184-INCH SYNCHROCYCLOTRON DECOMMISSIONING*

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184-Inch Synchrocyclotron History and Description

Cyclotron design began under Prof. E. O. Lawrence in 1940 on a 1.225 M$ budget. In 1942 the machine was used to electromagnetically separate Uranium 235 from 238. 1946 magnet completion preceded first operation utilizing the principle of phase stability accelerating deuterons and alphas. Between 1955 and 1957 it was rebuilt to obtain 730 MeV protons, 460 MeV deuterons, 910 MeV alphas, and He 3 from an arc-type ion source. The pole diameter was increased to 188.75 in, the gap was reduced to 14 in, and core weight increased to 4000 tons. Auxiliary coils were added. The field was increased to 23.4 kG.

Power was supplied by DC-producing MG sets. Shims were added to the poles to obtain a field strongest at the center and decreasing radially uniformly to promote vertical focusing. The steel vacuum tank was 20 × 25 × 4 ft. RF was supplied to a dee by a vacuum tube oscillator with a variable capacitor and vibrating reed. A dummy dee grounded to the vactank was employed to provide accelerating voltage. The 15-ft-thick walls and 9-ft-thick roof were 150 lbs/cu ft reinforced concrete.

While most physics experiments were meson-related (the pi zero meson was discovered here in 1950), other activities were biophysics experiments to study effects of ionizing radiation on living tissue, pituitary studies, radiotherapy of ocular melanoma, and studies of arteriovenous malformations. Nuclear chemistry studies (fission, spallation, fragmentation) were also done. [Ref. 1]

The 184 was last run on December 29, 1987 by G. Hampton to provide a biomedical beam. For more history see Ref. 2.

Description of the Decommissioning Task

Cyclotron shutdown freed the site for construction. Decommissioning work included relocation of Van de Graaff and biomedical programs, radiation measurements, planning, estimate preparation, tooling design and procurement, scheduling, shipping arrangements, rigging studies, obtaining of permits, waste disposal coordination, and cleanup.

A series of planning meetings was held in the fall of 1987 to assign responsibilities for shielding removal, cyclotron disposal, staffing, and safety. The work was divided for purposes of assigning responsibilities, namely (a) things outside the shielding and contractors (W. Ganz); (b) the cyclotron and everything inside the shielding (R. Reimers); and (c) the shielding (S. Blair). Health and Safety (J. Haley) was involved in all activities on a daily basis. G. Hampton was in charge of supervision, building management, and operations. R. Everett was in charge of rigging, truck loading, container preparation, and fork lifts. The maintenance department reworked utilities under W. Ganz.

During decommissioning all the cyclotron parts and equipment inside the cyclotron cave were found to have induced radioactivity and were disposed of at the DOE Westinghouse Hanford Company site.

Shielding blocks were surveyed and core-sampled to determine radioisotope concentrations. They were then segregated for reuse, transfer to other DOE sites, or landfill based on activity content and shape. Items outside the shielding were nonactive and contamination-free with the exception of a Uranium spill on the east floor extending down the trench to the pits which was chipped out and removed as were several inches of the induced floor inside the shielding.

1988 Decommissioning Resources Used

(Including shielding work)	Months Effort
Riggers & Mechanical Technicians	64
Laborers	30
Engineers, Inspectors, Supervisors	24
Plumbers, Electricians, Carpenters	18
Welders	12
Health and Safety	12
Machinists, Sheet Metal, Assemblers, Mach. Repair, Photo, Communications	8

Tools and Equipment. LBL technicians used forklifts as large as 15 tons and a 14-ton "cherry picker" crane as well as the two 30-ton building cranes. Tooling to remove the 2.5 to 4-in diameter bolts holding the cyclotron together had been built in the 1950s but was discarded. It was remanufactured because without it, disassembly would have been impossible since the bolts were prestressed to as much as 200 tons apiece to resist magnetic and gravity loads. Plasma cutting equipment was purchased so that welders could cut copper and aluminum. Sawing or ultra-high-pressure waterjet use were rejected as being too slow or incompatible with waste disposal. Hoppers, crates, drums, and pallets were used to separate metals from non-metals, active items from inactive ones, toxics from non-toxics, liquids from solids, and to conform to regulatory requirements. See the "Waste" section.

Time and Space. Staging and storage space used was in or near the cyclotron building. Schedule:

Project funded, begin meson cave and Van de Graaffs' removal	Oct. 1, 1987
Complete removal of meson cave and Van de Graaff accelerators	Dec. 21, 1987
Shutdown of cyclotron beam after last radiotherapy treatment	Dec. 29, 1987
Begin disassembly of cyclotron, shielding, and Biomedical	Jan. 4, 1988
Completed removal of Biomed facilities and equipment	Feb. 28, 1988
Completed disassembly of cyclotron	Sept. 30, 1988

Funding occurred as part of Light Source site clearance. The estimate for removing items inside the shielding was 1121 k$ incl. 15% contingency. Costs were 1105 k$. Shielding costs were also under budget.

	Cyclotron acct 742605	Shielding acct 742604	Total
Stores, Misc. Supplies, Tech. Services	103k$	95k$	198k$
Blanket Orders (waste burial)	215	0	215
Purchase Orders (mostly trucking)	112	283	395
Contract Labor	51	0	51
Rigging (research techs.)	183	127	310
Maintenance (plumbing, electricians, carpentry)	106	6	112
Mech. Shops (tooling fab., welding, cutting)	131	6	137
ME (engr., planning, mgmt.), Including 40k$ Off-budget	104	19	123
Mech. Tech. (disassembly)	55	0	55
Elect. Engr., Elect. Tech., Admin.	5	3	8
Support Burden	55	5	60
Total Cost to 1/31/89	**1105k$**	**546k$**	**1651k$**

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Disassembly

Reimers, Rothfuss, Haley, and Burleigh planned disassembly. Most tooling was done by shutdown. [Ref. 3]

Cave, Equipment, and Program Disassembly. In the period Oct.–Dec. 1987 the meson cave's shielding, its Van de Graaffs, and experimental equipment were relocated, salvaged, or stored.

Cyclotron disassembly began on Jan. 4. By Feb. 2 the Biomedical treatment cave and patient facility contents including the ISAH patient positioner, radiotherapy equipment, and electronics had been relocated to the Bevalac so that the therapy/research program could continue without interruption utilizing the Bevalac's new high-intensity helium source. The cyclotron roof had been removed concurrently.

Cyclotron Disassembly. In Jan., 5000 gal of inactive PCB-free mineral cooling oil were drained from the main coils. By Feb. 28 the beamlines, strong focus section, beam regenerator, and dees had been removed. Shielding was removed at the same time. Coordination of the monitoring, segregation, and shipping of the blocks with the disassembly of the cyclotron was one of the important health and safety tasks since the cyclotron fields at times produced backgrounds which made it difficult to measure block activities sufficiently accurately to segregate properly. In these cases the blocks were taken to a shielded area to be monitored. Utilities were removed throughout the 9-month period. Asbestos-containing building walls and asbestos in the piping insulation were removed by contractors. The walls were removed last as they provided shelter, security, and containment during removals.

Surface readings on cyclotron parts varied up to 800 mR so dosimeters were read daily or hourly as required and personnel were rotated to minimize exposure. All cyclotron parts were active. The field was mostly caused by long half-life species such as Cobalt 60 which predominated. The average field in the gap was measured on Jan. 5 to be 27 mR/hr and remained so until the most active items were removed as early as possible in Feb. to minimize exposure during further disassembly of the shims, poles, and vacuum tank during the next months. Fortunately, high-intensity proton beams had ceased long ago.

The 1955–7 upgrade resulted in a design utilizing the poles as part of the vacuum barrier. This was complex to disassemble as the vacuum tank was trapped between pole disks and there was only a 14-inch gap into which one had to crawl to work. Numerous pole shims requiring weeks to remove had to be unbolted by technicians in the gap working in fields up to 50 mR/hr. LBL set upper limits of 100 mR/wk avg whole body exposure, 200 mR/mo, and 1000 mR/yr total whole body exposure. No one received this much. Volunteer technicians, machinists, and assemblers rotated through the project so no one bore a disproportionate percent of the total exposure.

Auxiliary coils (100 tons each incl. entrapped pole tips) were difficult to pull out of the vactank and took about a month to get out. The 14-ton vactank was cut in half in place, removed by the crane, cut up and shipped to the disposal site. The lower coil and its cover (150 tons) took about 5 weeks to remove. There were 11 oily 47-year-old pancakes of up to 16 tons each. The lower pole base was encased in concrete to provide a support for the coil cover. There were also many welds needing burning. Two welders were on almost continuous duty for 7 months for burning whatever could not be disassembled by other means. Natural gas, oxyacetylene, or plasma units with H-Ar mix were used.

Copper coils were plasma cut into pieces 90 inches long that would fit into the special disposal boxes [Ref. 8] designed for this job by R. Tafelski & R. Reimers as about half of the coil copper was very slightly active with surface readings up to 100 microR/hr. The copper farthest from the beam had no activity detectable by a meter reading down to .01 mR/hr and an attempt to salvage it is underway pending approval by DOE and the State of California Dept. of Health Services.

Pole bases (300 tons each) had been welded into one piece to resist dynamic and static magnetic forces. They were cut up by oxyacetylene and carbon arc units for ease of handling, loading, and shipment.

The attack on the upper coil (150 tons), upper pole tip (125 tons), and upper pole base was begun in Aug. by the riggers. The last parts were hauled away Nov. 18. The yoke remains to support the crane. Its lower portion has been cast in concrete to upgrade its stability.

Electrical and Radiation Safety

Electrical. The cyclotron building contained numerous wires, power cables, cords, motors, generators, and signal cables up to 47 years old. In this environment it was fortunate that George Hampton (who had been associated with the cyclotron since the early fifties as both an electronics technician and accelerator operator) was available to serve as on-site supervisor of the cyclotron removal.

LBL electricians were employed under his guidance to disconnect and reconnect power as needed since the lights, alarms, cranes, etc., still had to function throughout the demolition (a large part of the building and its systems was being demolished concurrently with the cyclotron's demise). No one other than electricians did electrical work. There were no electrical accidents but there were several minor outages.

Radiation Hazards. Residual gamma radiation levels from induced materials in the cyclotron measured one week after shutdown inside the cyclotron dees were from 5 to 50 mR/hr. The average field where the technicians worked was 27 mR/hr. The dees' corners were found to be about 800 mR/hr on the surface. Inside the shielding on the platform outside the cyclotron the dose rate from the induced shielding plus the induced cyclotron parts was 0.5 mR/hr average. Recent cyclotron operations did not significantly contribute to machine activation and primarily long-lived radionuclides remained. Fields exterior to the cyclotron remained fairly constant until the higher-level active parts were removed.

About 3 kg of natural uranium which had leached into concrete under the shielding prior to 1953 was found. It was a low-level swipe-free source of alpha until removed and not considered to be a personnel health hazard. The concentration over about 50 square feet averaged 2 microcuries per square foot.

Radiation Safety Procedures. Film badges were used by all persons on the project. Hand and pocket dosimeters as required were worn by those inside the shielding. Pocket dosimeters were Kit #M-187, calibrated per ANSI N12.4-1972. Workers and monitors each read their integrating light-sensitive dosimeters daily (sometimes hourly) and logged the values. Personnel were trained to read and wear them properly. Max allowed exposures were 100mR/wk, 200 mR/mo, 1000 mR/yr as noted above. To take the cyclotron apart, workers had to dismantle the machine from within the gap and vacuum tank areas using time and distance to reduce exposures. Personnel were rotated to minimize exposure.

ALARA (as low as reasonably allowable) exposure rules were explained during radiation safety training given to all personnel. This included a presentation on risks, dosimeters and biological monitoring, assignment of a film badge, a lecture on background radiation, biological effects, regulations, and procedures to minimize exposures. Eating, loitering, and nonessential personnel were excluded from inside the shielding. Items with surface readings above 5 mR/hr were moved to a cave to minimize unnecessary exposures. Radiation monitors were on site during the workday. Levels down to 10 microroentgen could be read with some meters. Items leaving the building were checked by a monitor using meters having either milli- or microroentgen/hr detection capabilities.

Air sampling was performed at the site during all dismantling. Samples were changed daily or weekly and assayed for alpha, beta, and gamma. Small concentrations of accelerator activation products, most notably Co 60, Eu 152, and Na 22, were found on the air samples.

No individual sample exceeded DOE's worker-permitted air concentration limits (DAC DOE 5480.11). Overall averages for the 10-month period were 0.3% DAC for uranium and under 0.01% DAC for Co 60, Eu 152, and Na 22. Personnel were bioassayed at the end of the project. Whole body counts at Donner Laboratory were done on those persons closest to activity during the cutting and on several others as controls. No unusual activity was observed except Cesium peaks believed attributable to Chernobyl. These Cs peaks were lower than the natural Na peaks and of no concern. High-volume filtered exhaust systems, breathing apparatus, and standby fire personnel were used during torch and plasma cutting of active items to avoid breathing any volatilized activity. A daily log of exposures was kept for 70 persons. The total personnel dose was 1.629 Rem. 32 persons had positive exposures. The avg dose for these 32 persons was 51 mR. The highest total dose for any one person for the period Jan – Oct 1988 was 165 mR.

Waste

Waste consisted almost entirely of steel, copper, aluminum, reinforced concrete, and cables.

Concrete & Steel Shielding. 494 blocks weighing 8081 tons came from cyclotron and cave walls and roofs. The cyclotron walls consisted of three rings of blocks each five feet thick. Inner ring blocks contained low-level induced material. Some of the middle ring also did, but the outer blocks contained only natural activity. The roof consisted of three layers of roof blocks each three feet thick. The inner layer contained induced low level activity. Blair and Haley's disposal study (SLAC, BNL, LANL, and landfill companies were contacted) showed that trucks were the best way to ship blocks as they involved the fewest material transfers and provided more control over the shipment. Some blocks (incl. all roof blocks) were retained for LBL reuse, others were stored at LBL or LANL, while unusable shapes were excessed. A large quantity were in the latter category and had activity levels not more than 5 microR/hr above background. These slightly active concrete shielding blocks were sent to an Alameda County landfill after exhaustive review by Calif. State Dept. of Health Services, DOE SAN, and LBL safety groups, using the draft EPA proposal on naturally-occurring and accelerator-produced radioactive material. [Ref. 7] Concrete disposal was coordinated by Haley and Blair.

Activity. Monitoring of the waste boxes' surfaces showed that 140 were below 4 mR/hr. The other eleven (holding dee and shim parts) were between 4 and 40 mR/hr at the box's surface.

Containers. 55-gal drums were too small to be useful for most items so a 55-ft^3 fire-retardant wooden caulked container (LBL # 22J1223C) was designed [Ref 7]. It received Hanford's approval as a dry active waste shipping box. 151 of these (costing $495–$682 ea) were shipped. Boxes cut costs by requiring less burial space than drums and also by minimizing cutting and shipping costs. As boxes were not allowed >20% void, we used 24 tons of diatomite filler and vibrated so it sifted down to fill voids. Pipes >1 in.were crushed. Irregular pieces were strapped to fire-retardant plywood pallets and covered with poly. Items such as alpha emitters were shipped in over 100 closed 55-gal drums.

Preparation, Shipping, & Burial. Solid waste items being shipped to the disposal site had to meet DOE and DOT requirements for preparation, identification, and cleanliness. Active parts going on pallets were cleaned and wrapped. Packages were logged, monitored, and stenciled. Contents and specific activity were recorded. LBL contracted with a certified hauler of solid active waste to move loads averaging 20 tons. Loads over about 43,000 lbs or 8-ft width needed special permits. Drums were shipped in an enclosed truck. Each truck was loaded and monitored so that the field at the truck's edge and the driver's location did not exceed levels prescribed by the DOT. Each truck to Hanford had signs indicating activity. Hanford trips cost about $1200 and took 2 days. It took 1–2 hrs to get a truck loaded, monitored, and documented. Up to 8 trucks/day were processed for a total of 274 truckloads of shielding and about 45 loads of active waste. Shipping cost varied from $9.67/ton for local trips, up to $70/ton for Richland, and $72.11/ton for LANL. Burial cost $11.66/CF ($26.07 on 10/1/88).

Waste Type	Tons	Destination	Level @ box or block surface
Concrete	3084	LBL stor. & reuse	2.0 mR/hr max
Concrete	2542	Landfill	0.005 mR/hr max
Steel & Concrete	2455	LANL	
Cyclotron Parts	900	Hanford	40.0 mR/hr max

Industrial Hygiene, Industrial Safety, and Fire Safety

Health and Safety personnel provided gloves, masks, safety shoes and glasses, tinted goggles, vacuums, filters, ear protectors, hard hats, and breathing systems. Rigging activities were the schedule-pacing item. Normally one crane was used at a time. Rigging supervisor R. Everett tested and controlled access to the cranes which were operated by his qualified technicians. M. Mikula inspected the cranes which were repaired by LBL maintenance. Forks to 15 tons were used by the riggers. Shop personnel operated 1.5-ton forks. The Fire Marshall monitored activities and provided special equipment and advice. Small oil fires erupted near flame cutting, but little smoke and no damage ensued as we had fire watches.

Summary and Acknowledgements

Decommissioning has been done safely on budget and schedule.

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