REPORT ON LOS ALAMOS PION FACILITY (LAMPF)*

Kenneth M. Crowe

Lawrence Berkeley Laboratory
University of California
Berkeley, California

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Not being a member of the LAMPF staff, I am rather unprepared to present a progress report on the pion facility to compete with the technically excellent presentations from the other rival accelerator projects. However, I will try my best to give a view as a potential customer of the facility, which hopefully will correspond to the interests of most of the audience.

The first figure shows a schematic layout of the machine; the design characteristics are given in Table I.

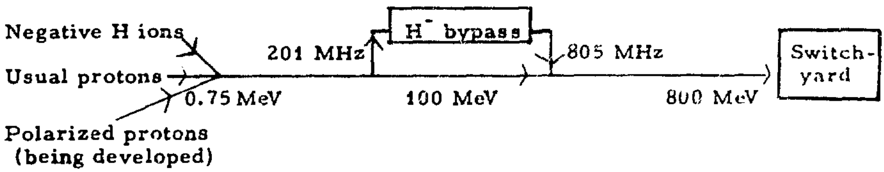

Figure 1. Schematic layout of LAMPF.

Table I. Accelerator characteristics

Beam energy:	800 MeV, continuously variable
Beam intensity:	
Average current:	1 mA
Extraction efficiency:	100%
Pulse length:	500 μsec-1000 μsec
Repetition rate:	120 cps
Beam quality:	
Energy spread:	±0.4%
Beam area in transverse phase space:	π mrad•cm
RF microstructure:	0.25-nsec pulses separated by 5 nsec

As of February 1973, the status of the machine was as follows:

Ion	Energy (MeV)	I_{peak} (mA)	I_{ave}
H^+	0.75	34	> 1 mA
	100	10	0.310 mA
	217	10	59 μA
	800	2 to 3	~ 1 μA

The H^- Beam. With regard to the negative ion beam, a post-deadline announcement has been received from Director Louis Rosen. I quote: "On Friday evening, April 6, negative and positive hydrogen ions were simultaneously accelerated to 100 MeV. The peak currents were low—50 μA H^- and 200 μA H^+—but no unexpected problems were evident." The following projections have been made for the beam that will be available for experiments:

Spring 73	Fall 73	Winter 73	Summer 74 (?)
1 μA	10 μA	100 μA	1 mA

This schedule of beam intensity vs. time takes into consideration the completion of the beam areas, caves, switchyards, etc., and the tune-up of the machine. The latter deals with the activation of the machine due to beam loss, which must be decreased from a few percent at present to 10^{-3} before 1 mA can be delivered on a steady basis. Incidentally, the plans for eventual improvement of the macro duty cycle from 6% to 12% are not presently being given as high a priority as some experimenters would recommend. The micro duty cycle is, of course, determined by the accelerator operation and is a few percent at the rf frequency of 200 MHz.

The energy will be varied and will be kept as low as possible consistent with the experiment, say 400 to 600 MeV, to minimize the wear on the rf system and hence to minimize the cost of operating and repairing the machine. As you can imagine, it is misleading to assume that the machine is to operate initially as a variable energy source. The running time will be divided up to allow repairs, turn-on, machine experimenting, users-physics diagnostics, and rest! (See Fig. 2.) The purpose of this division of running time is to optimize the progress toward full operation within the serious budget restrictions. Current thinking is that about 25% of the "on" time will be for experiments. A guesstimate is between 20 and 40 hours per week.

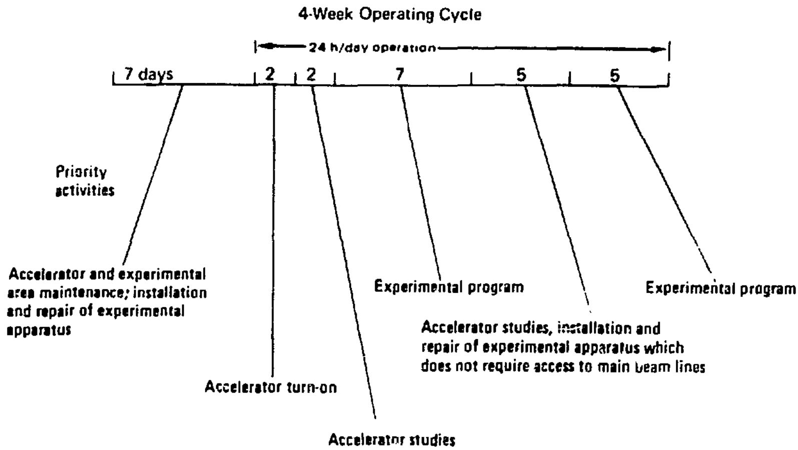

Figure 2. Initial division of running time.

The allocation of time has been made by the Program Committee, which is listed below:

L. Rosen, Chairman	D. Lind
D. Nagle, Alternate Chairman	F. Low
K. Crowe	D. Measday
J. Eisenberg	R. Perkins
H. Friedlander	A. Poskanser
J. Halpern	R. Rau
N. Hintz	T. Rothberg
V. Hughes	T. Schifter
A. Kerman	T. Tombrello

As you can see by the size and the composition of the group, it has a wide representation in nuclear theory, particle physics, and nuclear chemistry; their discussions are lively, I assure you.

Let me go quickly now to the experimental programs. There have already been more than 136 experiments proposed, which are distributed among the various channels as shown in Table II. The summary of each proposal is available from LAMPF; so (by necessity) I will concentrate only on the approved high-priority experiments. I shall briefly list them all so that if you wish you can look up the details of any of the first round of experiments. It is a bit of speculation as to when, in real time, these programs will be completed; but one may use the time assigned as an indication.

Table II: Summary of proposals—September 1972

Channel	Proposals approved	Proposals deferred	Proposals resubmitted	Other*
Energetic Pion Channel and Spectrometer (EPICS)	11	5	1	3
Low-Energy Pion Channel (LEP)	13	1		13
Stopped Muon Channel	10	3		6
Pion and Particle Physics Channel (P^3)	9	4	2	8
Nucleon Physics Laboratory (NPL)	8	5		9
High-Resolution Proton Spectrometer (HRS)	8	1	1	2
Nuclear Chemistry	2**			
Neutrino Facility	1			4***

*This includes those proposals which have not yet been acted upon, those to be resubmitted, those rejected, those to be given to a subcommitee, and one withdrawn.

**There are 15 nuclear chemistry proposals listed with their respective channels.

***Action on the full neutrino program was deferred. Only one was to be resubmitted.

Figure 3 shows the layout of the experimental areas. I will discuss the program in each area ever so briefly, beginning with the EPICS beam and spectrometer program.

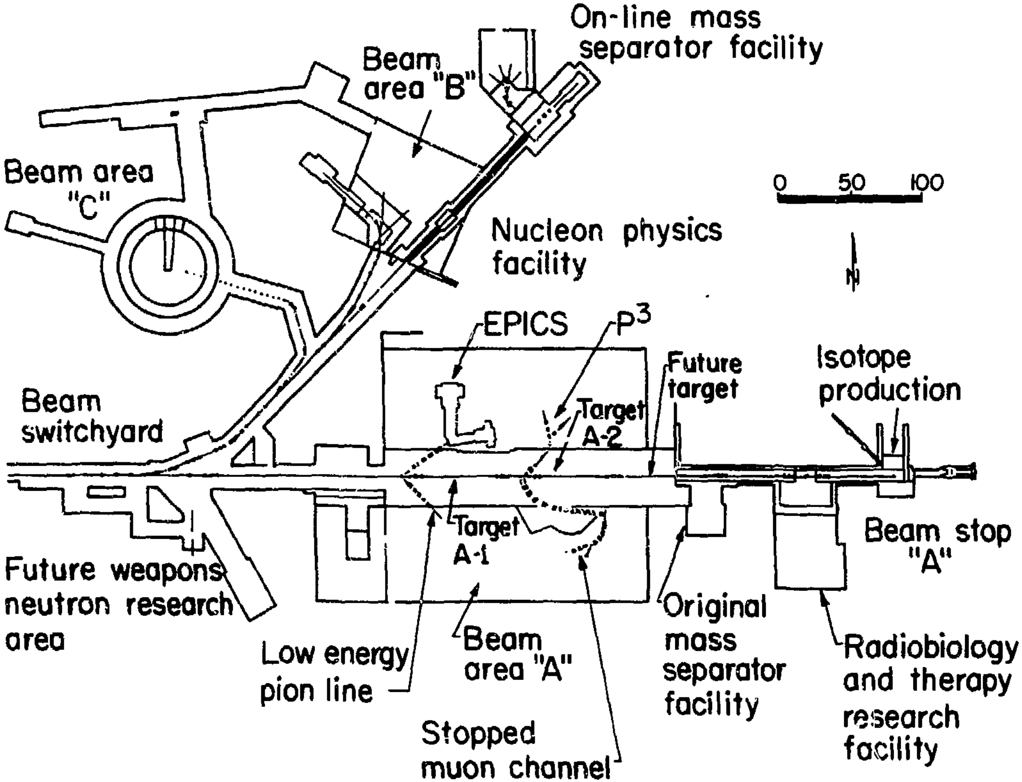

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Figure 3. LAMPF experimental areas.

Energetic Pion Channel and Spectrometer (EPICS)

EPICS is designed to serve two primary demands: good energy and angular resolution, and a pion energy range and beam intensity sufficient to measure cross sections from low energies to above the (3,3) pion-nucleon resonance with adequate counting rate. The complete system consists of a high-intensity, high-resolution pion beam channel, a particle separator for reducing backgrounds, and two spectrometers.

The EPICS tune-up is under the direction of H. A. Thiessen. Targets of ^{12}C, ^{13}C, and CH_2 will be bombarded for about 350 hours with pions of from 100 to 300 MeV. Angles are from + 20° to 150°.

To orient you on the quantitative aspects of the spectrometer and channel, Table III gives the fluxes and counting rates for 1 mA operation of LAMPF.

Table III. Fluxes and counting rates for 1 mA operation of LAMPF, using 5 gm/cm^2 carbon production target and 100 mgm/cm^2 carbon scattering target.

	T_π (MeV)	Beam intensity (π/sec)	Scattered particle count rate (π/hr·μb·sr)	Beam contamination ($\pi^{\pm}$: $\mu^{\pm}$: $e^{\pm}$)
	50	0.1×10^8	0.5	1 : 0.8 : 0.67
	100	1.0×10^8	6.7	1 : 0.5 : 0.07
π^+	150	2.5×10^8	21.0	1 : 0.3 : 0.02
	200	3.4×10^8	33.0	1 : 0.25 : 0.01
	250	4.8×10^8	52.0	1 : 0.16 : 0.01
	300	4.1×10^8	46.0	1 : 0.10 : 0.01
	50	0.4×10^7	0.2	1 : 0.8 : 2.4
	100	2.3×10^7	1.5	1 : 0.5 : 0.28
π^-	150	4.0×10^7	3.4	1 : 0.3 : 0.11
	200	5.4×10^7	5.2	1 : 0.25 : 0.06
	250	5.3×10^7	5.6	1 : 0.16 : 0.04
	300	4.2×10^7	4.8	1 : 0.1 : 0.05

The following survey experiments will be made:

Exp. # 18	(Zeidman)	Survey of π scattering by complex nuclei
Exp. # 23	(Barns)	Pion-nucleus elastic and inelastic scattering at 180 MeV
Exp. # 9	(Sobottka)	Pion scattering on calcium isotopes
Exp. # 46	(Peterson)	πd scattering

These will be concerned with obtaining a resolution of 2.2×10^{-4} and a solid angle of 10 msr at 100 to 700 MeV/c. The channel as designed has a resolution of 2.2×10^{-4} (FWHM) and a solid angle of 4 msr.

Low-Energy Pion Channel (LEP)

The low-energy pion channel is designed to provide $\pi^{\pm}$ beams for the energy region from low energies (~ 20 MeV) through the resonance region (~ 300 MeV). It will service a wide variety of research: nuclear structure, nuclear chemistry, elementary particle, and biomedical. This channel has a long list of experimental proposals. The scheduled priority experiments are as follows:

Exp. # 96	(Nagle)	$\pi^{\pm}$ elastic H, D scattering	150 hrs
Exp. # 2	(Jakobson)	$\pi^{\pm}$ cross sections	150 hrs
Exp. # 25	(Burman)	Double charge-exchange cross sections	200 hrs
Exp. # 29/54	(Gotow/Gross)	π^{-} elastic scattering at 20 MeV	100 hrs
Exp. # 50	(Crowe)	π^{-} radiative capture on tritium	300 hrs
Exp. # 121	(Segel)	$N\gamma$ from stopped π^{-}	120 hrs
Exp. # 131	(Gross)	$\pi^{+} + d \rightarrow 2p$ at 10 to 60 MeV	125 hrs
		Total approved	~ 1610 hrs

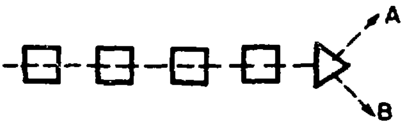
There is a substantially longer list of approved experiments that will eventually be included in this channel. The LEP fluxes expected are shown in Table IV.

Table IV. Pion intensities for the LEP channel.

T_π(MeV)	σ(45°) (μb/MeV ster)	$\Delta p/p = \pm 0.05\%$ $\Delta\Omega$	ΔE	N^+/sec	$\Delta p/p = \pm 1.0\%$ $\Delta\Omega$	ΔE	N^+/sec
25	13	0.01	0.05	0.55×10^6	0.02	0.93	2.2×10^7
50	20	0.01	0.09	4.0×10^6	0.02	1.74	1.6×10^8
100	26	0.01	0.16	1.9×10^7	0.02	3.16	7.3×10^8
150	24	0.01	0.22	3.3×10^7	0.02	4.44	1.3×10^9
200	18	0.01	0.28	3.3×10^7	0.02	5.64	1.3×10^9
300	5.3	0.01	0.40	1.9×10^7	0.02	7.92	7.4×10^8
Horizontal spot size		± 1.5 cm,		± 80 mr	± 1.6 cm,		± 130 mr
Vertical spot size		± 0.13 cm,		± 30 mr	± 0.5 cm,		± 40 mr

Stopped Muon Channel

The construction of the muon channel is well along, and it should be one of the first to produce results. In this channel, two beams are available:



Fractional momentum $\frac{\Delta p}{p}$	Beam A	Beam B	% of beam
± 1%	20 cm^2	40 cm^2	60
± 3%	40 cm^2	80 cm^2	80

Beam fluxes are as follows, assuming 1 mA of proton beam at 800 MeV:

P_π MeV/c	P_μ MeV/c	Charge	$N \times 10^6$/sec MeV/c
180	100	+	9.5
90	50	+	0.38
180	100	-	1.6
90	50	-	0.14

Estimates have been made of the contamination of the beams. For pions, $\pi/\mu < 5\%$; for electrons, $e/\mu \simeq 0.1\%$; for protons, $p/\mu < 1\%$. Neutron fluxes (n/sec) are estimated to be $7 \times 10^5/m^2$ due to the bend, $10^4/m^2$ present in the room, and 10^6 associated isotropically with the stopping μ^- beam. Scheduled priority experiments are listed below:

# 101 (Boehm) # 69 (Lu)	Feasibilities — crystal diffraction
# 7 (Perkins) # 12 (Powers)	μ nuclear structure
# 37 (Hughes)	Muonium
# 60 (Knight)	Muon chemistry
# 85 (Welch)	$\gamma\nu$ correlations
# 115 (Wolfsberg)	Fission
	Total hours = 1280

Pion and Particle Physics Channel (P^3)

The P^3, which should be completed early this fall, is a versatile, high-demand channel, capable of transmitting the highest energy pions produced at LAMPF. Basically it is a conventional two-bend channel with a third bend for matching the beam to one of two output legs. Flux estimates are given in Table V.

Experiments scheduled are as follows:

Exp. # 34 (Minehart)	$\pi^{\pm}d$, for pions between 40 and 400 MeV	220 hrs
Exp. # 80 (Phillips)	$\pi^{\pm}$ forward elastic scattering on ^{12}C, ^{13}C, ^{16}O, ^{40}Ca, and ^{208}Pb	300 hrs
Exp. # 99 (Rebka)	$\pi^- p \rightarrow \pi^- \pi^+ n$ near threshold	250 hrs
Exp. # 58/120 (Nefkin)	$\pi^- p \rightarrow \pi^0 n$, $n\gamma$ from 250 to 655 MeV/c, with a polarized target	300 hrs

The list of other proposals on this beam is quite long.

Table V. P^3 flux estimates, for $\Delta\Omega$ = 8 msr, $\Delta p/p$ = 5% , length = 20 meters, 5.8-cm carbon target (ρ=1.73 gm/cm^3), 20° production.

T_π(MeV)	$\pi^+(\times 10^9)$	P/π^+ (no degrader)	$\pi^-(\times 10^8)$
52	0.07	-	0.23
79	0.27	-	0.69
105	0.7	-	1.6
155	1.7	3.8	3.2
205	3.1	5.3	5.0
255	4.8	5.0	6.4
305	6.1	5.5	6.2
358	5.5	8.2	4.5
408	2.8	20	1.7
486	0.8, (1.5)*	100, (50)*	0.35
553	0.13, (0.3)*	670, (290)*	-
600	(0.05)*	(2000)*	-

*Crude extrapolation to 780-MeV protons

Nucleon Physics Laboratory (NPL)

High quality nucleon beams at 300 to 800 MeV will be provided at the Nucleon Physics Laboratory. At least two neutron beams and a low-intensity, flexible, external proton beam are planned. The neutrons will be generated by 10 to 100 μA protons in a liquid deuterium target, and the neutron beam will be formed by collimation in the forward direction. The external proton beam is planned as a low-intensity beam of 10 to 100 nA current; much higher currents are possible but will require the addition of a substantial amount of shielding. It is expected that the LAMPF polarized proton beam (about 100 nA at P ~ 0.9) will be available in 1974.

The NPL is located at the end of the LAMPF H^- beam line. The H^- beam, which will be shared on a simultaneous use basis with the HRS facility in Area C, will be capable of a maximum current of 100 μA. After part of the H^- beam is stripped and diverted to Area C, the remainder is sent toward the NPL. Once again, part of it can be stripped to form two separate simultaneous beams, one of positive ions and the other negative, both of which enter the NPL. It is planned to develop operating techniques that will permit simultaneous operation of both beams so that two experiments can proceed at the same time.

In the discussion at this conference of the nucleon-nucleon problem, there was clear agreement that progress in this area will be made with a definite set of experiments. The experiments scheduled at LAMPF reflect this interest:

Exp. # 27 (Willard)	pp spin correlation
Exp. # 81 (Phillips)	pd → ppn (pp and np coincidence spectra)
Exp. # 56 (Northcliffe)	pd → ppn (n spectrum)
Exp. # 125 (Dieterle)	np backwards angle
Exp. # 129 (Wolfe)	$\pi^{\pm}$ production in np collisions
Exp. # 64 (Segraves)	Total cross section
Exp. # 65 (Simmons)	$P(\theta)$

Clearly this represents a long program which will be followed in parallel at the other meson factories. Perhaps I should remark here that continuous variability of the proton energy seems to be more difficult to achieve at LAMPF than, for example, at TRIUMF. Let us hope there will be a healthy coordination among the laboratories so that these differences are given consideration when programs are planned.

The future of the polarized proton beam and the 0° neutron beam made with > 10 μA protons on a > 50-watt liquid deuterium target, and future expansion at this facility are being considered. Chester Hwang and James Simmons are two of the LAMPF physicists who can provide more information if it is needed.

High-Resolution Proton Spectrometer (HRS)

The High-Resolution Spectrometer facility will be able to obtain an overall resolution in momentum of 0.01% (corresponding to about 100 keV energy resolution at a bombarding energy of 800 MeV; 50 keV, at 400 MeV) and ± 0.8 mrad resolution in scattering angle.

Nuclear reaction products resulting from the population of low-lying states of many nuclei will be individually resolved, and measured with sufficient angular resolution to delineate clearly the rapid angular oscillations of the cross section that characterize nuclear reactions near 1 GeV. The large solid acceptance angle of the spectrograph, 3.6 msr, will make it possible to measure cross sections 10^{-2} smaller than have been previously measured near 1 GeV.

The future use of this facility to carry out the program which is already under way at Saclay is described in great detail in numerous documents, available on request from the HRS group. J. E. Spencer and N. Tanaka are two of the contact physicists in this group.

The layout of the channel and spectrometer is shown in Fig. 4; the elevation in Fig. 5.

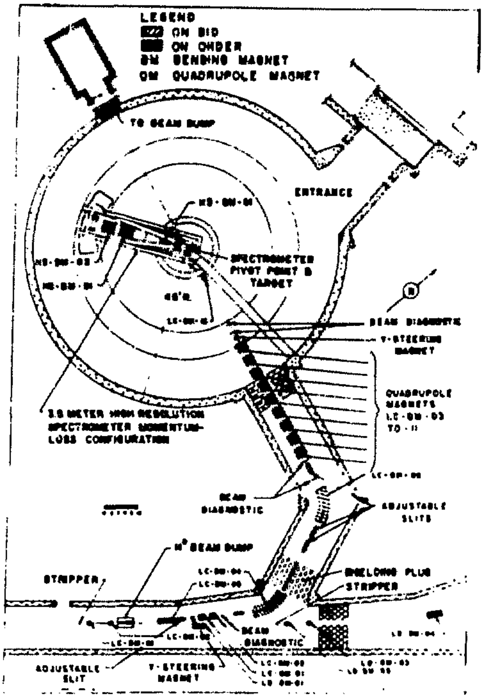


Figure 4. Status of magnets along Beam Line C and the HRS.

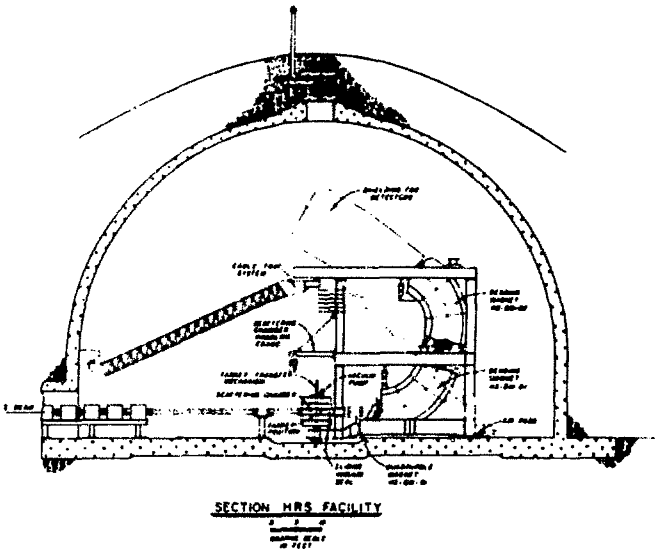


Figure 5. Elevation of HRS facility.

Progress on the installation has been somewhat delayed for a number of reasons; thus it is difficult to predict when the facility will operate. But estimates now are that April 1974 is a reasonable target date. Because of this uncertainty, only a few engineering tune-up experiments, which test the apparatus, have been approved.

Other Channels

The three remaining areas are the nuclear chemistry channel, the biomedical channel for pion irradiation, and the neutrino facility. Since the first two are somewhat removed from the interest of this group, I will not go into any details on these programs.

The Neutrino Facility and its research program are still in the distance; however, Exp. 31 (Nemethy at Yale) has been approved. This experiment will study electron neutrinos from the "exotic" μ decay: $\mu^+ \rightarrow e^+ + \bar{\nu}_e + \nu_\mu$. These decays are to be detected in a Cerenkov detector by observing positrons from $\bar{\nu}_e + p \rightarrow n + e^+$. The latter reaction is allowed only for the so-called multiplicative muonness selection rule. Predictions of the expected decays under the two forms of the selection rules are as follows:

	Additive	Multiplicative
$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$	100%	50%
$\mu^+ \rightarrow e^+ + \bar{\nu}_e + \nu_\mu$ (exotic)	0%	50%

I assume this audience to be familiar with the forms of the selection rules and the relation of this experiment to the muonium-antimuonium conversion experiments.

This experiment is expected to yield 60 events/day at full intensity with a 6-cubic-meter detector; it would be sensitive to any "exotic" decays exceeding 10% of all the muon decays.

Since the descriptions I have presented here of LAMPF and its experimental programs have been summary in nature, and since the Facility is developing rapidly, I may have raised more questions than I answered. However, all the planning and work to date has been documented, in a myriad of reports; and I'm sure that any of the LAMPF staff would be happy to lead you to them and to provide you with whatever details you would like.

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*Work performed under the auspices of the U. S. Atomic Energy Commission.