Relevance of Particle Accelerators to National Goals

Louis Rosen

There was a time, not long ago, when science and motherhood were beyond reproach. Today, both are under attack. Much of the basis for this attack is emotional, even irrational. It is born of ignorance on the one hand and frustration on the other. However, not all of the troubles of science can be blamed on unreasoning critics. A substantial part of our misery is self-inflicted. We have not taken seriously that part of our responsibility to society which dictates that we explain and interpret and justify our activities, in language understandable to the nonspecialist. We and we alone can do that. We and we alone can provide the best advice on meaningful priorities based on the intellectual and practical worth of our pursuits. We and we alone can provide the best assessment of the probability that a given development will have a utilitarian purpose at an acceptable cost. We and we alone can develop the sophisticated phenomenological models which have some chance of predicting the interaction of technology, industry, education, society, and our environment.

History suggests and our common sense argues that, by and large, the evolution of science has stimulated and has been a by-product of the advance of civilization. But not everyone agrees with this thesis; there are those who would invoke time reversal. By misuse of our advanced technology, it may indeed be conceivable to faithfully recreate the physical conditions of the Middle Ages, but not the social and mental climate which made those conditions tolerable.

We are admonished from many quarters, from the President on down, to start asking not what our society can do for science, but what science can do for our society. And it is precisely this question, to the extent it concerns particle accelerators, that I wish to discuss.

Relationship of Accelerators to National Goals

An accelerator is the embodiment of mathematical theory and physical truth; it is a thing of beauty and utility. National goals are less easily characterized. However, before relating accelerators to national goals, one must identify the latter. What is a national goal? The following examples specify some goals enunciated by our last four presidents.

President Eisenhower spoke of ". . . the living standards of our people, their health and education, their better assurances of life and liberty and their greater opportunities."

In President Kennedy's inaugural address, he said, ". . . our basic goal remains the same . . . a peaceful world community of free and independent states, free to choose their own future and their own system so long as it does not threaten the freedom of others."

President Johnson's State of the Union Message in 1967 said, in part, ". . . let us keep on impoving the quality of life." Under President Johnson's Administration, a select Committee on Government Research wrote a report entitled "National Goals and Policies" in which it set forth the primary objectives of basic research programs as "1. Increasing the store of new fundamental knowledge; 2. Improving the number and quality of trained scientists and engineers; and 3. Promoting the eminence of the U.S.A. as a bastion of freedom of man and mind."

In President Nixon's inaugural speech, he emphasized the "goals of full employment, better housing, excellence in education; in rebuilding our cities and improving our rural areas; in protecting our environment and enhancing the quality of life."

I examined the stated goals of these four presidents, and synthesized from them common-denominator goals which can be stated as follows: (i) adequate military strength to discourage initiation of violence against us and our vital interests; (ii) a high level of economic prosperity for all our people; (iii) good health conditions for all our citizens; (iv) broad opportunities for education; (v) significant progress toward acquisition of fundamental knowledge about ourselves and our environment; and (vi) international collaboration in many areas of human endeavor. It is my contention that the particle accelerator is an aid, in some cases an indispensable aid, for achieving these goals.

Inventory of Particle Accelerators

Let us first have a look (Fig. 1) at the worldwide inventory of particle accelerators, which are used primarily for research, about half of which are in the United States. They are plotted on a coordinate system that identifies energy and intensity, for these two quantities denote the primary characteristics of the accelerators. But I should hasten to add that in many circumstances energy resolution, duty factor, beam quality, and type of particle accelerated are very important features.

All of these machines have great value for intellectual and educational pursuits. However, I suspect that most of us feel that basic knowledge about the constituents of matter and about the forces that govern the most fundamental properties of subnuclear matter is most likely to arise from experiments at the highest energies, as long as sufficient intensity is available to make statistically significant observations. The national goals to which the highest-energy accelerators contribute are those involved with education, with the acquisition of new basic knowledge, and with fostering international collaboration.

To understand the importance of these goals, we must recognize that one of the main distinguishing characteristics between man and the lower forms of animal life is his curiosity—curiosity about himself, his immediate surroundings, and the universe. Curiosity cannot be used as collateral at the bank, but it is one of the elements which gives life substance and meaning. One of the

The author is director of the Los Alamos Meson Physics Facility at the Los Alamos Scientific Laboratory of the University of California, Los Alamos, New Mexico 87544. This article is adapted from a talk given at the National Particle Accelerator Conference, Chicago, Illinois, 1–3 March 1971.

major ways to satisfy human curiosity is through the interrogation of nature in the pursuit of science. In order to pursue science, one must continually press on the frontiers. Where are the frontiers? They are usually at the extremes—very high temperatures and very low temperatures, very high pressures and very good vacuums, the very large (cosmology) and the very small (nuclear and subnuclear entities). Particle accelerators permit us to explore the smallest quantities of matter and energy in nature. What more can we ask of an intellectual pursuit? One can ask whether the dividends are worth the effort; however, the history of science tells us that up to now the practical results alone have more than paid for all the scientific effort to date. Even the highest-energy accelerators already have economic ramifications, for they are producing technological spin-offs in computer technology, cryogenics, vacuum technology, and the art of constructing large magnetic fields and fabricating materials which have no electrical resistance. All of these advances will have a decisive influence on the technologies required in the future to sustain comfortable life on this planet.

Construction and utilization of the highest-energy particle accelerators therefore contribute to national goals by promoting activities which (i) stimulate a high order of intellectual pursuit, (ii) provide the basic knowledge for future technologies, and (iii) promote international collaboration. Points (i) and (iii) are essentially self-evident; but what about point (ii), which, at this time, may be the most important consideration? Let us discuss this question by examining not what might be but what already is, because what today are considered low-energy accelerators were yesterday characterized as high-energy accelerators.

Role of Particle Accelerators in Industry

In a talk on 14 April 1970, Communist Party Chief Brezhnev stated that it is in the application of science and technology to Russia's economy where

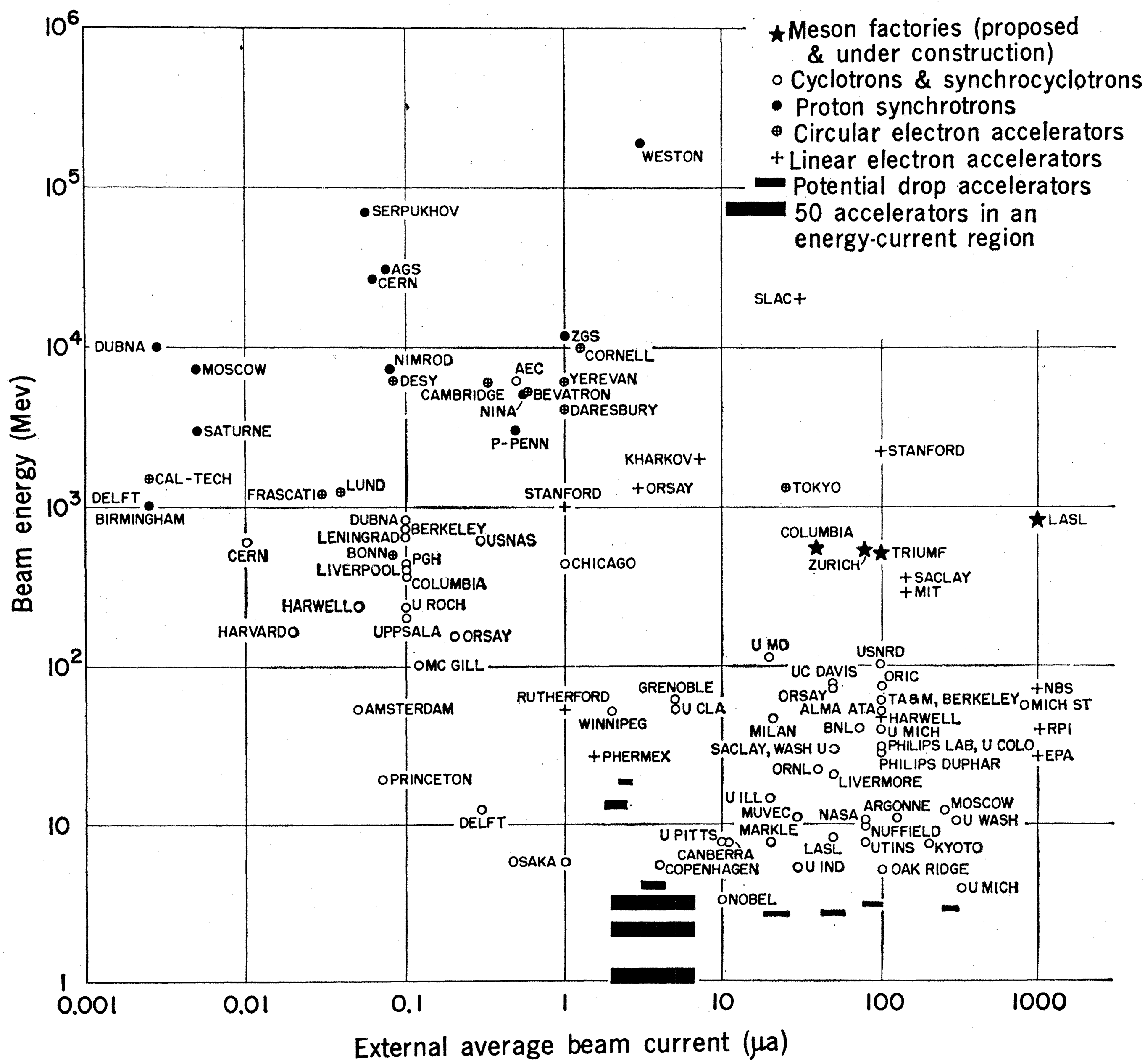

Fig. 1. Worldwide inventory of particle accelerators.

". . . the center of gravity in competition (between the two great world systems) is to be found." Let's see what he had in mind.

Table 1 shows our balance of trade situation for the years 1962 through 1968. We divide all of the commodities that the United States exports or imports in international trade into the four categories: (i) agricultural products; (ii) minerals, fuel, and other nonmanufactured and nonagricultural products; (iii) manufactured products which are not technology-intensive; and (iv) technology-intensive manufactured products. Only in the last category does the United States enjoy a favorable balance of trade which barely counteracts all the other unfavorable balances (Table 2).

The service-producing sector of our country's economy now consumes more than 50 percent of the labor force; that is a measure of our prosperity. In 1890, 42 percent of our working population was engaged in agriculture; today it is 4 percent. How do accelerators enter this picture?

In the United States there are about 1000 accelerators of all kinds; these represent about 50 percent of the world's inventory. Less than 150 are devoted mainly to basic research. Of the remainder, about one-third are devoted to industry and medicine, and the rest to the applied sciences. Those devoted to industry and medicine represent a capital investment of $77 million. The annual production of goods and services associated with these machines is about $2 billion. The main uses of these accelerators are in nuclear medicine, radiation therapy, and radiation processing of materials (Table 3).

Table 1. United States trade with the world, 1962–1968 (*6*).

	All commodities ($10^9)						
	1962	1963	1964	1965	1966	1967	1968
Exports	21.4	23.1	26.2	27.2	30.0	31.2	34.2
Imports	16.4	17.2	18.7	21.4	25.6	26.9	33.2
Balance	5.0	5.9	7.5	5.8	4.4	4.3	1.0

Table 2. United States trade with the world, 1962–1968 (*6*).

	Technology-intensive products ($10^9)						
	1962	1963	1964	1965	1966	1967	1968
Exports	10.2	10.6	12.1	13.0	14.4	16.0	18.4
Imports	2.5	2.6	3.1	3.9	6.0	7.0	9.4
Balance	7.7	8.0	9.0	9.1	8.4	9.0	9.0

Table 3. Increase of accelerator population and investment, 1964 and 1968 (*7*).

Application	Accelerators (No.)		Investment ($10^6)	
	1964	1968	1964	1968
Nuclear science and engineering	282	297	101.4	129.7
X-rays and neutrons	234	376	24.2	46.9
Radiation effects	225	315	26.3	36.4
Atomic and solid state physics	5	35	0.5	2.8
Radiation processing	36	60	3.7	6.5
Totals	782	1083	156.1	222.3

Table 4. Estimated radioisotope sales ($10^6).

Types	Sales ($10^6)		
	1969	1970	1971
Basic radionuclides	10	11	13
Radiochemicals	12	14	16
Radiopharmaceuticals	32	40	50
Sealed sources	5	6	7
	59	71	86

Nondestructive Testing

A growing application of accelerators is in the area of nondestructive testing. Uses here are in three main categories: (i) radiographic inspection using x-rays and gamma rays (for example, inspection of pipeline welds); (ii) alpha and beta particles have long been used as thickness gauges, and now protons are beginning to show promise [using 147-megaelectron-volt (Mev) protons, the Harwell Group have shown that the thickness of graphite can be determined to an accuracy of 0.0015 percent, compared to 2 percent by conventional methods]; and (iii) activation analysis, mainly with neutrons.

Radioisotope Production

Two-thirds of all radioactive nuclei were discovered via accelerator-induced reactions. However, 80 percent of the curies are now produced by reactors; but this situation appears to be changing, especially in the medical area, to which we shall return.

Table 4 shows market predictions for sale of radioisotopes. The point is that the sales are substantial and the rate of increase large. The present market for cyclotron-produced isotopes is $3 million per year, and is increasing rapidly. It is estimated that a market for about 20 cyclotron facilities may develop for radioisotopes by 1975. Here the economics are far less important than the pain and suffering these isotopes can prevent.

Power Reactor Applications

Accelerators have played and continue to play a critical role in the development of power sources based on nuclear fuels. This goes to the heart of those national goals which are involved with the conservation of our fossil fuels, environmental pollution, and the quality of life. I give a few examples of how nuclear cross-section measurements have affected this area of national endeavor.

1) Careful measurements of the ratio of neutron capture to fission for ^{239}Pu showed that an entire family of water-cooled plutonium-fueled reactors would not be feasible as breeder reactors; thus the country saved hundreds of millions of dollars.

2) Some years ago, I published results

on the interaction of fast neutrons with ^{7}Li (*1*), which showed that a controlled thermonuclear reactor could operate on the deuterium-tritium (D-T) cycle (which is much easier than the D-D cycle because the required temperature is lower) and produce more tritium than is consumed. For historical reasons, I show you Fig. 2. It now appears likely that the first thermonuclear reactors will operate on the D-T cycle.

However, J. R. McNally, Jr., of Oak Ridge National Laboratories has recently proposed (*2*) the use of energetic protons (or deuterons, tritons, and ^{3}He) to ignite ^{6}Li or ^{6}LiD fuel in order to avoid the problem of heating incoming fuel material to fusion energies. It appears that ^{6}Li burning can be catalyzed by protons of a few megaelectron volts—for example, in the sequence of exoergic reactions ^{6}Li(p,-^{3}He)^{4}He, followed by ^{6}Li(^{3}He,pα)^{4}He. Of course, many other reactions are involved in such a fuel cycle. One barrier to the pursuit of this idea is our grossly incomplete knowledge of reaction cross sections for light nuclei at low energies.

It is a fact that particle accelerators provide the basic information for calculating nuclear properties of reactors. Basic nuclear data are still needed, especially for fast reactors, which make the best use of our uranium resources. Fuel cost uncertainties resulting from nuclear data uncertainties are $\sim 2 \times 10^{-4}$ dollars per kilowatt-hour (electrical). Present nuclear power capacity is 3000 megawatts (electrical); our electrical generating capacity is estimated to require doubling during the next decade. By 1980 it is projected that 30 percent of our total electrical energy will be nuclear; and the uncertainty in annual fuel costs would be about $100 million in 1980, $300 million in 1990, and $700 million by the end of the century.

Neutron and gamma-ray cross sections are destined to play a crucial role in reactors for space applications, for desalination in the agricultural and industrial complexes, and for process heat. The problems are mainly those of neutron economy and materials damage by radiation.

Radiation Processing

Radiation processing may be used to increase the melting point, tensile strength, durability, and adhesive property of materials. Of the 270 accelerators in private industry, 46 are devoted to radiation processing on a production scale, exclusive of food processing. The current value of irradiated products, not including food, is about $200 million per year, and much of this is due to electron accelerators. Radiation curing of coatings and finishes (especially for building materials, textiles, and metals) is the area of greatest potential in the near future. Irradiation of plastics accounts for the largest share of capacity in this field, with applications to packaging materials and electrical insulation showing economic advantages and rapid commercial utilization.

As an example, pigmented monomers (without solvents) are processed by electron curing. The monomer is polymerized to produce a superior paint finish. The elimination of solvents from the paint industry should reduce the pollution problem.

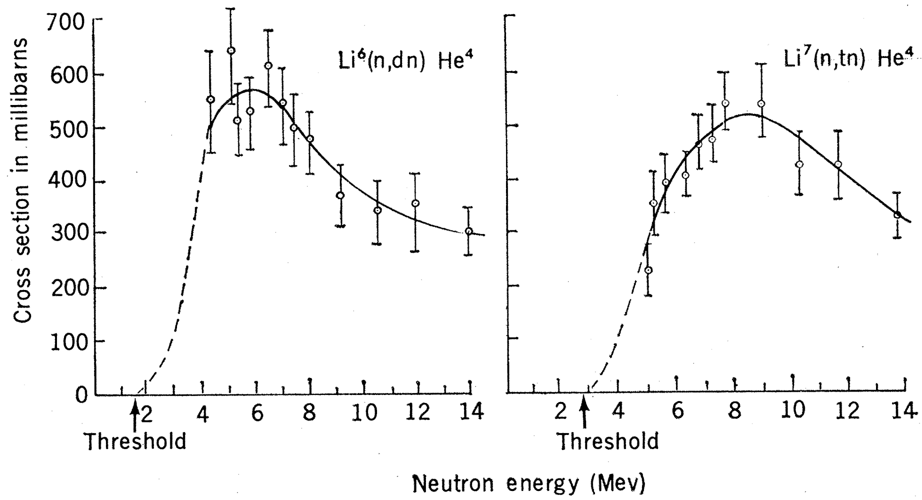

Fig. 2. Energy dependence of the cross section for the ^{6}Li(n,dn)^{4}He and ^{7}Li(n,tn)-^{4}He reactions (*1*).

Role of Particle Accelerators in Defense

The role of particle accelerators in national defense is not as great as it used to be, but it remains extremely important. Neutron and gamma-ray cross sections from zero energy up to 15 Mev are still required. But perhaps the most serious problem in this category is the detection, control, and monitoring of fissionable materials, mainly those produced in power reactors. We must have the capability of nondestructive interrogation of materials. Accelerators need to be developed which produce neutrons and gamma rays of appropriate energy and intensity and which can be used to deduce the contents of sealed packages.

By 1980, power reactors around the world will be producing plutonium at the rate of 100 kilograms per day, sufficient for tens of nuclear weapons per day. By an act of Congress in 1964, plutonium is now another commerical commodity, subject to private ownership. Simple, reliable methods must soon be developed for interrogating materials and accurately determining their makeup. Neutrons and gamma rays, produced by accelerators, offer one possibility, and much has already been accomplished in this direction. Here, accelerators appear destined to play a central role for a long time to come.

Sooner or later there must evolve an all-inclusive international treaty for control of fissionable materials. Effective verification procedures are essential to the implementation of any agreement which involves production and distribution of fissionable materials and the limitation of development, production, and deployment of nuclear armaments. Highly specialized accelerators will certainly be a part of the policing mechanism.

The nondestructive analysis techniques, particularly the accelerator-based active interrogation techniques which give promise of high accuracy and sensitivity, may be immediately applicable to the identification and control of air and water pollution, which is now a vital national goal. Neutron activation techniques, in particular, offer an extremely sensitive method for tracing low-level contaminants in air, water, and soil.

Table 5. Principal nuclear medical function procedures performed during 1966 (*8*).

Radio-nu-clide	Compound	Procedure	Physicians licensed for procedure (No.)	Physicians performing procedure (No.)	Patient administrations	
					Number	Percent
^{131}I	Sodium iodide	Thyroid uptake	1527	1284	301,052	57.2
^{131}I*	Labeled albumin	Blood volume determination	1381	908	101,994	19.4
^{131}I*	Sodium iodohippurate	Renal function	817	388	33,245	6.3
^{57}Co	Labeled vitamin B_{12}	Vitamin B_{12} absorption	952	582	24,996	4.7
^{51}Cr	Sodium chromate	Blood volume determination	1064	437	22,468	4.3
^{60}Co	Labeled vitamin B_{12}	Vitamin B_{12} absorption	1149	556	16,486	3.1
^{131}I*	Labeled fats	Fat malabsorption	1054	505	7,742	1.5
^{51}Cr	Sodium chromate	RBC survival	1110	604	6,530	1.2
^{59}Fe	Chloride or citrate	Iron turnover	836	287	3,139	0.6
^{131}I*	Labeled albumin	Cardiac output	627	79	1,503	0.3
^{131}I*	Rose bengal	Hepatic function	33	23	1,202	0.2
Total for principal procedures listed above					520,357	98.8
Total for 39 other procedures with less than 1000 administrations					6,119	1.2
Total for all function procedures					526,476	100.0

* Administrations with either ^{131}I or ^{125}I.

Table 6. Radionuclides from LAMPF of interest in medicine. The conditions assumed are 750 Mev, ½ ma, and 2.5-cm thick target.

Product (half-life)	Daughter	Target	Production yield	Comments
^{67}Ga (78 h)		As	68 ci/d	Soft-tissue tumor-scanning agent
^{68}Ge (280 d)	^{68}Ga (68 m)	As	320 mci/w	Short-lived positron emitter for multiple applications
^{72}Se (8.4 d)	^{72}As (26 h)	Nb	8.7 ci/w	A new arsenic brain-scanning agent
^{82}Sr (25 d)	^{82}Rb (75 s)	Nb	26 ci/w	Short-lived Rb for rapid dynamic flow studies
^{83}Rb (83 d)	^{83}Kr (1.9 h)	Nb	15 ci/w	Rb for muscular dystrophy studies
^{123}Xe (2 h)	^{123}I (13 h)	La	27 ci/d	Lower iodine radiation dose to patients (about 1 percent of ^{131}I)
^{172}Hf (5 y)	^{172}Lu (6.7 d)	Ta	3 ci/mo	General purpose, rare earth tracer
^{44}Ti (47 y)	^{44}Sc (4 h)	V	25 mci/mo	Potential bone and soft-tissue scanning agent
^{42}Ar (33 y)	^{42}K (12 h)	V	6 mci/mo	Established useful K nuclide

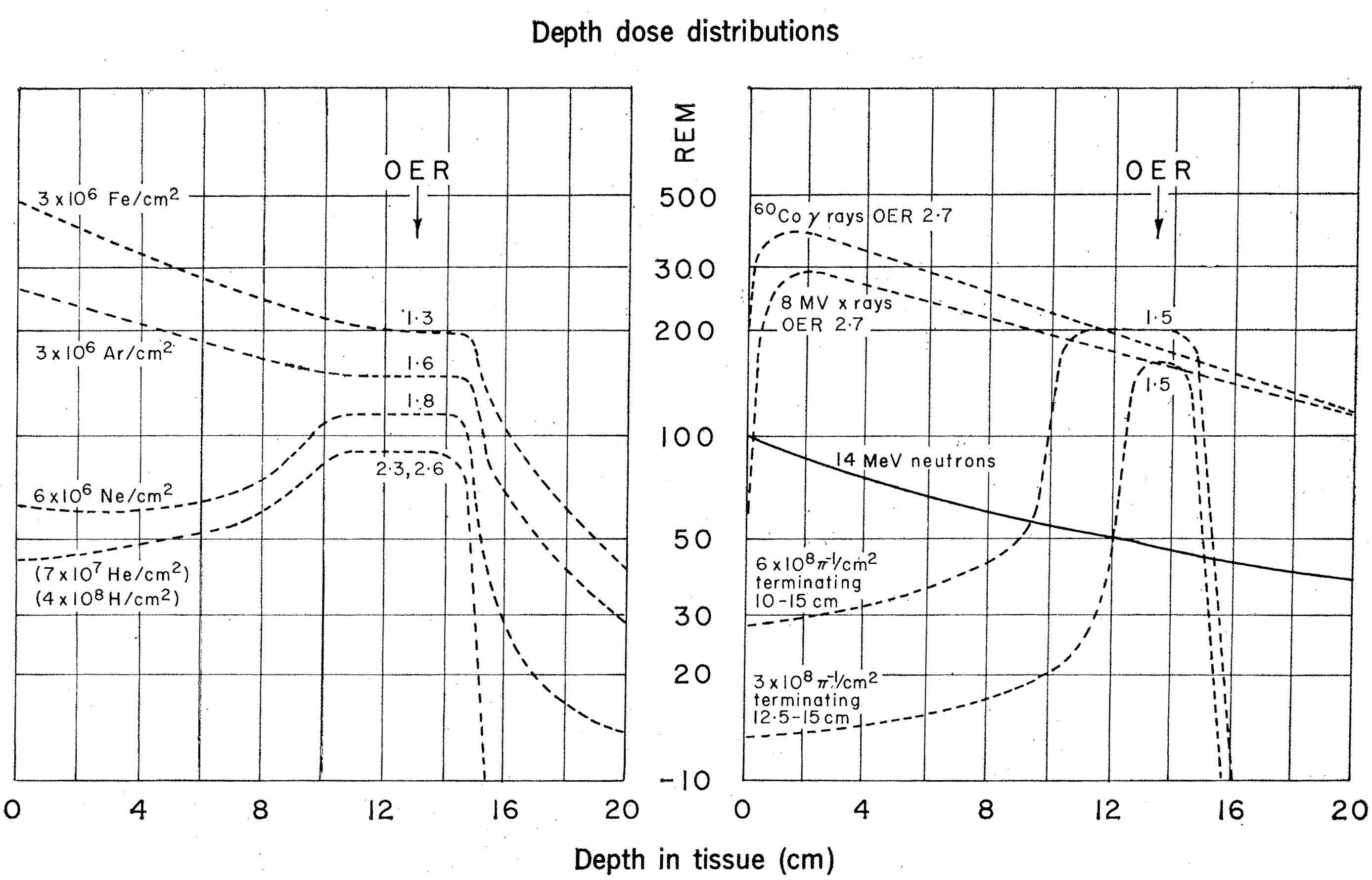

Fig. 3. Depth dose distributions. Dashed lines are based on data from Fowler (*9*) and solid line, from Horst and Conrad (*10*).

Particle Accelerators for Medical Purposes

Perhaps in no area has accelerator development had such a marked impact on mankind as in medicine—in nuclear medicine and in radiation therapy.

Table 5 illustrates the uses of radioisotopes in diagnostic medicine. At the moment most of the isotopes are discovered with accelerators and manufactured with reactors. However, accelerator-produced isotopes are increasing in quantity. Table 6 shows some of the radioisotopes which can be produced by high-intensity proton accelerators of energy greater than 100 Mev.

Of all isotope administrations, about one-third employ ^{131}I. The use of ^{123}I for in vivo thyroid uptake studies, brain scans, blood volume measurements, and liver and lung scans reduces the radiation exposure to patients by about a factor of 100 over ^{131}I because ^{123}I has no particulate radiation and has a much shorter half-life. This reduced radiation dose to the patient is especially important in pediatric and obstetric cases.

The second most widely used radioisotope in organic function studies is accelerator-produced ^{57}Co for vitamin B_{12} absorption tests. In 1959 ^{57}Co was not employed in nuclear medicine, but by 1966 it was used with greater frequency than ^{60}Co because of the shorter half-life and greater counting efficiency of the lighter isotope.

The new Brookhaven linear accelerator (linac) and the Los Alamos Meson Physics Facility (LAMPF) can produce substantial amounts of ^{72}Zn. Preliminary studies indicate that this nuclide may become a routine scanning agent to be used in all males over middle age for early detection of prostatic cancer. No such agent exists at the present time, although prostatic cancer is currently the third most frequent cause of death in male cancer patients. This form of cancer is currently diagnosed by rectal examination, and it cannot be detected until the nodule in the anterior lobe of the gland has grown to such an extent that, in 70 percent of the cases, metastasis has spread beyond the gland.

In 1968, 300,000 people were treated by 3.5 million radiotherapy treatments. This represents a $300-million effort toward the arrest of cancer. Table 7 indicates the increases in cancer cure rates as the quality of radiation improved.

Concluding Remarks

Particle accelerators appear to be essential for the balanced progress of science and education. They contribute to the study of the most fundamental laws of nature as well as the structures and properties of nuclear matter. They will remain a vital instrument in man's struggle to make best use of his living space and the resources of this planet.

I have talked about what has been and what is now, but what about the future? Some trends in accelerator applications are discernible. I have already mentioned that new accelerators need to be developed in order to develop nuclear energy sources on the one hand and help with the worldwide management of fissionable materials on the other. New types of accelerators are needed for uses in every sphere from the preservation of food to the sterilization of sewage, and the field of medicine appears to have an insatiable appetite for accelerators which are tailored to its purposes.

Just now, cyclotrons for the production of the short-lived isotopes ^{15}O, ^{13}N, and ^{11}C (half-lives of 2, 10, and 20 minutes, respectively) have been or are in the process of being installed at the Massachusetts General Hospital in Boston, Sloan-Kettering Institute in New York, Washington University in St. Louis, Mount Sinai Hospital in Miami, Argonne Cancer Research Hospital in Chicago, and the University of California at Los Angeles.

With increased emphasis on nuclear medicine, the medical profession will be in a position to make use of new radionuclides which have properties more amenable to diagnostic procedures. Many of these can be provided by accelerators. Perhaps the most dramatic utilization of accelerators is in the treatment of malignancies. Figure 3 illustrates the advantages to be realized by using high-energy charged par-

Table 7. Comparison of 5-year survival rates in several categories of cancers managed by radiation therapy alone or by a close integration of radiation and surgical therapy (7). The 5-year survival rates are ranges of published results from institutions throughout the world.

Category of cancer	Percentage 1940	Percentage 1960
Oral cavity	25–30	50–56
Oropharynx (base of tongue, tonsillar region, pharyngeal walls)	15	30–40
Nasopharynx	15	35
Supraglottic region of larynx	15–20	50
Pyriform sinus and hypopharynx	5–10	30
Squamous cell carcinoma of uterine cervix	25–30	60
Infiltrative tumors of urinary bladder (stage B_2-C)	10–15	30–35

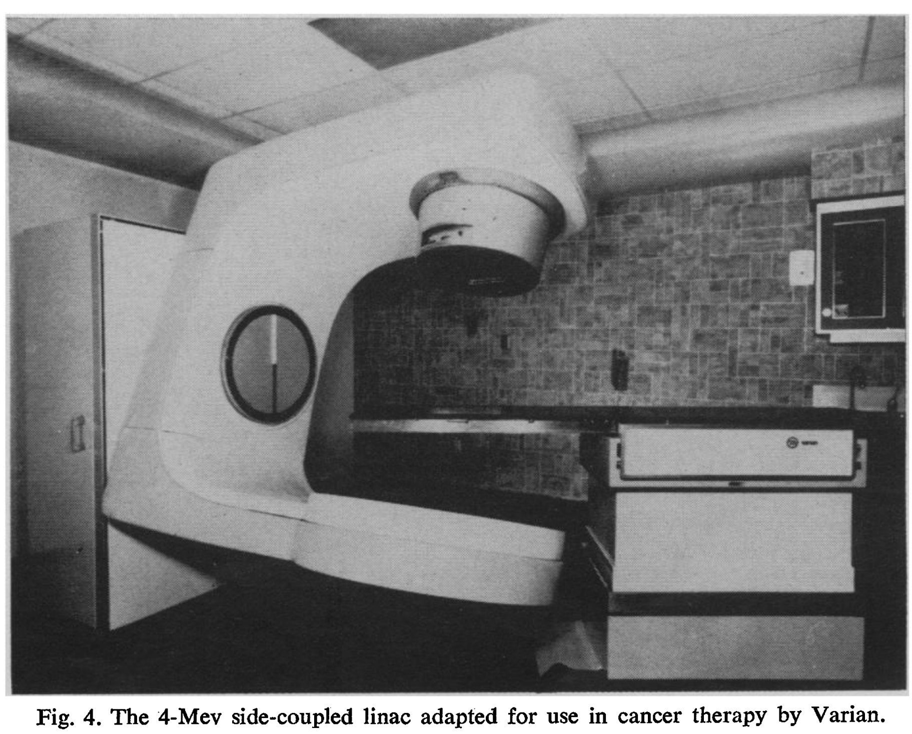

Fig. 4. The 4-Mev side-coupled linac adapted for use in cancer therapy by Varian.

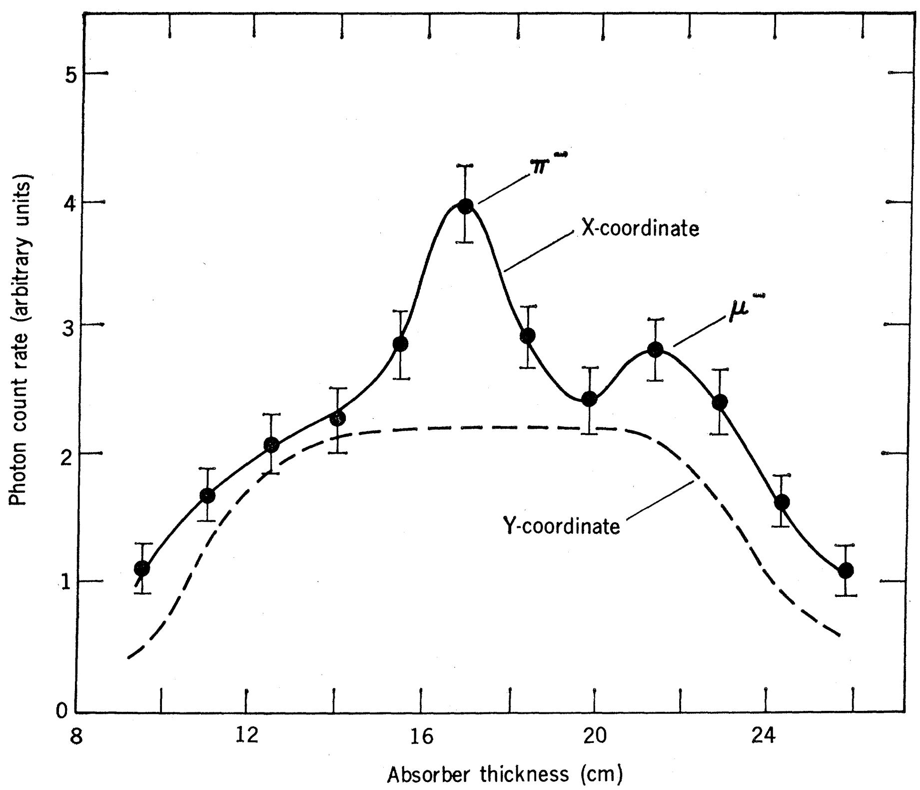

Fig. 5. Experimental results showing pionic x-ray deposition above background.

ticles in radiation therapy. High-energy protons are much superior to the x-rays, and we have been remiss in not using our high-energy accelerators for this purpose. Our U.S.S.R. colleagues are far ahead of us in this field, and I commend them for that.

In order to build LAMPF, a new accelerator structure had to be invented and developed. This was accomplished by Nagle, Knapp, and their colleagues (*3*) at Los Alamos Scientific Laboratory (LASL). Very soon after the feasibility, stability, and efficiency of this accelerator was demonstrated by building an electron prototype, the basic design features were adopted by industry, which is now producing them for x-ray machines of 4 megavolts, and higher. At least five companies in this country and abroad are building these machines; Fig. 4 shows the Varian version. Several dozen are already installed in hospitals, and several dozen more are under construction.

Lest you worry that high-energy machines be left out of medical applications, let me assure you that this is not

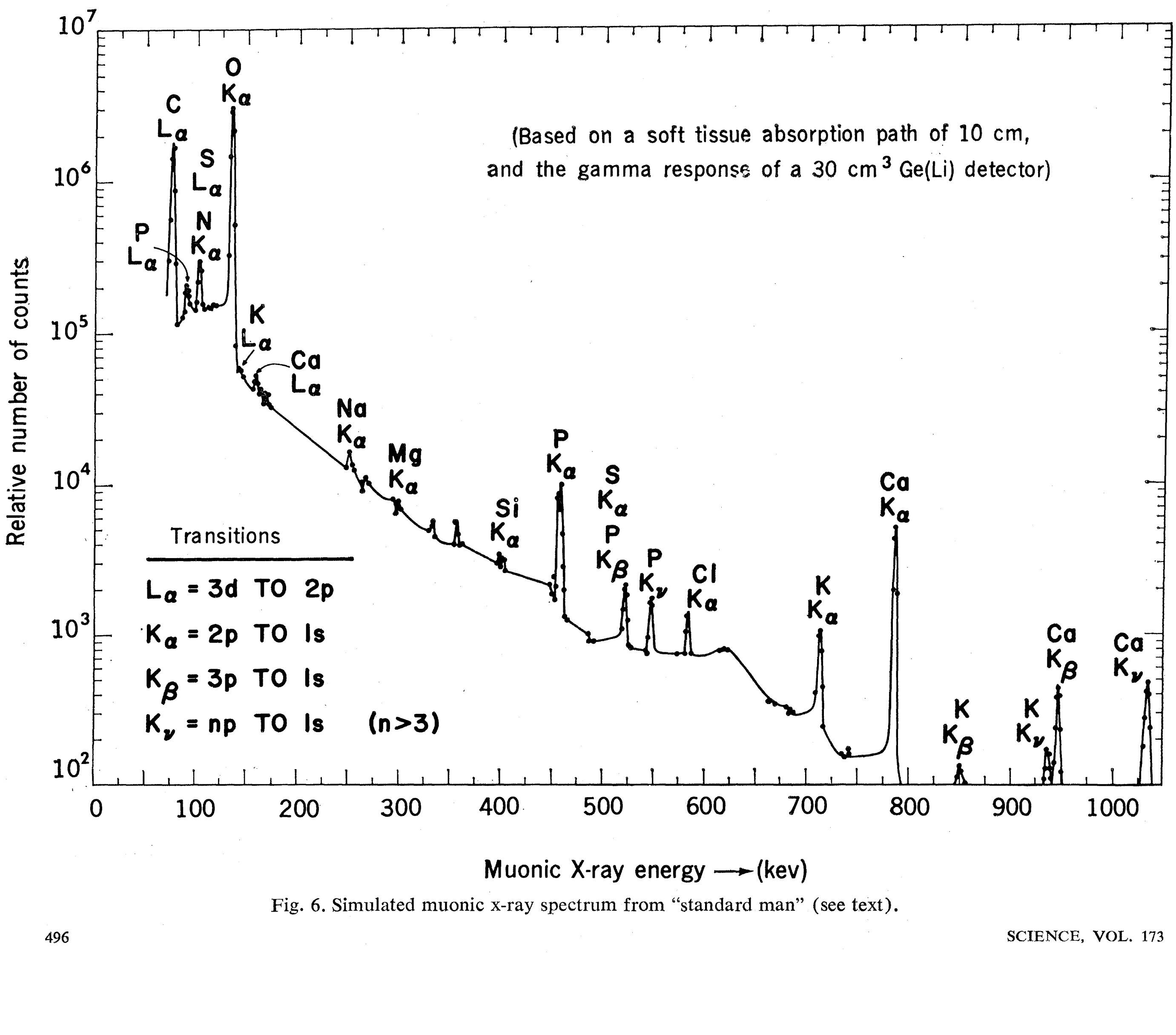

Fig. 6. Simulated muonic x-ray spectrum from "standard man" (see text).

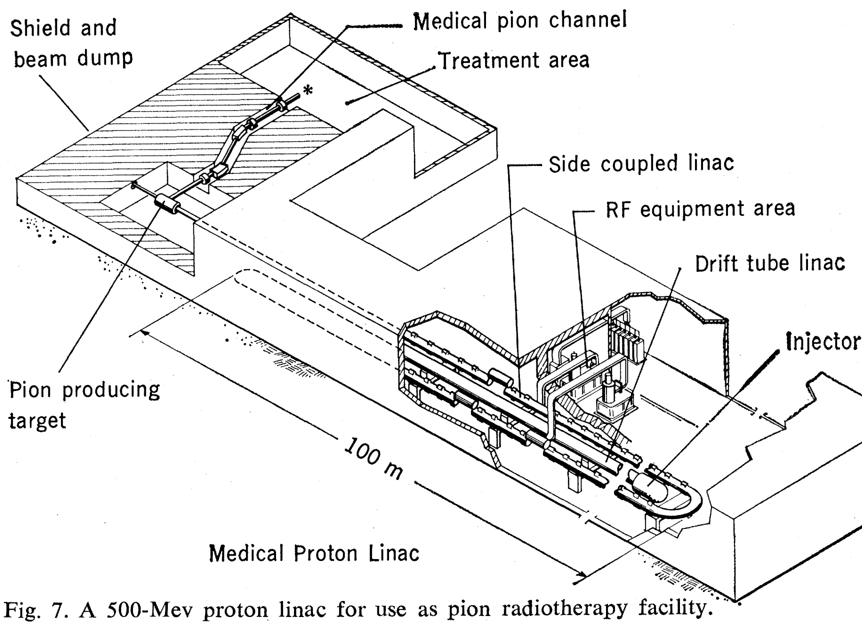

Fig. 7. A 500-Mev proton linac for use as pion radiotherapy facility.

the case. The LASL meson factory, as well as those in Canada and Switerland, are scheduled to provide negative pions for radiation therapy. A serious problem with negative pions in radiotherapy appears near solution; it has to do with determining the beam transport mechanism necessary to achieve stopped pions uniformly and at a prescribed depth in the tumor volume. A pion channel has been designed which can deliver 50 to 100 rads per minute uniformly over a volume of 1000 cubic centimeters. Almost as important is the recent demonstration that the stopped pion region will be amenable to visualization either by observing nuclear gamma rays or pi-mesic x-rays. Figure 5 displays some recent results, obtained by P. N. Dean (*4*), which show unambiguously that the pionic x-rays can be seen above background and will be usable for visualization of the energy deposition as it occurs; this will permit the therapist to irradiate precisely the volume he wishes.

It is now beginning to appear that muons too may be useful in diagnostic medicine. It occurred to me, several years ago, that muons might be used to determine elemental composition in tissue just as neutron activation analysis is now used, but with less damage to the host organism. Recently some results have been obtained by Lundy, Hutson, and Balagna (*5*) which are most encouraging. Figure 6 shows a simulated spectrum of muonic x-rays that one would see in "standard man." Our "standard man" is one who has been ground up and thoroughly mixed. The lines due to various elements stand out in bold relief.

The promise of pions and muons in medicine naturally raises the question of whether one might devise an inexpensive, single-purpose meson factory. Nagle, Knapp, and Hagerman have given some thought to this question. Nagle has come up with the concept shown in Fig. 7. A 3-Mev pressurized Cockcroft-Walton accelerator feeds protons into a 400-megahertz drift-tube linac which in turn injects into a 1200-megahertz side-coupled linac. The initial estimate is that a 500-Mev, ½-milliampere average current, low-duty factor machine can be built for about $5-million. It is beginning to appear that two of the particle physicists' most cherished particles are destined for a central role in diagnostic and therapeutic medicine.

Finally, I see particle accelerators assuming an ever more prominent role in our everyday life. It is not completely unreasonable to expect, within our lifetime, the emergence of a mail-order catelog, part of the index of which would look like Fig. 8.

Sears & Montgomery Inc.

Modern Particle Accelerators for Every Purpose

Accelerator type	Function
Electron linacs (1 to 100 Mev)	Inspection and surveillance of nuclear materials Polymerization of plastics
Isochronous cyclotrons (100 to 400 Mev)	Isotope production Radiation therapy with protons and alpha particles
Meson factories	Isotope production Radiation therapy with negative pions Mu-activation analysis for medical diagnosis
Electrostatic accelerators (0 to 100 Mev)	Radiation damage with neutrons and charged particles Isotope production Neutron cross sections Neutron activation analysis

Fig. 8. Prospects.

References and Notes

1. L. Rosen and L. Stewart, *Phys. Rev.* **126**, 1150 (1962).
2. J. R. McNally, Jr., *Nucl. Fusion* **11**, 187, 189, 191 (1971).
3. D. E. Nagle and E. A. Knapp, in *Yale University Conference on Linear Accelerators, 1963* (Yale Univ. Press, New Haven, 1964), p. 171; in *Proceedings of the Fifth International Conference on High Energy Accelerators, Frascati, Italy, 1965* (Comitâto Nazionâle Energìa Nucleâre, Rome, 1966), p. 403; *IEEE Trans. Nucl. Sci.* **12**, 623 (1965).
4. P. N. Dean, *Radiat. Res.*, in press.
5. A. S. Lundy, in *Proceedings of the Biomedical Sessions of the Fourth LAMPF Users Meeting, 30 to 31 October 1970* (LA-4602-MS, Los Alamos Scientific Laboratories, Los Alamos, N.M. 1970), p. 41.
6. P. E. Haggerty, testimony before the subcommittee on Science and Astronautics, House of Representatives, 13 August 1970.
7. Report of Subpanel on Accelerators to Nuclear Science Panel of Physics Survey Panel of the National Academy of Sciences.
8. *Survey of the Use of Radionuclides in Medicine: Preliminary Reports* (MORP 68-10, U.S. Department of Health, Education, and Welfare, Washington, D.C., July 1968).
9. P. Fowler, *Proc. Phys. Soc. London* **85**, 1051 (1965).
10. Horst and Conrad, *Fortschr. Geb. Rontgenstr. Nuklearmed.* **105**, 299 (1966).
11. Work performed under the auspices of the Atomic Energy Commission.