma-rays from (neutron,gamma) interactions with actinides for diagnostic calibration.

Weapons-Related Research from LANSCE

- The capability to perform neutron powder diffraction of actinide materials from ~10 Kelvin to just below the melting point has enabled (1) structural studies of plutonium metal and plutonium hydride (and other actinides) over this range, and (2) measurements of Debye-Waller factors (elastic constants) of alpha plutonium.
- The vibrational spectra of TATB-insensitive high explosives, and related molecules, have been examined as a function of static pressure.
- A nondestructive technique for determining the residual stress produced by fabrication and deformation in polycrystalline composite materials (e.g., ceramic reinforced lightweight metals) has been demonstrated and

the results have helped assess a theoretical model of these materials, which are used to predict component performance.

- Measurements of helium bubble formation in metals have been taken (and plans have been made to take measurements in plutonium).

Future Capabilities and Opportunities

There are valuable opportunities for the Nation to utilize the unique capabilities of LAMPF to address issues for the future weapons complex and for management of long-lived wastes. The Laboratory's capabilities in accelerator technology, accelerator-based neutron sources, and nuclear materials processing can be used, together with LAMPF, to develop and assess the potential of new techniques for producing the tritium needed for the ongoing nuclear stockpile and for transmuting long-lived nuclear waste to shorter-lived forms.

Accelerator production of tritium (APT) offers many environmental advantages over traditional approaches, for example, not containing fissionable material. As the future tritium production requirement becomes smaller because of stockpile reductions, APT becomes both more economically advantageous and technically attractive as compared with other solutions. Accelerator-based neutron sources could also provide effective, economical transmutation of long-lived high-level waste and actinides (such as plutonium waste) into shorter-lived waste that decays in roughly 100 years rather than 10,000 years. This would dramatically ease the requirements on geological repositories. While Los Alamos continues to support today's efforts in waste management, such as the Yucca Mountain Project, accelerator transmutation of waste (ATW) offers the potential for a major shift in waste management strategy. Los Alamos has proposed to develop and assess these technologies.

The unique characteristics of the LAMPF accelerator at Los Alamos are the closest in the United States to those of an accelerator required for APT and ATW. This feature, together with the tritium and process chemistry capability available at Los Alamos, makes LAMPF ideally suited to perform many of the risk-reduction experiments necessary for APT and ATW.

APPENDIX C

APPLICATIONS OF LANSCE TECHNOLOGY

Metal Matrix Composites

Metal matrix composites (MMCs) are increasingly replacing conventional materials in structural applications that require high strength-to-weight or stiffness-to-weight ratios. The benefits of improved efficiency due to lighter components are encouraging both the aerospace and automotive industries (including Ford, Rockwell, and General Motors, among others) to investigate applications for MMCs. Before manufacturers use a new material in a critical assembly—for example, as part of an airframe—they must extensively test and model it. Computational models predict safe service lifetimes, but are limited by assumptions concerning the initial state of the component. Experiments are essential to validate these predictions. Residual stresses among the constituent phases strongly affect the strength and fracture resistance of MMC materials. Conventional techniques of measuring residual stress are hard to apply to composites and are limited because of their inability to distinguish between the matrix and reinforcement. Neutron diffraction, which can only be performed at a high-flux neutron source such as LANSCE, offers a unique nondestructive alternative for examining the stress state of crystalline composites.

At LANSCE neutron diffraction has been used to examine a variety of MMC materials and to make direct comparisons with computational models. Our experiments confirm the ability of models proposed by collaborators at Brown University to predict qualitatively and, in several cases, quantitatively, the internal stresses in composite materials. However, there are some intriguing differences between the experimental results and the predictions. In particular, the behavior of the reinforcement is harder to model than the matrix, and the form of the reinforcement, either fibers or particulate matter, affects the validity of the models. Our experimental results show the limitations of the computer simulations and indicate where enhancements are needed.

Several experiments have been carried out to study residual stresses in more conventional materials, such as welded plates and connecting rods from an automobile engine. Studies of this sort are important examples of the way in which facilities at national laboratories can contribute to the enhancement of United States industrial competitiveness.

Polymers

Synthetic macromolecules at solid or fluid interfaces have an enormous spectrum of applications to a wide variety of technologies. They provide a mechanism to achieve colloid stabilization in water treatment, ceramic processing, inks, fuels, and other suspensions and emulsions; they are used for mechanical protection of solids against friction and wear; and they are used as model biomembranes. Surface-active molecules have been developed for environmental clean-up as well as for the separation of proteins, and macromolecular films are being developed for optoelectronic devices. This partial list is indicative of the ubiquitous involvement of surface-active macromolecules in modern society.

Although there is a substantial body of theoretical literature on the morphologies of adsorbed polymers, grafted chains, block copolymers, etc., for the most part experimental evidence has been inferential. In an attempt to correct this situation, experiments are under way at LANSCE to probe the structure of macromolecular layers by neutron reflection. This technique permits the determination of the average density profile perpendicular to flat layers as well as providing information about the texture or roughness of the layers. By combining neutron reflection studies with surface-force measurements by our collaborators at the University of California at Santa Barbara, we aim to advance the understanding of the interactions within complex fluid layers. As a first step, neutron reflection measurements have been made on polymer molecules that were anchored to a solid/liquid interface by a lipid bilayer. By changing the density of the lipid layers, the grafting density of the polymer "brush" extending into the liquid can be controlled. When fully analyzed, the data are expected to yield information about the density of the polymer "brush" that can be compared with recent theories.

Experiments have also been conducted on a related system of diblock copolymers, each molecule of which consists of two different polymer molecules bonded to each other to form a single chain-like molecule. Under suitable solvent conditions, block copolymers can adsorb with one compact, tightly bound block and one extended, swollen block (a brush) stretching away from the surface into the solvent. The neutron reflectivities of a surface coated with such a copolymer are well described by parabolic as well as error-function density profiles for the brush, but the data cannot be fitted to exponential or power-law decays. These experiments represent the first experimental confirmation of the theoretically predicted parabolic profile.

One of the difficult problems facing any attempt to recycle polymer products is the nonmiscibility of different polymer molecules. In many cases, a mixture

of two polymers will separate into small contiguous regions that are rich in one or another of the polymers—a process known as microphase separation. The mechanical properties of the mixture are then determined by the strength of the interfacial regions between different domains. The interfacial strength is governed, in turn, by the degree of diffusion of molecules across the interfaces to form bridging links between neighboring domains. The only method that has been used successfully to study diffusion across polymer interfaces is neutron reflection. Measurements made at LANSCE have yielded values for interfacial widths and shapes as a function of annealing temperature that have vindicated theoretical models in some cases. Even more interesting has been the study of films made from copolymers composed of two immiscible polymers. The morphologies that arise in this case are complex and are often driven by small perturbations such as interactions with the solid surface on which the copolymer is deposited.

Antigen Sites

Antibodies are protein products of the immune response that recognize and bind to antigens, which are foreign substances in the body. Over 70% of the antibody in serum is of the so-called IgG class, which can be visualized as Y- or T-shaped molecules having two identical antigen binding sites at the ends of the upper arms, joined by a flexible “hinge” to the stem region. The specificity occurs at the binding sites, and the variety of immune response elicited depends on the stem region. Fragments of the IgG's have been crystallized and high-resolution structures have been found previously. However, information about the complete structure of functional IgG's was lacking. Using neutron scattering and appropriate contrast-matching conditions, we have measured the distance between bound antigen sites for three immunoglobulins (IgG subclasses 1, 2a, and 2b). To obtain high-quality results required the production of large quantities of monoclonal antibodies, as well as bacterial expression systems that allow production of deuterated protein antigens. This work was carried out in the Laboratory's Life Sciences Division.

APPENDIX D

LAMPF-PRODUCED RADIOISOTOPES

⁷²Se. This LAMPF-produced radioisotope is the parent of ***⁷²As***, a positron emitter. The development of this ***⁷²Se/⁷²As*** generator and related arsenic radiopharmaceuticals holds the promise of a wide variety of clinical diagnostic PET procedures without the necessity of an on-site cyclotron. The commercial success of the ***⁸²Sr/⁸²Rb*** generator indicates the potential of generator-produced positron emitters, but the diversity of arsenic chemistry should lead to many more clinical applications than are possible with the Squibb generator. Development of the ***⁷²Se/⁷²As*** generator coupled with development of arsenic radiopharmaceuticals could explosively enhance the clinical utility of PET because PET centers could be established without the need for an on-site cyclotron. This would permit the use of PET in small hospitals and in rural settings using generator-based PET isotopes such as ***⁸²Rb*** and ***⁷²As***. LAMPF is the only supplier of ***⁷²Se*** for this research.

²²Na. LAMPF is the major supplier of this positron emitter that has a variety of commercial applications.

⁸⁸Y. LAMPF is the only supplier of the ***⁸⁸Zr*** parent for generating the requisite high-specific-activity ***⁸⁸Y*** used for chemical development of monoclonal antibody labeling with ***⁹⁰Y***.

⁸²Sr. This LAMPF-produced radioisotope is the parent of ***⁸²Rb***, which is a positron emitter. The ***⁸²Sr/⁸²Rb*** biomedical generator is a commercial product manufactured and marketed by Bristol-Myers Squibb Diagnostics. The ***⁸²Rb*** produced from the generator is used clinically in cardiac imaging by PET. Many new PET centers are dependent on this generator for diagnostic procedures because they do not have on-site cyclotrons to supply radiopharmaceuticals. DOE is the major supplier of this isotope.

¹⁰⁹Cd. LAMPF is the only North American supplier of this isotope for portable x-ray fluorescence instruments used on the floors of metallurgical shops for analysis of steels.

^{95m}Tc. Recently, separation and recovery of this radioisotope from irradiated molybdenum metal targets have been accomplished. This radioisotope will satisfy a requirement for a longer-lived technetium radioisotope for biodistribution and other nuclear-medicine applications research. It will also be useful as an environmental tracer.

Los Alamos National Laboratory FY 1991 Medical Radioisotopes Shipments.

Isotope	Customer	No. of Shipments	Shipped (mCi)	Received (mCi)
²⁶ Al	CSNSM, France Harwell Laboratory, UK TRIUMF, Canada University of Manchester, England	4	0.0063	0.0063
⁷² As	University of Texas	2	190	95.00
⁷³ As	EPA/RSO U.S. Geological Survey University of Arizona USDA, Grand Forks, North Dakota Walther-Straub Institute, West Germany Wayne State University	7	22	22
⁷ Be	Amersham International, UK Battelle/U.S. Department of Energy Isotope Products Laboratory McClellan AFB U.S. Department of Energy	5	6	6
¹⁰⁹ Cd	Battelle/U.S. Department of Energy E.I. DuPont/NEN Products Isotope Products Laboratory North American Scientific	12	3039	3036
⁶⁷ Cu	Brookhaven National Laboratory California State University IBM Research Center Los Alamos/INC-11 Medical Research Council, UK National Institutes of Health Oak Ridge National Laboratory Paul Scherrer Institute Purdue University Texas A&M University Texas Instruments UC, Davis UMDNJ Washington University	31	1615	1296

Los Alamos National Laboratory FY 1991 Medical Radioisotopes Shipments (Continued).

Isotope	Customer	No. of Shipments	Shipped (mCi)	Received (mCi)
⁶⁸ Ge	Computer Technology & Imaging Cross Cancer Institute, Canada Duke University E.I. DuPont/NEN Products E.I. DuPont/Washington University Isotope Products Laboratory Societe Gondrand Turku University, Finland University Hospital/Cleveland	17	1095	1091
²² Na	Brookhaven National Laboratory E.I. DuPont/NEN Products	2	1645	1477
⁸³ Rb	Instituut Stralingsfysika, Belgium Los Alamos/P-6 University of Pittsburgh	3	6	6
³² Si	Isotope Products Laboratory	1	0.001	0.001
⁸² Sr	E.R. Squibb & Sons	8	9016	8600
⁴⁸ V	University of Washington	1	4	4
⁸⁸ Y	Amersham International, UK Analytics, Inc. Bionetics Research, Inc. Brookhaven National Laboratory E.I. DuPont/NEN Products Hoechst, West Germany Isotope Products Laboratory National Institutes of Health National Research Council, Canada Royal Institute of Technology, Sweden Teijin, Japan U.S. Bureau of Mines UC, Davis VA Medical Center	26	78	77
⁸⁸ Zr	Vrije Universiteit, The Netherlands	1	2	2
Totals		120	16 718	15 712

APPENDIX E

NUCLEAR MEDICINE RESEARCH ACTIVITIES

Biomedical Generators

We have established the parameters for the automated separation of selenium and arsenic for the $^{72}\text{Se}/^{72}\text{As}$ biomedical generator. This, coupled with arsenic radiopharmaceutical development, could explosively enhance the clinical utility of PET because PET centers could be established without the need for an on-site cyclotron. PET in small hospitals and in rural settings would be possible.

We have done a comparative study of ^{72}As and ^{18}F (the prototypical positron emitter) by making uniform phantom PET images using both isotopes on two different PET systems in collaboration with the University of Texas Health Science Center at Houston. Qualitatively, the images generated by the two isotopes are quite favorably comparable. Quantitative comparisons are in progress.

New Agents for Accelerator-Based Radiopharmaceuticals

We have developed methodologies for rapid arsenylation of linker molecules for labeling of amines and amides. Arsenylation of models for receptor ligands appears to be rapid and in good chemical yields.

We have developed methodologies for the arsenylation of porphyrins. Prospects for use in labeling porphyrins with radioarsenic from aqueous solution are not good, but we can circumvent these difficulties with an alternate procedure of isolating arsenic trichloride followed by reaction with porphyrin. This synthetic approach is designed to complement our metallated porphyrin applications research by supplementing SPECT imaging with PET imaging in complementary radiopharmaceuticals.

Myasthenia Gravis Research

In a collaborative effort with the Mayo Clinic, we prepared labeled antigenic fragments of the human acetylcholine receptor for studies of potential therapy agents for myasthenia gravis. Fragments labeled with stable isotopes of copper were as immunogenic as the unmodified fragments. We prepared the ^{67}Cu -labeled fragments for experiments of cytotoxicity to the specific T-cell subpopulation responsible for processing the acetylcholine receptor antigen. Rats immunized with H α 125-147 or with CuC $_3$ P-H α 125-147 exhibited excellent delayed cutaneous hypersensitivity to both forms of the peptide (an *in vivo* correlate of helper T-cell responsiveness), as well as to the uncapped form of the peptide and to authentic acetylcholine receptor protein. In ELISA tests,

polyclonal and monoclonal anti-H α 125-147 antibodies recognized CuC₃P-H α 125-147 as equivalent to the original peptide. Thus these preliminary studies indicated that our labeling and purification methods produce CuC₃P-H α 125-147, which retains the immunogenicity of the unmodified H α 125-147.

Imaging Agents for Lymph Nodes and Therapy for Lymphoma

A porphyrin molecule (H₂TCPP) has been shown to localize in small abscesses and other small sites of advanced inflammation. The uptake in these inflammatory sites was found for the first time in semiquantitative studies and appeared to be sufficient for imaging and therapeutic procedures.

Cell-culture studies have confirmed our previous results that lymphoma cells localize significantly greater quantities of H₂TCPP than normal lymph node cells. This finding suggests that H₂TCPP and ⁶⁷CuTCPP can be used to follow the spread of lymphoma in lymph nodes and as a procedure to treat this deadly disease.

Early Detection and Treatment of Lung Cancer

Preliminary studies using the Johns Hopkins Sputum Archive have shown that H₂TCPP will identify precancerous lung cells four years prior to the earliest clinical diagnosis. This success with early diagnosis, coupled with the potential of the ⁶⁷CuTCPP for therapy (experimental results show similar uptake for H₂TCPP and ⁶⁷CuTCPP in viable cells), suggests that a cure for lung cancer could be based on LAMPF-based radioisotope-labeled pharmaceuticals.

In collaboration with the National Cancer Institute, studies have demonstrated that H₂TCPP is localized in fresh surgically removed lung-tumor tissue. The uptake in the lung-tumor tissue was found to be more than adequate for therapy procedures.

Positron-Emission Tomography (PET) and ⁶⁸Ge

PET is rapidly becoming recognized as a life-saving modality for diagnosis of heart and neurological diseases in the clinical setting. Its true clinical value is being recognized in the fact that most private insurance companies are reimbursing for PET procedures at the 80% level. Also, federal regulatory agencies such as the Food and Drug Administration and the Health Care Finance Administration are working closely with the Institute of Clinical PET to remove barriers to the growth of PET as a valuable diagnostic tool. Beyond this, PET is a unique research tool for investigation of *in vivo* biochemical function in both normal and disease states and will continue to provide important basic understanding in the important fields of medicine and molecular biology.

Every PET instrument must be calibrated using sources containing a positron emitter. Moreover, virtually every clinical scan must be accompanied by a patient "transmission" scan to permit proper image interpretation. Germanium-68 decays to gallium-68, which is a pure positron emitter. The long half-life of ^{68}Ge (271 days) and its lack of significant photon emissions (only a 2077-keV gamma at 3% branching intensity) make it the ideal isotope for these calibration and transmission sources. In fact, no other isotope approaches its utility and safety for these applications. Every PET camera now uses this isotope for calibration and transmission sources.

Manufacturers and users of ^{68}Ge sources indicate that all current PET scanners would be virtually useless without the ^{68}Ge sources. Thus, availability of ^{68}Ge is essential to the continued use and growth of PET.

Forecast Growth of PET

According to the Institute of Clinical PET, there were 56 United States PET facilities and 77 foreign PET facilities as of October 17, 1991. It is estimated by contacts at CTI Services, Inc., a major supplier of PET products and services, that the average capital investment at a PET Center is \$5-million for PET cameras and cyclotrons plus any necessary building costs. For the equipment alone, then, the current worldwide overall capital investment in PET is greater than \$0.5 billion, with at least 40% of that investment in the United States. Moreover, each clinical site has the potential of generating several million dollars per year in revenues. PET is expected to grow in number of centers and applications at the rate of 20% to 30% per year over the next five years. Thus, by 1997 there could be as many as 150 PET centers in the United States and more than 200 overseas. Moreover, several companies are being started with the goal of establishing mobile PET units, which could dramatically increase the availability of the modality to hospitals and other medical institutions in the United States. The industry is currently on a very rapid growth curve.

Currently all of the ^{68}Ge being used by the two major United States manufacturers of sources (CTI Services and DuPont) is being produced and distributed by the Department of Energy. These two manufacturers have identified no other suppliers that can provide the material. They provide the sources for virtually all of the United States and European PET centers. There is every indication from these manufacturers that a diminished supply of ^{68}Ge from the Department of Energy would have a very adverse effect on the growth of the PET industry. If for any reason the supply of the isotope were eliminated, it is probable that the viability of PET outside a few research-oriented facilities would be lost.

Los Alamos makes ^{68}Ge by irradiating targets at LAMPF and chemically processing these targets at its High-Level Radiochemistry Facility. All of the material produced is sold, primarily to CTI Services (Los Alamos was their sole supplier in the past year) and DuPont, and we are developing cost-effective methods for increasing our production capacity to continue to meet the demand for the isotope into the foreseeable future. In our view, LAMPF-produced ^{68}Ge is vital to the near-term future of PET. Any plans for a National Biomedical Tracer Facility must incorporate production and supply of ^{68}Ge if LAMPF is not to be available in the longer-term future.