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BEVATRON OPERATION AND DEVELOPMENT. 63

July through September 1969

Kenneth C. Crebbin and Don M. Evans

November 21, 1969

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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Lawrence Radiation Laboratory
University of California
Berkeley, California 94720

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ABSTRACT

The Bevatron provided beam to 16 experiments this quarter and accelerated a total of 1.83×10^{18} protons. A new thin-septum magnet (0.130 in.) was installed in the east straight section of the first magnet in the EPB system. This magnet is compatible with the present energy-loss extraction system and will be used to continue resonant-extraction studies. A quadrupole magnet was also installed just downstream from this septum magnet. Extraction efficiency using the energy-loss system is now about 50%.

Computer control of the external beam transport magnets was expanded to include control of more magnets and more versatile programming options. The control system was also expanded toward eventual control of the pulse modes of the Bevatron magnet power supply.

I. MACHINE OPERATION AND EXPERIMENTAL PROGRAM

The Bevatron operation record is shown in Fig. 1. The beam was on for 82.5% of the scheduled operating time. The beam was off 11.0% of the scheduled operating time because of equipment failure and 6.5% of the time for experimental setup, tuning, and routine checks. During this quarter, the Bevatron accelerated 1.83×10^{18} protons.

The Bevatron was shut down on July 4, 1969, and resumed operation for experimenters on August 12, 1969. The details of this shutdown are covered in Section II of this report.

During the period covered by this report we provided beam for 11 primary experiments and 5 secondary experiments for a total of 16 experiments. Experiments #73 and #76, being done with the 25-inch hydrogen bubble chamber, were completed this quarter.

Two new primary and two new secondary experiments started operation this quarter. The two new primary experiments are:

(a) Experiment #84, being done by the LRL Moyer-Helmholz group: a study of $\pi^- p \rightarrow \pi^0 \pi^0 n$, using a π^- beam from an internal target near the north straight section of the Bevatron.

(b) Experiment #122, being done by the LRL Trilling-Goldhaber group: a study of Λd interactions, being done in the 25-inch hydrogen bubble chamber.

*Preceding Quarterly Reports: UCRL-18890, UCRL-19299.

The Bevatron operated 85 12-hour periods for high energy physics out of a scheduled 103 12-hour periods. During this time, we integrated 205 12-hour periods of data-taking and 136 periods of tuneup for primary experiments. Forty-two more 12-hour periods were integrated by secondary experiments, for a total of 383 12-hour periods for high energy physics.

The primary magnet pulsing mode this quarter employed a 1500-msec flattop at an energy of 4.9 GeV. The pulse rate was 10.9 pulses per minute (ppm). There were two secondary pulsing modes this quarter. First was a 1000-msec flattop mode at 5.4 GeV at 10 ppm. The second mode included a 375-msec back porch at 4.9 GeV. The pulse rate was 9.3 ppm. In general, the 25-inch bubble chamber took a beam pulse at the beginning of flattop and again at the end of flattop, with the long-spill counter experiments operating between these two pulses. In the mode employing a 5.4-GeV flattop followed by a 4.9-GeV back porch the 25-inch bubble chamber beam pulses were at the beginning and end of the high energy flattop, and the counter experiments received the long beam spill on the back porch.

A summary of the experimental program for this quarter is shown in Table I.

II. SHUTDOWN

The Bevatron was shut down from July 4 through August 3, 1969. The major job during this shutdown was the replacement of the first bending magnet (M1) in the extraction system of the external proton beam. The magnet that was removed had been installed during the spring of 1967 as a major step in the development of a resonant extraction system. This magnet had a half-inch-thick septum. The new magnet that was installed during this shutdown has a 0.130-in.-thick septum. Tests have subsequently shown that this new magnet has resulted in significant improvement in the extraction efficiency both for the present energy-loss system and for the future resonant-extraction system.

At the time when the first resonant extraction test magnet was installed in 1967[1] it was necessary to remove the first quadrupole magnet (Q1) of the extraction system. This was done in order to devote all the electrical feed circuits in the drive shaft of the magnet plunge system to the resonant-extracted magnet system. The septum magnet had two additional magnetic circuits on the magnet: the perturbation to drive the 2/3 resonance and a spiller coil to control the beam spill. The magnet is plunged 28 in. each Bevatron cycle by a drive shaft that passes through a vacuum seal. All the electrical circuits to the magnet are carried inside the 6-in. drive shaft. There were only enough electrical circuits in the drive shaft to provide for the septum magnet and the perturbation and spiller coils, so the quadrupole, Q1, was removed. One of the requirements in the design of the magnet for resonant-extraction studies was that it be compatible with the present energy-loss target extraction system so that we could continue normal operation of external proton beams for experiments while the studies were being conducted.

When we resumed operation in early summer 1967, tests were made on the energy-loss-target extraction system with the new magnet. The extraction efficiency was about 35%, the same as we had previously experienced with the original bending magnet (M1) and the quadrupole (Q1). The spot size at the first focus was slightly larger than it was previously, but usable. Prior to the installation of this new extraction magnet, studies had been started in an attempt to improve the extraction efficiency of the energy-loss-target system. In particular we were unable to account for a large fraction of the missing 65% of the beam. These studies continued after the resonant-extraction test magnet was installed. A scintillator was installed on the upstream face of the M1 magnet and was monitored by closed-circuit television. This type of monitor system was later extended to the second set of plunged magnets, M2 and Q2. These diagnostic tools aided considerably in determining the beam distribution inside the Bevatron during beam extraction. Some modifications were subsequently made in relative radial positions of the extraction magnets and the energy-loss target. However, no increase in beam extraction efficiency was achieved.

Studies were then directed toward the beam exit-port region of the Bevatron. Gold and aluminum foil activation runs were made at the exit port to measure the beam profile. These measurements showed the beam to be much wider than had previously been measured. The full width at half maximum was about 3 in. The beam previously had been measured at somewhat less than 2 in. total width. This larger-size beam was wider than the exit port and M3 magnet-aperture combination. The gold foil activation measurements showed a loss of about one-third of the beam in going through the M3 and Q3 magnets. The aperture of M3 was adequate (5 in.) for the beam, but because of space limitations it was not possible to get the M3 magnet properly aligned. This is shown in Fig. 2.

As a result of these tests, two changes were made to improve extraction efficiency. The face plate on the west tangent tank was removed and remachined to permit moving M3 into better alignment with the external proton beam, and as mentioned previously, a new quadrupole was designed to be placed in the east tangent tank just downstream from the septum magnet. To provide power for this magnet it was necessary to replace the 6-in. probe tube with a new tube with more feedthroughs and circuits. These changes were made during this shutdown.

After the shutdown, and when the vacuum in the Bevatron had returned to normal operating levels, the extraction efficiency was checked. The beam spot at M3 was back to about a 2-in. width and the extraction efficiency was up to about 50%.

The remainder of the manpower effort during the shutdown was devoted to routine maintenance of the Bevatron main motor generators and associated equipment.

III. BEVATRON DEVELOPMENT AND STUDIES

The bulk of the effort this quarter on Bevatron development was devoted to resonant-extraction studies. A report on the status of resonant extraction will be given in the next quarterly report of Bevatron Operation and Development. Effort was also devoted to high beam studies and to improvement in the computer control of Bevatron equipment.

It was observed that at high beam intensities, 4×10^{12} protons, the vertical height of the beam is clipped by the M1 magnet. This causes about a 20% beam loss in circulating beam, and hence a reduction in actual extracted beam relative to total accelerated beam.

IV. COMPUTER CONTROL

1. System

The Bevatron digital control and data acquisition facility has recently acquired additional PDP-8's to accommodate extension of the digital control facilities into new areas of Bevatron operations.[2] There are now two digital processors in an on-line configuration, one in control of EPB extraction and EPB transport magnets, the other in programming the Bevatron guide field. Continued development work with a third processor is providing new techniques for proton beam parameter study, and is moving in the direction of meaningful beam diagnostics.

To facilitate software handling and to assist program development, a fixed-head disk has been acquired and incorporated into the system. Minimal display facilities are maintained to assist in operator control and to provide near real-time presentation of data in both on-line and developmental branches of the digital control and data-acquisition field.

2. EPB

Necessary peripheral hardware has been constructed to extend the digital control provision from the previous 18 energy-tracking magnets[3] to an additional 10 tracking and 12 dc magnets, bringing the total to 40. The "dc" control function does not exclude the possibility of energy tracking or special function control, or both. An extension of the special function generation provides the capability of assigning any combination of up to 24 perturbation and slope units to any magnets under control.

The perturbation ("P") and slope ("S") units are software devices, each of which includes a time delay and a gate. All time delays in service, in the program, are started from an optional interrupt. The delay and gate lengths are adjusted by shaft encoders normally used for adjusting magnet current levels. The basic time increment is the time between magnet update cycles, so several milliseconds is the possible jitter to be encountered. Numbers are assigned to the "P" and "S" units and all parameters associated with their operation are adjustable from, and monitored at, the EPB control console. No reference to a teletype is required.

The difference between a slope unit and a perturbation unit lies entirely with the way the control word for a magnet is handled <u>during</u> the gate time. The amplitude adjustment of a slope unit determines the signed numerical value of the increment to be successively added to the currently calculated value for control word. In analog terms, the present value of the time integral of the increment is algebraically added to the calculated value of the control word.

The perturbation unit operates the same in every respect except that during the gate time a fixed offset is added to the currently calculated control word. At the conclusion of the gate period, the offset is removed and the magnet goes back to wherever it might have been directed had the perturbation unit not existed. By mixing the units, special time-variable functions may be created to provide special conditions for proton beam spill control. These units can be impressed upon magnets that are normally being operated upon by some proportion of $\int \dot{B}$, i.e., energy tracking. So long as the time tolerances noted above are acceptable, the inclusion of these provisions allows some considerable reduction in the amount of <u>hardware</u> otherwise required to implement the functions.

3. Bevatron Guide Field

In the process of developing the EPB magnet control, a high-resolution digital integrator for guide field B was developed. This consists of a 21-bit up-down scaler driven by a voltage-to-frequency converter monitoring the $\dot{B}$ winding within the guide field.

A natural extension of the use of this device is to control the ignitrons in the cubicles associated with the two motor generators providing the excitation to the Bevatron magnet. Appropriately, a PDP-8 processor has been installed to create the program to provide a wide variety of pulsing modes.

Currently, the software takes operator input in the form of a requested profile, defining field levels and durations to be obtained for a particular setup. The information is analyzed with a view toward establishing maximum repetition rate while keeping power consumption within specified boundaries. Motor speed is observed along with rates of rise in "flat" regions. Presently the loop is closed on the integral of $\dot{B}$, and overshoots due to system inertia can be eliminated upon request. Though no closed-loop control of rate of rise is presently exercised, work toward this end is under way.

4. Beam Diagnostics

In order to provide closed-loop control of spilled beam on experimenters' targets, the development of a suitable real-time beam position and profile sensor is required. A number of potentially useful devices are currently under investigation. A third PDP-8 digital processor is being utilized to assist in data acquisition and reduction to further this development procedure.

One such device is a multiple-strip ion-collection unit that translates the ionic current from 47 strips in the Bevatron aperture to voltages held on capacitors in a parallel sample-and-hold configuration. These capacitors are then scanned through a sequential multiplexer and converted to digital data within the processor. Necessary parameters are then calculated and offered as reduced data to the investigator. These parameters include locations of peaks and centroids, the integrals of the scanned waveforms, and the full-width, half-maximum points.

Other techniques under investigation include a means of establishing the rate of spill of beam. A photomultiplier output is accumulated in a fast counter, gated for a short time period. The value of counts is read into the digital system and the counter is again gated on. By repeatedly collecting the accumulated counts, real-time data can be provided. Normalized digital information can be output to digital-to-analog converters to reconstruct an analog waveform which may be useful in closed-loop beam spill, by introduction into the feedback loop of a spilling magnet.

The development of these techniques, and a continuously available value of field, together with a means of rapid measuring of rf frequency, can result in a significant step toward closed-loop control of accelerated beam.

IV. BEVATRON MOTOR GENERATOR

The magnet pulsing record is shown in Table II.

REFERENCES

1. Kenneth C. Crebbin and Robert Frias, Bevatron Operation and Development. 54, UCRL-17931, Jan. 31, 1968.
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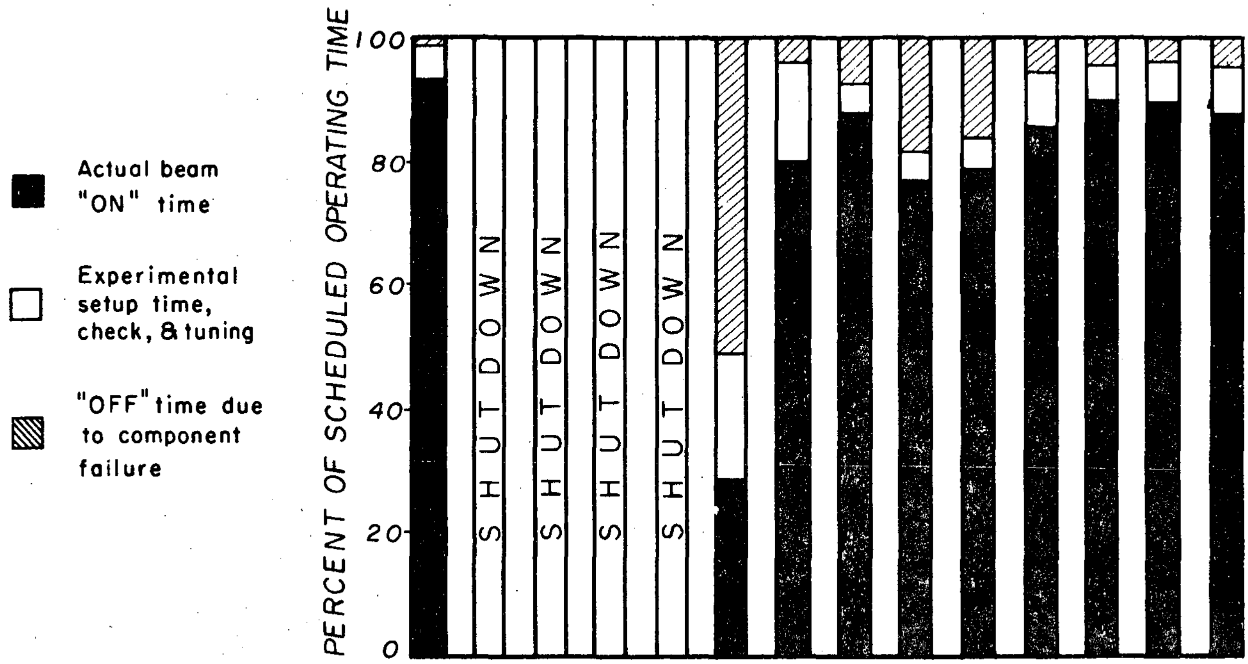
3. Don M. Evans, Digital Control of Bevatron EPB Transport Magnets, IEEE Trans. Nucl. Sci. NS-16 [3], 866 (June 1969).

STAFF

Edward J. Lofgren	Bevatron Group Leader
W. A. Wenzel	Alternate Group Leader
Walter D. Hartsough	In charge of Bevatron operations
Kenneth C. Crebbin Fred H. G. Lothrop Wendell Olson	Operation Supervisors
William Everette	Radiation Control
G. Stanley Boyle Donald N. Cowles Robert G. Gisser Ashton H. Brown Joseph F. Smith	Operating Crew Supervisors
Richard L. Anderson Douglas A. Bentson Robert W. Brokloff Gary M. Byer Charles H. Hitchen Robert M. Miller Harvey K. Syversrud John E. Tommaney Stanley T. Watts	Bevatron Operators
Robert V. Aita Robert W. Allison, Jr. Robert A. Belshe James P. Brannigan Duward S. Cagle Kenneth C. Crebbin Warren W. Chupp Tom Elioff Hugh M. Ellison Don M. Evans Robert Force James B. Greer James R. Guggemos Fred H. G. Lothrop Donald Milberger Robert Richter Edward W. Stuart Marsh M. Tekawa Glenn White Emery Zajec	Development and Support
Edward Hartwig Robert Force	In charge of Electrical Engineering Group
Marion Jones	In charge of Electrical Coordination Group
Kenow Lou Abe Glicksman Cedric Larson	In charge of Mechanical Engineering
Harold Vogel Robert Frias	In charge of Motor Generator Group



Week of		6/29	7/6	7/13	7/20	7/27	8/3	8/10	8/17	8/24	8/31	9/7	9/14	9/21	9/28
Crew hours		144	168	168	144	168	168	168	168	168	144	168	168	168	168
Turn on & maintenance time	(h)	0	0	0	0	0	8	10	10	10	13	10	10	10	10
Scheduled operating time	(h)	128	0	0	0	0	109	158	158	158	131	158	158	158	158
Scheduled Bevatron test time	(h)	16	0	0	0	0	8	14	6	14	12	14	16	16	18
Scheduled shutdown time	(h)	16	168	168	144	168	51	0	0	0	0	0	0	0	0
Holiday		24	0	0	24	0	0	0	0	0	24	0	0	0	0

Fig. 1. Bevatron operating schedule. XBL6912-6406

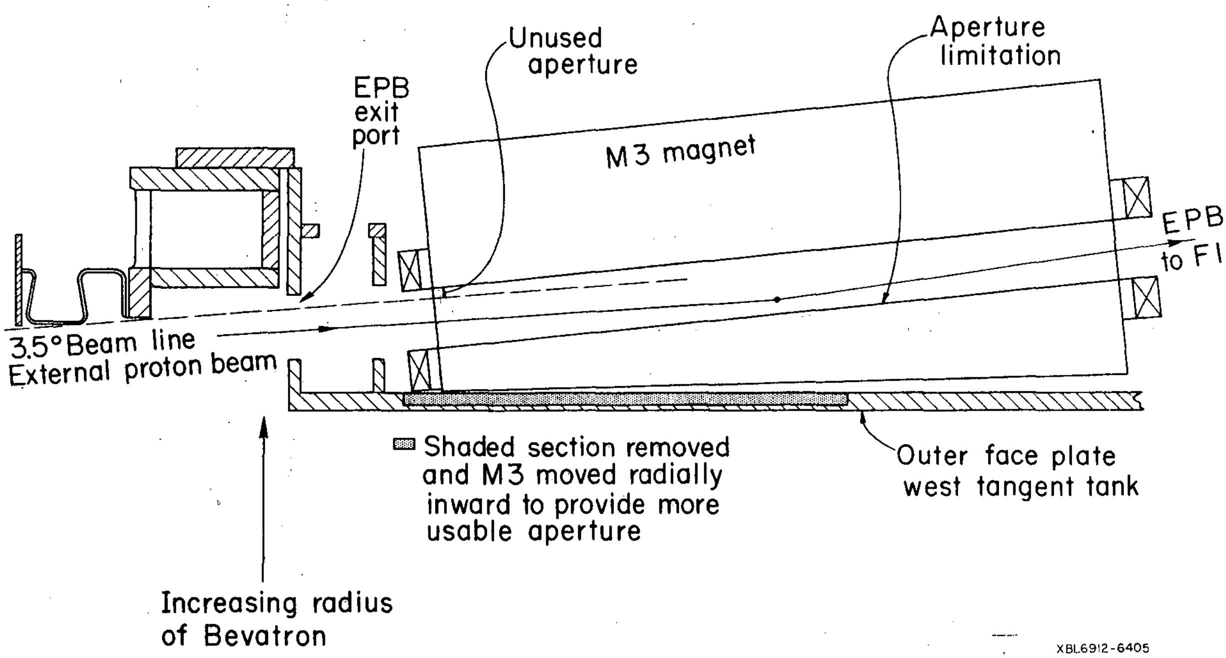


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Fig. 2. External proton beam extraction magnet (M3) aperture restriction.

Table I. Summary of Bevatron Experimental Research Program June through September 1969.

Groups	Experiment location	Run	Start	End	Experiment	Beam Time: This quarter July - September: 12-Hour periods	Beam Time: This quarter July - September: Hours	Beam Time: Start of run through September 1969: 12-Hour periods	Beam Time: Start of run through September 1969: Hours	Pulse Schedule	Primary or secondary experiment
Internal Group											
Powell-Birge (Kalmus)	EPB 25-in. BC	72	2/21/68	In progress	π^+p Interactions	0	0	151	1599	1:1	P
Powell-Birge (Ely-Kalmus)	EPB 25-in. BC	73	6/8/68	7/2/69	K^-p and K^-d reactions	1	11	116	1196	1:1	P
Trilling-Goldhaber (Kadyk)	EPB 25-in. BC	76	10/30/68	7/3/69	Λp Scattering	2	24	43	468	1:1	P
Lofgren (Wenzel)	EPB X1F3	82	5/21/69	In progress	$K_L^0 \to \mu^+e^-$, e^+e^-, $\mu^\mp e^\pm$, branching ratios	12	141	16	210	1:1	P
Moyer-Helmholz (Kenney) Group A (Pripstein)	Internal west area straight section	84	8/9/69	In progress	Study of $\pi^-p \to \pi^0\pi^0$	21	257	21	257	1:1	P
Powell-Birge (Gidal)	EPB 25-in. BC	87	11/26/68	In progress	π^+p Interactions	0	0	52	542	1:1	P
Miller	EPB X1F3	95	5/25/69	In progress	$K^0\mu3$ charge asymmetry	18	185	32	355	1:1	P
Nuclear Chem. Hyde-Poskanzer	EPB X1F2	104	9/21/69	In progress	Production of light fragments from p-N collisions	12	135	266	3045	1:1	P
Segrè-Chamberlain (Stiening) U. Chicago (Hildebrand)	EPB X1F2	107	6/14/69	In progress	Study of $K^+ \to \pi^+\nu\bar{\nu}$	74	829	90	1005	1:1	P
Trilling-Goldhaber (Kadyk)	EPB 25-in. BC	122	9/23/69	In progress	Study of d Interactions	2	33	2	33	1:1	P
Miller	Internal west area straight section	P-32 (95)	5/31/68	In progress	$K^0\mu3$ charge asymmetry tests for projected Exp. #95	5	52	31	393	1:1	S
Lofgren	Internal west area straight section	P-33	10/11/68	In progress	Preliminary counter checks for projected Exp. #82	18	230	50	624	1:1	S
External Groups											
U. Hawaii (Cence) LRL-Moyer-Helmholz (Perez-Mendez)	EPB X1F3	60	1/14/69	In progress	Ke_4 decays	67	722	163	1795	1:1	P
UCRL (Nefkens) LRL (Crowe)	Internal west area straight section	88	12/5/68	In progress	$\pi^-p \to n\gamma$ Differential cross sections	82	915	239	2598	1:1	P
UCLA (Schlein) CIT (Gomez) NAL (malamud)	EPB 25-in. BC	112	2/16/69	In progress	Study of Kπ system	52	547	77	808	1:1	P
Space Science Laboratory (Smith)	Internal west area straight section	P-30	10/1/68	9/10/69 ss	Counter tests for balloon experiment	1	11	22	267	1:1	P
UCSD (Masek)	Internal west area straight section	P-38	8/13/69	In progress	Counter trigger study for a proposed experiment	19	235	19	235	1:1	S
U. of Wash. (Cook)	EPB X1F3	P-39	8/27/69	In progress	Testing equipment for Exp. #96	16	194	16	194	1:1	S

Table II. Bevatron Motor Generator Set Monthly Fault Report.

1969	4 to 6 pulses/min								7 to 8.7 pulses/min								9.3 to 17 pulses/min								Total				
	1.5 to 6.9 kA				7.0 to 9 kA				1.5 to 6.9 kA				7.0 to 9 kA				1.5 to 6.9 kA				7.0 to 9 kA								
	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Arc-backs (AB)	Arc-through (AT)	P/F	Ignitrons replaced
Jan.	3 979	-	1	3 979	-	-	-	-	3 307	-	-	-	-	-	-	-	241 713	7	15	10 987	5 144	3	5	643	254 786	10	21	8 219	1
Feb.	661	-	-	-	-	-	-	-	1 740	-	-	-	21 868	2	1	7 289	280 881	5	8	20 063	18 290	2	1	18 290	323 440	9	10	17 023	1
March	-	-	-	-	-	-	-	-	120 914	-	-	30 228	4 212	8	1	4 212	247 406	1	5	24 741	1 738	1	2	579	374 270	10	8	20 793	0
April	1 022	-	-	-	-	-	-	-	1 625	2	-	812	7 288	1	-	7 288	276 881	7	4	25 171	1 220	2	1	407	288 036	12	5	16 943	0
May	316	-	-	316	-	-	-	-	9 263	1	1	4 632	7 928	2	-	3 964	344 117	2	2	86 029	7 544	1	5	1 257	369 168	6	9	24 611	1
June	-	-	1	-	-	-	-	-	5 927	-	-	-	10 989	-	1	10 989	373 406	7	5	31 117	1 793	-	2	897	392 115	7	8	26 141	0
July	-	-	-	-	-	-	-	-	16 007	-	-	-	859	1	-	859	26 576	-	6	4 429	-	-	-	-	43 442	6	1	6 206	4
Aug.	1 479	-	-	-	-	-	-	-	164 051	10	5	10 937	44 654	2	1	14 885	103 805	1	1	51 903	3 576	-	-	-	317 565	7	13	15 878	1
Sept.	2 559	-	-	-	-	-	-	-	109 279	3	3	18 213	18 741	1	-	18 741	212 857	1	3	53 214	100	-	-	-	343 536	6	5	31 231	0
Oct.																													
Nov.																													
Dec.																													

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BERKELEY, CALIFORNIA 94720