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A developmental program involving several high-current linear accelerators has been pursued at Livermore. At present components for a machine designed to accelerate 0.25 ampere of protons to 3.7 Mev and of deuterons to 7.5 Mev are being assembled following experience gained from previous work.

A 100-kv dc injector supplies the protons and deuterons for the linacs. A hydrogen arc of 100 amperes, 60 volts, in an axial magnetic field is maintained behind a copper plate which has small holes close to the axis. Adjacent to the arc chamber a 5-inch-diameter cylinder at arc potential forms the first electrode of the accelerating lens system. Potentials up to 130 kilovolts have been held across the one-inch gap to a grounded electrode. Such a geometry has focused 0.75 ampere of protons into a 3-inch-diameter hole 57 inches from the arc source. Solenoidal magnets at the grounded electrode and at intervals along the beam provide necessary focusing.

The first of two accelerators to be described A-54, is a 48.5-megacycle resonant cavity accelerator somewhat like the 40-foot linac in Berkeley.[1,2] The rf cavity was a copper-clad steel cylinder 12 feet in diameter and 20 feet long; it had 22 drift tubes with 3-inch-diameter bores. The drift tubes contained solenoid magnets to provide 5 kilogauss to focus the protons.[3] In order to include space enough for the magnets the drift tubes were almost $2\,\beta\lambda$ long, where $\beta\lambda$ equals the distance a proton travels during one rf cycle. That is, the protons were accelerated between drift tubes on only every other rf cycle.

With drift tubes, the cavity resonated at 48.5 Mc and was energized by a shielded grid triode, RCA ceramic 2332. The tube was operated as an amplifier to deliver 400 kilowatts continuous rf power. The amplifier could be driven from a master oscillator or from a signal from the cavity.

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1. L. W. Alvarez, et al., Rev. Sci. Instr. 26, 111 (1955).
2. Bruce Cork, Rev. Sci. Inst. 26, 210 (1955).
3. Smith and Gluckstern, Rev. Sci. Inst. 26, 220 (1955).

The beam energy was 490 ± 50 kev. At 220 ma an operating efficiency of 97% was maintained over an 8-hour shift. About half of the dc injected beam could be accelerated to full energy.

The highest rf gradient held consistently was 10% above deuteron gradient; however, no deuteron operation was possible because no adequate high-voltage power supply was available. Deuteron acceptance by the cavity required either an rf buncher-booster or a 200-kv dc injector. A buncher-booster is a paddle resonator similar to the quarter-wave paddle machine to be described.

The quarter-wave paddle machine was designed to produce the same beam as the A-54 accelerator. In order to make the acceleration per gap efficient, the machine was operated at a lower frequency, 24.5 Mc. Thus, the ions could get across a gap during the peak of the rf voltage even with a 3-inch-diameter bore. The four accelerating gaps varied from 2 inches to 3.7 inches.

The injector was essentially the same as that used on A-54. However, the dc beam was modulated with several kv of rf so that the ions were bunched as they approached the first accelerating gap, and therefore the percentage of accelerated beam was increased.

Each pair of acclerating gaps (and the buncher) was formed by a drift tube in a cavity, with the drift tube supported by a shorted quarter-wave resonant stem. A drift tube and stem look like a big paddle. The drift distances were almost 3/2 $\beta\lambda$ long, so that the solenoid focusing magnets could be contained inside the drift tubes. The rms axial field was 5 kilogauss for protons and 10 kilogauss for deuterons.

The rf voltages and relative phases of the cavities were variable so that 70-kv and 140-kv injection were adequate to accelerate respectively protons and deuterons. Again RCA-2332 tubes were used as amplifiers, driven from a common high-frequency source. A variable phase shift was introduced between the separate amplifiers for each cavity. Each accelerating cavity was tuned to resonate at the proper frequency by servo-driven slugs, which vary the capacttance of the drift tubes.

It was found during operation that the average proton beam energy could be varied between 440 kev and 510 kev without significant broadening of the energy distribution which was ± 100 kev. Proton beam currents as great as 0.3 ampere at 0.5 Mev were measured. High-power deuteron beams were obtained only on pulsed operation, because of power-supply limitations, inadequate water cooling, and insufficient shielding against neutron irradiation. The highest average deuteron beam so far was 30 ma at 0.96 Mev. Peak pulsed deuteron beam currents were limited to 125 ma by the limited output of the injector power supply.

An accelerator called A-48 is now being assembled out of the injector, the quarter-wave paddle machine, the 20-foot tank of A-54 with a new set of 1-βλ drift tubes, and another 20-foot tank also with 1-βλ drift tubes. The quarter-wave machine will operate at exactly half the frequency of the two 20-foot tanks, and each rf component must be accurately phased in order to accept the bunched beam from the preceding section. Each tank will have a servo-operated tuner to maintain resonance. The design beam is 0.25 ampere of 7.5-Mev deuterons. Eventually an alpha-particle source will be developed, but its currents will probably be much smaller. Any set of sections can be operated independently of the succeeding sections so A-48 will produce particles with all the following energies:

Particle	Injector Energy (Mev)	λ/4 Energy (Mev)	"A" Vessel Energy (Mev)	"B" Vessel Energy (Mev)
Proton	0.070	0.5	1.9	3.7
Deuteron	0.14	1.0	3.7	7.5
Alpha	0.28	2.0	7.5	15.

One serious problem is to dissipate the large amount of power on a target. A precessor consisting of a magnetic field rotating at 36 cps is being designed to spread the beam out over a target 3 feet in diameter in order to keep the target from melting.

During the next year A-48 will be assembled and tested, and deficiencies will be corrected. Then various experiments will be attempted to explore the research capabilities of this high-current machine. In particular it is planned to make some radioactive isotopes that are not now available because of small activation cross sections.

The design parameters for the A-48 accelerator are as follows:

	$\lambda/4$	A	B
Drift tube diameter (in.)	18.5	27.5	33.25
Tank diameter (in.)		158	143
Bore diameter (in.)	3	3	4
Gap lengths = g (in.)	1.96 → 3.69	1.96 → 4.0	3.84 → 5.68
Drift tube lengths = l (in.)	11.5 → 17.2	6.14 → 10.9	11.8 → 15.6
No. of drift tubes	2 + buncher	1/2 + 20 + 1/2	1/2 + 12 + 1/2
Over-all length (ft.)	8	20	20
g/(l+g) Range	0.25	0.245 → 0.266	0.247 → 0.265
Resonant frequency (Mc)	24.4	48.8	48.8
Mean cavity gradient (Mv/ft)		0.25	0.29
Gap gradients (kv/in.)	150 → 90	85	97
End-to-end voltage (Mv)	1.26	5.1	5.8
Synchronous phase angle	30°	45°	35°
Phase acceptance	200° with buncher	135°	105°
Exit width of bunch in rf phase at 48.8 Mc	~100 → 120°	60 → 70°	40 → 50°
Exit angular divergence	± 2°	± 1°	<± 1°
R_S theoretical (megohms)	0.5	66	58
Exciting power (kw)	160	300	400
Magnet power supply (Mw)	1	1.5	0.9
Solenoid field (kilogauss)	10.2	8.2 → 7.1	7.1 → 6.5