UC-28

LBL-20493

c.1

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

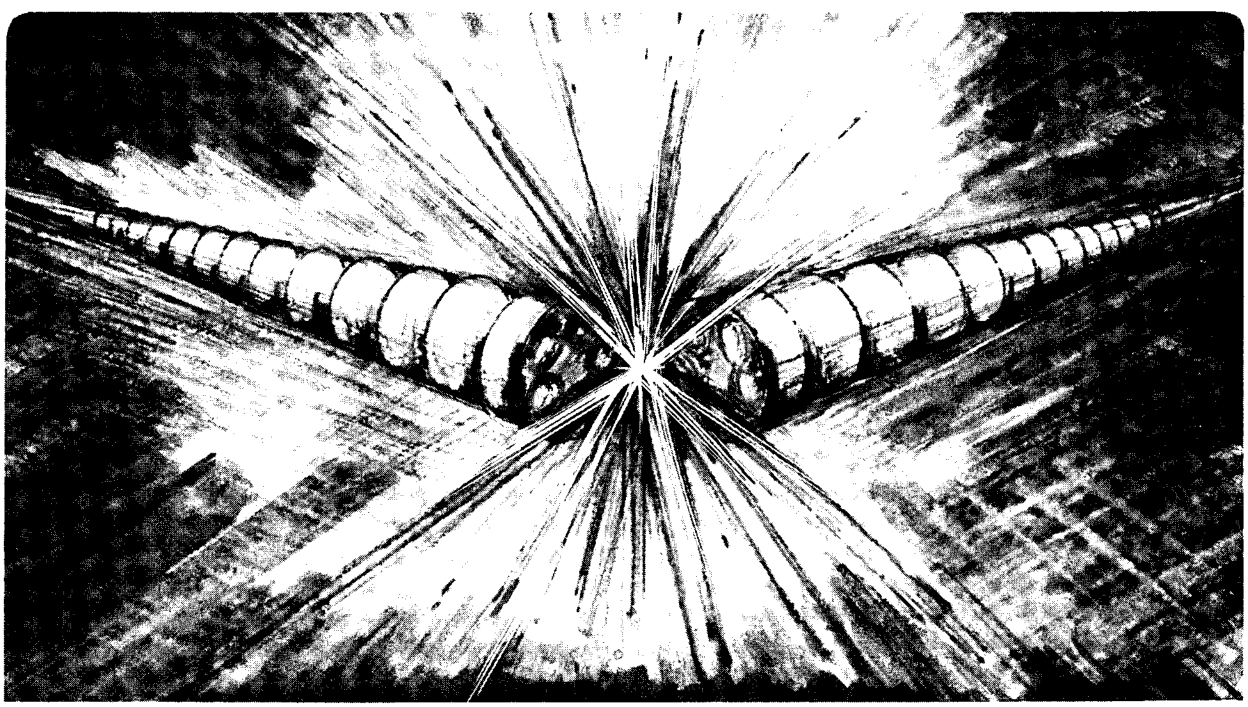
Accelerator & Fusion Research Division

Presented at the 1985 Annual Meeting of the Division of Particles and Fields, Eugene, OR, August 12-15, 1985

ACCELERATORS FOR THE STUDY OF MANY PARTICLE SYSTEMS

J.R. Alonso

August 1985



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

ACCELERATORS FOR THE STUDY OF MANY PARTICLE SYSTEMS*

Jose R. Alonso

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

Higher energy accelerators continue to play an important role in nuclear physics, probing ever more deeply into the properties and behavior of the constituents of nuclear matter. Three main projectile-types currently used are electrons, light hadrons (protons, mesons) and heavy ions; each addresses different aspects of the reaction process. Current and planned accelerators for each of these probes are discussed.

1. INTRODUCTION

Accelerators have played a key role in nuclear physics from the earliest days of the field. Each technological advance in accelerator design has opened up new discoveries, and opportunities for new views of nuclear phenomena. For example, the exquisite beam quality and fine energy resolution of modern Van de Graaffs and cyclotrons have permitted very high precision studies in nuclear structure and nuclear reaction dynamics not at all possible with earlier generations of machines addressing the same energy range[1)]. In recent years the trend has been towards using higher energy beams, with the aim of probing smaller details of nuclear constituents, or of achieving higher levels of excitation of nuclear matter. Three types of beams have emerged as being most useful for these studies; electrons, light hadrons (protons and mesons), and heavy ions. Each of these exhibits a different interaction with nuclear matter, providing complementary information about fundamental nuclear processes. In this paper we shall discuss the production of each of these beams, touching on particular characteristics of accelerators needed for each. We shall also briefly describe existing facilities, and current plans for the next generation of accelerators.

------

* Work supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Division, U.S. Department of Energy under contract number DE-AC03-76SF00098.

2. ELECTRONS

Interacting only through the electromagnetic force, electrons probe the charge carriers inside nucleons. As indicated in Figure 1, this implies interactions only with the quarks. The energy range currently of interest, up to 4 GeV, covers de Broglie wavelengths down to 0.1 fm, and hence spans the interesting range from where electrons scatter off clusters of quarks (nucleons) to where they interact with individual quarks.

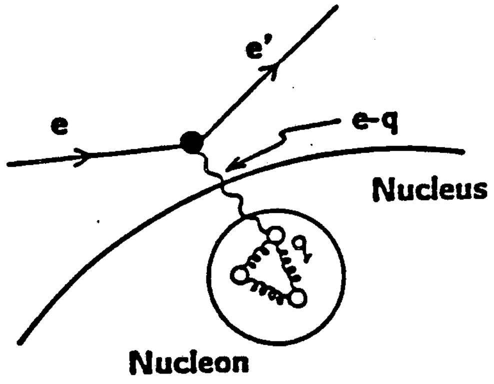


Fig. 1. Electrons couple only to charge-carriers in the nucleus.

Present-day electron accelerators in this energy range are mostly linacs, and have a very poor duty cycle; very short, intense beam bursts strike the target. This low duty cycle is mandated by the large amount of RF power needed for the acceleration process; availability of the power and the need to dissipate it in the accelerating structure have been serious technical problems. Because of the poor duty cycle, most experiments to date have been "inclusive", that is only one reaction product is detected, with the loss of detailed information about the remainder of the participants in the interaction.

There is general agreement[2)] that coincidence experiments must be performed next, requiring, ideally, a 100% duty factor. In addition, the interaction cross sections of interest are quite low, requiring high beam currents to produce acceptable data rates; currents of 100 to 200 μa are requested. In summary, the desired parameters for a new electron accelerator are: variable energies, up to 4 GeV, long duty cycle, and high intensity.

Several technologies exist today for achieving these goals. None however is without risks. Superconducting linacs, with lower power needs and very low losses,

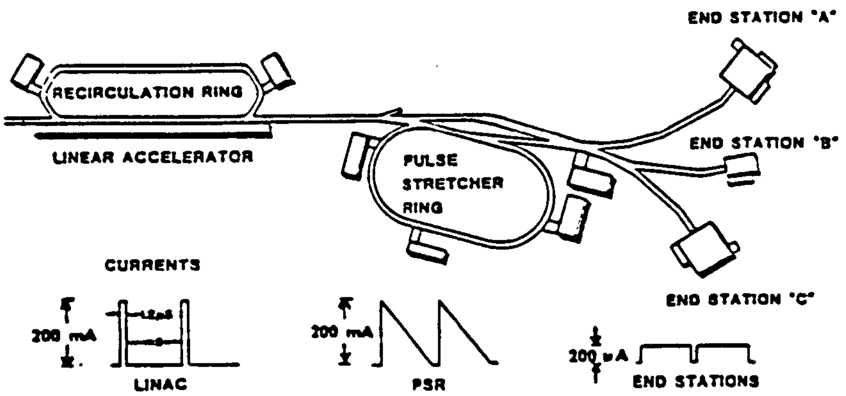


Fig. 2. Schematic layout of the CEBAF accelerator complex.

are attractive, but nothing of the required size has ever been built before. Microtrons, usually in the form of a modest linac with large 180° magnets at each end to provide multiple recirculating paths through the linac are an attractive source of CW electrons; a lower energy (60 MeV) facility at the University of Illinois stands out as an excellent demonstration of their practicability. Extending the technique to higher energies presents questions of transverse and longitudinal beam stability which are difficult to answer. A more attractive approach is to use a conventional high-current linac, followed by a pulse stretcher ring to provide a longer duty cycle. Even in this case, control of slow extraction from the stretcher ring, plus coherent and incoherent instabilities in the ring, present difficult problems. At the 1983 Particle Accelerator Conference, a full session was dedicated to the various options for CW electron accelerators[3)]. It provides interesting background for those desiring further information on the subject.

After an intensive competition, the design proposed by the Southeastern Universities Research Association (SURA) was selected by the NSAC subpanel empowered to review the various proposals. This design[4)], now called CEBAF (Continuous Electron Beam Accelerator Facility) is to be located at Newport News VA. Shown in Figure 2, it follows the third approach discussed above, namely of a linac (with one recirculating loop to double the intensity), followed by a pulse stretcher ring. The beam current profiles at various stages of the accelerator are shown in the traces below the schematic. The key to a continuous, uniform beam on target is the ability to carefully control the rate of spill of the beam from the stretcher ring.

3. LIGHT HADRONS

The interaction of hadronic probes with nuclear matter, shown schematically in Figure 3, is more complex, involving contributions from quark-quark, quark-gluon and gluon-gluon processes. Although more complicated, such strongly interacting probes have successfully yielded much experimental data on basic nuclear and nucleon properties. Different projectiles can be employed, either protons, available directly from the accelerator, or secondary particles such as mesons produced by directing the proton beam into a production target. To maximize the yield

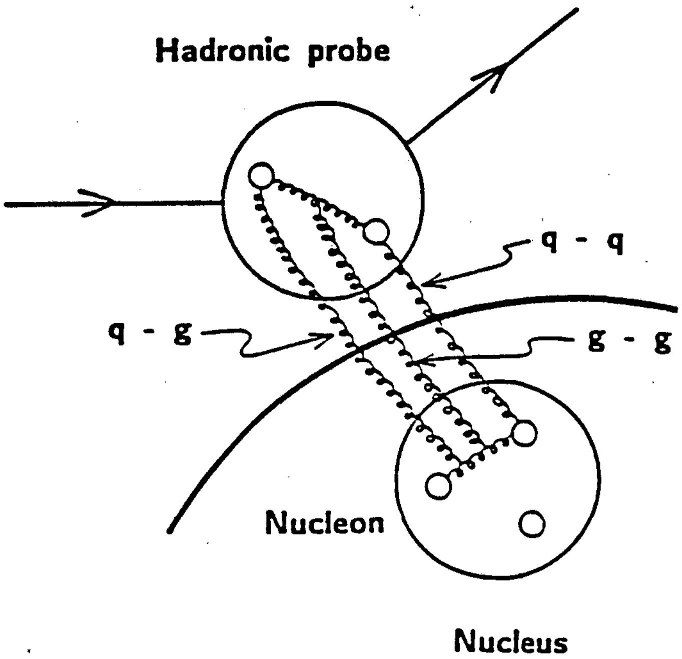


Fig. 3. Hadron projectiles interact with with both quarks and gluons in nucleons.

of such projectiles one requires energy sufficiently above the production threshold to ensure adequate phase space, and very high beam currents to overcome low production cross sections and the wide spread in production momentum and divergence. Three facilities specifically designed for high intensity meson production, LAMPF (Los Alamos), SIN (Zurich) and TRIUMF (Vancouver) have energies of 600-800 MeV, well suited for pion production, and beam currents approaching 0.5 to 1 milliamp, two to three orders of magnitude higher than previous accelerators in this energy range.

The next logical step is to provide beams of the same intensity but at an energy of around 30 GeV, to produce good fluxes of kaons and antiprotons in addition to the lighter mesons. It is not surprising that the three above-mentioned facilities all have proposals for adding boosters to their existing machines to reach the desired energy[5]. These plans make economic sense, as a significant portion of the very high cost of such a high energy facility lies in providing the high intensity beam suitable for injection into the final accelerator, a beam already available at all three of these laboratories.

Preserving the beam intensity presents some formidable problems in accelerator design. The present accelerators achieve their large currents by being continuous-beam machines, two cyclotrons (SIN and TRIUMF) and one linac (LAMPF), but continuation of these technologies to the desired energies is not practical. All are proposing synchrotrons as boosters, but must go to great lengths to achieve high intensities. A synchrotron typically injects beam over a short period, (short compared to the acceleration and spill cycle), thus losing much of the intensity available from a CW injector. To overcome this, a series of beam accumulation and bunching rings, and final beam stretchers must be employed. An example of such a design is shown in Figure 4, from the proposal for TRIUMF II[6]. A total of five new rings are proposed, first an accumulator to store 10^5 turns from the cyclotron, then a booster to raise the energy to 3 GeV. Several booster bunches are transferred to the

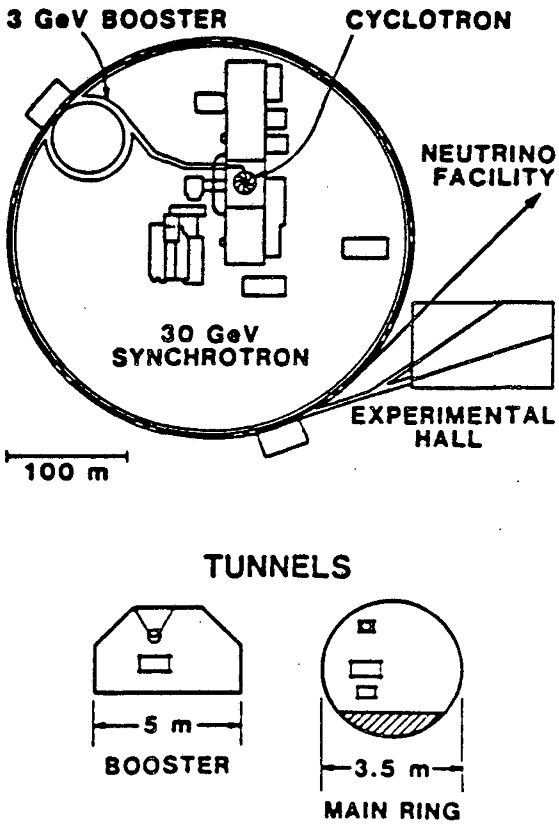


Fig. 4. Layout of TRIUMF Kaon Factory. Two new rings are located in the Booster Hall, three in the Main Ring Tunnel.

large tunnel into the collector ring, are then accelerated to 30 GeV in the driver ring and are put into the stretcher ring which peels beam out to a production target while the acceleration cycle is repeated in the other rings. This multi-stage acceleration will produce 100 μamps at 100% duty factor. (The total beam power is 3 MW!)

Although all aspects of the design are within the state of the art, there are many technical problems which must be addressed; space charge limits at injection of the rings, proper matching between rings, and most importantly, minimizing beam loss at all stages. In dealing with beam currents of this magnitude, the problems of activation of accelerator components and environs is particularly acute, both for component lifetime and for required maintenance access and handling.

4. HEAVY IONS

The interaction of a high energy heavy ion with a target nucleus is of a different nature from the reactions described above. In central (head-on) collisions, the principal aspect is the transfer of projectile kinetic energy into excitation of the overlapping nuclei. This excitation energy can be high enough to drive nuclear matter into a region of temperature and density far removed from its normal state, potentially creating environments thought to exist only in the primordial universe,

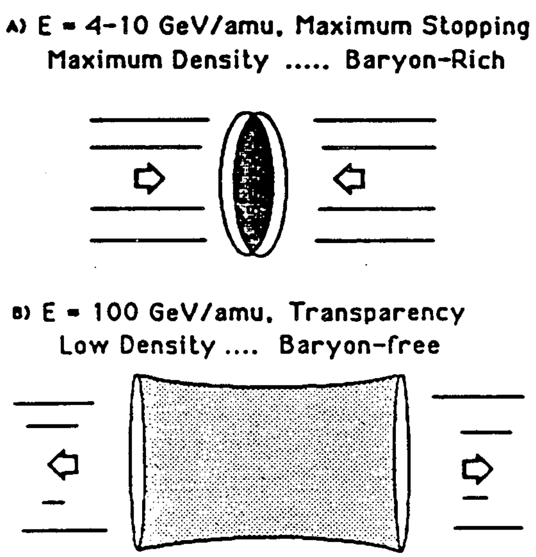


Fig. 5. Central collisions of relativistic heavy ions. A) Nuclei are stopped, creating a region of maximum density. B) Nuclei pass through each other, leaving a region of high temperature vacuum.

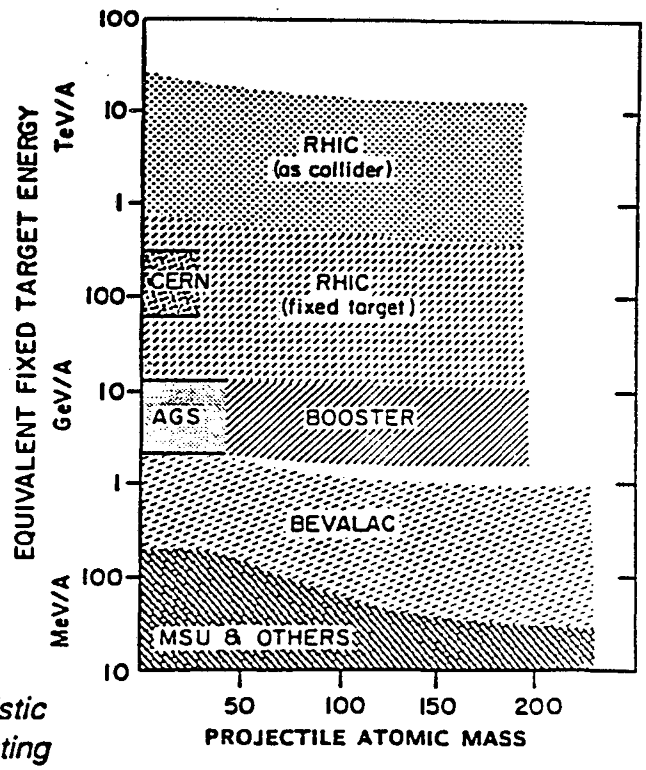


Fig. 6. Characteristics of present and planned high energy heavy ion facilities.

or in the interior of neutron stars or supernovae[7]. Energy densities achievable are also believed to be high enough to cause quark deconfinement, producing a quark-gluon plasma in the interaction region. Study of this new form of matter, and of these astrophysical environments provides a strong justification for building relativistic heavy ion accelerators.

Two distinct reaction types are envisioned, depending on the total kinetic energy available (see Figure 5). A maximum-density region is produced when the projectile has sufficient energy to just come to rest in the target nucleus. Since all the nucleons of the two nuclei remain inside the interaction region, the plasma produced is referred to as the "baryon-rich plasma". At the other extreme, a low density, high temperature region results when the kinetic energy of the incident nuclei is so high that the nuclei pass through each other, leaving behind a superheated, "baryon-free" region of space.

At the LBL Bevalac, the only facility where beams of uranium ions to lab-energies of 1 GeV/nucleon are presently available[8], experiments have demonstrated that nuclear transparency sets in for light nuclei ($A \approx 40$) at energies of a few hundred MeV/nucleon, but that top-energy mass-200 beams are stopped[9]. Best estimates of the optimum energy for production of the baryon-rich plasma are between 1 and 2 GeV/nucleon center-of-mass energy. Although Bevalac energies are generally felt to be too low to produce the plasma, nuclear densities about five-times normal have been inferred from observations[9], supporting the belief that at the right energy the plasma can in fact be created. Energies at least one to two orders of magnitude higher are deemed most desirable for studying the baryon-free plasma region.

Facilities existing and planned for study of these phenomena are shown in Figure 6. At energies above the Bevalac, the AGS at Brookhaven will be injecting light ions from their Tandem accelerators in mid 1986, and will be able to accelerate gold ions when a booster ring between the Tandem and the AGS is built, in about three to four years. To reach the energy needed to study the quark-gluon plasma the RHIC facility must be built[10]. This superconducting collider, to be located in the ISABELLE tunnel, will access the baryon-rich region when operated in a fixed-target mode, and the baryon-free region as a collider with 100-on-100 GeV/nucleon gold beams injected from the AGS. On a much earlier time scale, experiments on the CERN SPS with oxygen and possibly sulphur beams will take place in late 1986, utilizing a heavy-ion injector built by a GSI-LBL-CERN collaboration[11].

As is seen in the Brookhaven layout (Figure 7), achieving beams of these energies is a multi-stage process. (Note that the total energy for a mass 200 ion is 20 TeV!) Significant differences between heavy-ion and proton facilities come primarily in the size of the injector needed. Hydrogen is easily ionized, making an ion of q/A = 1. Producing highly ionized heavy ions of suitable intensity from an ion source is difficult; the normal route is to take lower charge states from the source and go through various stages of acceleration and stripping to eventually end up with fully stripped ions (with q/A still << 1) in the final accelerator or storage ring. Handling the stiffer ions requires larger accelerating structures, higher intensities in the earlier acceleration stages to overcome losses in stripping, and a very high synchrotron vacuum to prevent beam losses due to pickup or loss of electrons with residual gas. None of these problems is serious; there is a large body of expertise in the production and acceleration of heavy ion beams around the world.

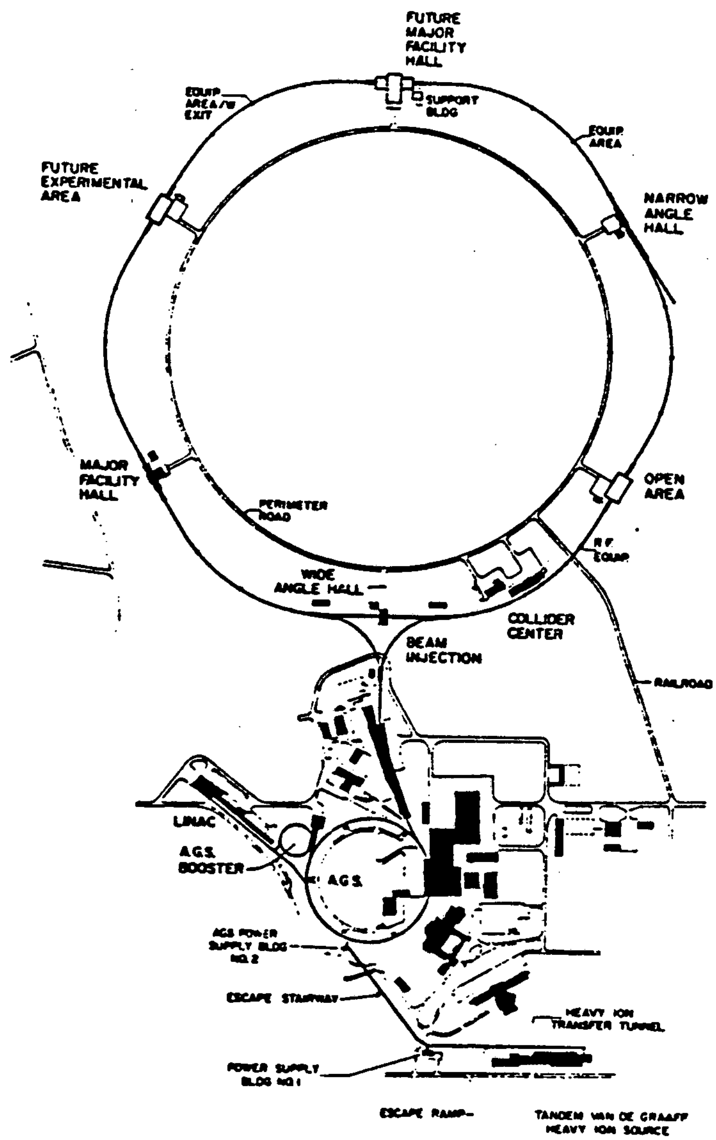


Fig. 7. Layout of the RHIC project. Ions will go from the Tandem to the Booster to the AGS and finally to the Collider.

5. SUMMARY: STATUS AND PROSPECTS FOR MAJOR NUCLEAR PHYSICS FACILITIES

The large construction projects discussed above are all in the $100M to $200M cost range; it is clear that all cannot be built at the same time in one country. In the United States, the Nuclear Science Advisory Committee (NSAC) has established priorities for the various initiatives; first continuous electron beams, then relativistic heavy ions. Although CEBAF has been a well-specified project for about two years now, it has received no construction funding to date. It is expected that the Booster for the AGS will be funded in the next few years, but prospects for construction money for RHIC are not good in the near term.

The brightest possibilities for a Kaon factory now are at TRIUMF, where enthusiastic reception by the community and funding sources seem to indicate a construction start within about two years.

6. ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of Hermann Grunder and Bev Hartline in the preparation of this paper.

7. REFERENCES

1) See for example, "Proceedings of the International Conference on Reactions Between Complex Nuclei", Robinson, R.L., McGowan, F.K., Ball, J.B., and Hamilton, J.H., eds, North Holland, (1974).

2) "The Role of Electromagnetic Interactions in Nuclear Science", report of the DOE/NSF - NSAC Subcommittee on Electromagnetic Interactions, Barnes, P.A., (Chairman), (1982), unpublished.

3) IEEE Trans. Nucl. Sci. NS-30, pp. 3250-3298, (1983).

4) "Conceptual Design Report: Continuous Electron Beam Accelerator Facility", Southeastern University Research Association, (1984), unpublished.

5) Thiessen, H.A., "A Review of Kaon Factory Proposals", IEEE Trans. Nucl. Sci. NS-32, 1601, (1985).

6) Craddock, M.K., et al, "The TRIUMF Kaon Factory", IEEE Trans. Nucl. Sci. NS-32, 1707, (1985).

7) "The Tevalac, A National Facility for Relativistic Heavy-Ion Research to 10 GeV per Nucleon with Uranium", LBL Accelerator & Fusion, and Nuclear Science Divisions, LBL-PUB-5081, (1982), unpublished.

8) Alonso, J.R., "Relativistic Uranium Beams--The Bevalac Experience", IEEE Trans. Nucl. Sci. NS-30, 1988, (1983).

9) Renfordt, R.E., Schall, D., Bock, R., Brockmann, R., Harris, J.W., Sandoval, A., Stock, R., Strobele, H., Bangert, D., Rauch, W., Odyniec, G., Pugh, H.G., Schroeder, A., Phys. Rev. Lett. 53, 763, (1984).

10) Samios, N.P., "Physics Opportunities with Relativistic Heavy Ion Accelerators", IEEE Trans. Nucl. Sci. NS-32, 3824, (1985).

11) Angert, N., et al, "A Heavy Ion Injector for the CERN Linac I", Proc. 1984 Linac Conference, Seeheim, Germany, p.374, (1984).

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720