LBL-3686
3/4/75
H.A. Grunder

THE BEVALAC--A HIGH-ENERGY HEAVY-ION FACILITY

Status and Outlook

The very stimulating preceding discussions left it quite clear that experimental work in this new field is urgently needed. This state of affairs is most encouraging for an accelerator group in the process of developing the very beams needed.

The high-energy heavy-ion facility, which has commonly been referred to as the Bevalac, is a synchrotron with a $B\rho$ of 9000 [kG-in or $2.3 \cdot 10^2$ kG-m] having special injectors. As Fig. 1 shows, the synchrotron has three injectors. The 50 MeV proton injector, originally from BNL, is a tool left over from the high-energy high-intensity days of this productive synchrotron. The 20 MeV linac is a proton linac, designed so conservatively that it was possible to accelerate modest but useful beams of ^{12}C, ^{14}N, and ^{16}O as well as deuterons and alpha particles in the $2\beta\lambda$ mode. This was accomplished in 1971.

After our first trials, a suggestion made earlier by A. Ghiorso to inject from the SuperHILAC into the synchrotron was actively pursued.

A few words may be in order here as to why the SuperHILAC as injector to the Bevatron is a reasonable linkup. Heavy-ion linacs are expensive, and hence if a proper linac exists nearby, it is advisable to make use of it. The SuperHILAC can accelerate particles with a minimum ε (ε = charge/mass) of 0.05 in the tank prior to a stripper and ε = .167 in the tank following the stripper. The acceptance of these relatively low charge states, using judicious choice of other parameters, assures very high instantaneous beam fluxes--several microamperes for the heaviest ions up to several milliamperes of the lower mass ions.

Furthermore and most importantly, the SuperHILAC has a built-in macroscopic duty cycle (ignoring the 70 MHz rf structure) of 25-50%. The highest duty factor can be obtained when ε is much larger than the minimum because then the electric gradient is much lower than the maximum.

If one keeps in mind that for injection purposes in our synchrotron a duty cycle of less than 1% is required, then it becomes apparent that a happy marriage can indeed be accomplished. The SuperHILAC operates with up to 36 pulses per second, and it is planned to divert one pulse per second into the transfer line, connecting the SuperHILAC with the Bevatron. One pulse in 4 to 6 seconds goes to the Bevatron; the others are used to facilitate tuning.

Another very important factor is the injection system at the SuperHILAC. The final element is a 750 kV air-insulated Cockcroft Walton used for ions with $\epsilon \geq 0.15$. This low-voltage injector is adequate up to mass 40. For higher masses, a larger potential is needed to produce the injection velocities required by the first linac cavity. For this a 2.5 MV-compressed gas-insulated, shunt-fed Cockcroft Walton--often called a Dynamatron--is used.

We are currently installing a digital control system which is capable of adjusting injection line, rf system, stripper area parameters, kicker magnets, etc., in such a fashion that each pulse of the 36 pulses per second could in principle be a different particle and a different energy at a different target location. Hence the choice of particles and energies at the SuperHILAC and the Bevalac experimental areas is to a large extent a free parameter. In fact, apart from the Bevalac beam, we plan two separate beams in the SuperHILAC area. One easily recognizes that three particles and three energies would be highly desirable--this in turn requires a third injector. Fig. 2 shows an ultra high-intensity heaviest ion preinjector consisting of a 400 kV Cockcroft Walton and a Sloan-Lawrence or Wideröe linac to match up to the existing pre-stripper Alvarez cavity. As you might expect, the building layout is such that this third injector can be easily installed.

We recognize the extreme importance of the heavy-ion work over a large energy range. Currently we operate from ~2.4-8.5 MeV/n and from 200-2.4 GeV/n, the highest limit depending of course on the charge-state of the particle in question. It is of extreme importance that both fields prosper; as stated above, we believe both experimental areas can develop reasonably independently and hence make use of their full potential.

I shall address myself now more to the high-energy side and its capabilities as they are today and in the immediate future.

The present vacuum of the synchrotron (3×10^7 Torr) allows us only to accelerate fully stripped ions; otherwise substantial charge-exchange losses are unavoidable. Let me remind you that in a synchrotron a charge-change of one unit per particle results in its loss.

Taking this and the output of the SuperHILAC into consideration, Fig. 3 gives the expected performance over the range of ions. [The present measured performance on the target in the experimental area is given in Table 1].

The sharp decline of intensity with mass number is due primarily to two factors:

a) Ion source performance for a given ε

b) Loss due to charge-exchange (recombination)

Reduction of each of these factors is within present technology well understood and hence quite straightforward, except for monetary considerations.

Preliminary data on equilibrium charge measurements from Marrus and Gould (private communication) suggest that our goal for krypton can be reached.

TABLE I

Present (Nov. '74) Performance of Bevalac Beams

Particle	Intensity (Present)	Intensity (Expected)*
^{2}H	10^{11}	10^{11}
^{4}He	3×10^{10}	10^{11}
^{12}C	2×10^{9}	2×10^{10}
^{20}Ne	10^{9}	10^{10}
^{40}Ar	10^{6}	5×10^{8}
^{84}Kr	-----	$10^{4} - 10^{5}$

*(See Figure 3)

The largest impact would be made by improving the vacuum of the synchrotron. A careful engineering study has been made at LBL with the conclusion that a vacuum of 10^{-9} Torr is quite practical (Fig. 4). At the SuperHILAC output of 8.5 MeV/n the equilibrium charge for lead from a foilstripper would be about 72, and hence $\varepsilon \approx 1/3$. This results in a maximum energy of 1.5 GeV/n. A substantial fringe benefit from an excellent vacuum in the synchrotron is the fact that lighter ions can also be accelerated with an $\varepsilon < 1/2$; in fact, the ε (min) will be given by the acceptance of the post-stripper tank which is $\varepsilon = .167$. This will allow the synchrotron, by judicious choice of the injection energy, to deliver heavy ions in the energy region of 20-200 MeV/n. The intensity will be about 10^{11} particles per pulse up to argon.

With some obvious improvements to the injectors of the SuperHILAC, an intensity of close to 10^8 lead particles per pulse is quite feasible. A further increase in intensity would be accomplished by providing the third injector which is currently under discussion. This would result in up to a factor of 100 in improved intensities. It would have the additional very important advantage of rapid changeover from one ion source to another. The most critical component in a high-intensity, high mass particle injector is the ion source. The 2.5 MV injector does not have the space nor the power for a high-power high-lifetime ion source.

As an experimentalist, I cannot resist telling you a little bit about our operations experience with the transfer line (see Fig. 1). We did a lot of worrying over this line through a wooded hillside with odd angles to anything you may care to take as reference, which finally had to match into the existing line from the 50 MeV proton linac. Given the SuperHILAC output in terms of energy spread and emittance of ∿0.5% FWHM and πcm mrad respectively, it became clear that all bends had to be achromatic. Furthermore, we added some small but strategically distributed steering magnets. We found that in fact the fears were unfounded and the transfer line worked quite well from the beginning.

Let me finish this short discussion with a project which could materially influence the heavy-ion capability at LBL.

An Experimental SuperConducting Accelerating Ring (ESCAR) is presently under construction near the Bevatron. Planned to have a vacuum of 10^{-10} Torr, it could very well be used for a booster for the present synchrotron. The energy of ESCAR is high enough to fully strip a beam injected without stripping from the SuperHILAC. This would increase the synchrotron energy from 1.5 - 2.5 GeV/n, as well as increasing the intensity another factor of five.

It was my purpose to demonstrate to you what LBL has done, is doing, and could do with appropriate planning and support.