TRIUMF–KAON PROJECT

KAON FACTORY STUDY

ACCELERATOR REVIEW COMMITTEE REPORT

TRIUMF

4004 WESBROOK MALL VANCOUVER, B.C., CANADA V6T 2A3

KAON FACTORY ENGINEERING, DESIGN & IMPACT STUDY

ACCELERATOR REVIEW COMMITTEE

Terms of Reference

The Accelerator Review Committee will report to the Steering Committee on all matters within the Engineering, Design & Impact Study relating to the KAON Factory accelerators. The Committee should assess:

1. The design of both the overall complex and the individual components.

2. The progress made during the year on each of the technical projects.

3. The degree of readiness for construction and the need in any areas for further R & D, with an indication of its importance with regard to the approval process.

4. The accuracy and completeness of the cost, schedule and manpower estimates for construction and operation.

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REPORT OF THE ACCELERATOR REVIEW COMMITTEE

February 28, 1990

Submitted by

Lee C. Teng
for the Committee

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EXECUTIVE SUMMARY

The TRIUMF-KAON Project will provide a unique world-class facility for basic research in particle and nuclear physics with performance capabilities which will not be available anywhere else. The committee unanimously agrees that the project is technically mature and urges that funding be secured to pursue the construction with the utmost urgency. The Specific Terms of References are addressed in the following.

1. Technical Assessment of the Design

Although the total design is ambitious the basic concept of the design is simple and conventional -- a 3 GeV synchrotron booster and a 30 GeV main synchrotron. To fully exploit the available beam intensity capability of more than 100 μA from the TRIUMF cyclotron each of the synchrotrons is preceded by a dc accumulator ring and the main synchrotron is also post-fitted with a dc beam spill stretcher ring to obtain a 100% duty factor making the unprecedented high intensity, high energy beam user-friendly for experiments. The use of the TRIUMF cyclotron as injector has been demonstrated to be technically feasible, more economical and, with time and experience considered, more reliable than any other newly constructed higher performance injector.

The designs of individual components have been competently pursued by the project staff. The difficult components have all been identified. These are:

- A-ring H^- stripping injection
- B-ring rf system
- B-ring and D-ring vacuum systems
- E-ring high efficiency slow extraction

Effective solutions to these difficult problems appear to have been found, although further improvements in the solutions are still expected.

2. Progress of Technical Projects During the Past Year

Several important R&D projects have been pursued and significant progress has been made during the past year in the Project Definition Study. These are:

- H^- beam extraction from the TRIUMF cyclotron
- B-ring rf system, especially the novel configuration with perpendicular biased yttrium-garnet tuners
- 1 MHz beam chopper for injection into A-ring
- B- and D-ring magnet and power supply prototypes
- Development of the vacuum chamber systems for the B- and D-rings

- Prototyping of the injection and extraction kicker systems
- Theoretical investigation of the stripping injection into A-ring and the slow extraction from the E-ring.

Most of these projects have progressed to a point such that designs of systems producing adequate performance have been demonstrated. Their continuation will undoubtedly lead to further improvements of the designs.

3. Degree of Readiness

Traditionally accelerator projects are approved, funded, and the construction staff, including the Project Leader, assembled as soon as one is convinced that solutions exist for all design problems. This is for the simple reason that the detailed improved and finalized design must be done by the Project Leader and his construction staff. These personnel are usually available only after the project funding is secured. The committee considers that the present state of design of the KAON-Project has already progressed beyond the threshold of readiness. The project now needs authorization and funding commitment so that the final construction Project Leader and staff can be attracted and engaged, otherwise the continued design effort will lose momentum.

The ongoing R&D program should continue to be strongly supported until definitive conclusions are reached. In addition to continuing the current developments, the committee recommends:

- Prototyping of magnets and power supplies of all rings with focus on the reduction of the numbers of different types of these components.
- Optimizing the location and the design of beam loss collectors.

4. Cost, Schedule and Manpower

The costing of major subsystems of the KAON-Project has been evaluated in depth. The estimates are in many cases based on quotations or budgetary estimates by industry and experiences of other laboratories. We consider the cost estimates as presented in the Project Definition Study to be on a firm footing. The allowed contingencies of 10% for conventional construction and 15-20% for technical components are sufficient.

The proposed 5-year schedule appears to be very tight. This would be adversely affected by any difficulties in the funding, staffing or supplier delivery schedules. The committee recommends an extension of the schedule by 1 year. This will not detract from the project's desirability in any way.

The manpower estimate is realistic. Personnel of proper quality must be found and brought to the project in a timely fashion.

5. Staging the Project

We have considered the possibility of carrying out the project in stages such that at each stage a reduced performance is obtained at a reduced cost, and that each intermediate stage allows for future extension of performance capabilities with added cost until the final fully scoped project as now proposed is achieved. Although such intermediate stages can be conceived, the reduction of performance capabilities at every stage is much greater than that justified by the reduction of cost and the final total cost for the total project if carried out in this staged manner will be considerably more than that estimated for constructing the project in a single stage. This is in addition to the much longer time delay until the most important physics necessitating the full-designed proton beam of 30 GeV, 100 μA, and 100% duty factor can be performed. We thus conclude that it is unwise to carry out the project in stages.

1 INTRODUCTION

The Accelerator Review Committee appointed by the Steering Committee of the TRIUMF-KAON Factory project met at TRIUMF on January 29-31, 1990 to review the project, specifically the progress and the results of the Project Definition Study (PDS) carried out in 1989. Members of the Review Committee are:

Roy Billinge	CERN
James Griffin	Fermilab
Eifionydd Jones	CERN
Motohiro Kihara	KEK
Grahame Rees	RAL
Lee Teng (Chairman)	ANL
William Weng	BNL
Bjorn Wiik	DESY

The detailed addresses and other communications information of the members are given in the list attached as Appendix 1. The Terms of Reference for the review as defined by the Steering Committee are attached as Appendix 2.

During the first one and a half days, the Committee heard reports from staff members of TRIUMF on the progress and status of the PDS including the technical design of the facility, the various R&D projects in support of the design, and the estimates of cost, schedule and manpower requirements. The committee was also given a cook's tour of the R&D projects. The remainder of the three visiting days were devoted to further discussions with the staff to clear up specific details, to informal discussions with the KAON project management, and to the preparation of the written report. The detailed program of the Review is attached as Appendix 3.

During our entire visit, the TRIUMF-KAON staff has been most cooperative and candid with all facets of discussions related to the project, and made all relevant material freely accessible. This greatly facilitated the task of review for the Committee. We are most grateful to them and specifically to the TRIUMF Director, Erich Vogt, the KAON project leader, Alan Astbury, the deputy leader, Mike Craddock, and the technical division head, Ewart Blackmore, for their hospitality, their openness, and their assistance and cooperation during the process of the review.

In this report, we address first the individual items specified in the Terms of Reference by the Steering Committee. This is then followed by some observations which we deemed important.

We want to state at the outset our unanimous conviction of the critical importance of the KAON project to the advancement of particle and nuclear physics. The project as envisioned is of the world-class and provides a unique facility for doing high precision experiments. We believe that the project should be strongly supported and should proceed with the utmost urgency.

2 ASSESSMENT OF THE DESIGN

2.1 Overall Definition and Configuration of the Complex

The KAON factory is designed to use the TRIUMF cyclotron as injector. The TRIUMF cyclotron now routinely accelerates a proton beam of ~ 150 μA current to an energy of ~ 500 MeV and has on one occasion operated at a current of 200 μA for one full week. It is thus a suitable injector for a 100 μA, 30 GeV KAON Factory. While other types of injector such as a linac could be used, the advantage of starting with a well understood and working machine outweighs other considerations.

The two step acceleration first to 3 GeV (B-Ring) then to 30 GeV (D-Ring) is well conceived both for the technological advantage and for the physics opportunity provided by the two energy levels.

In order to obtain the desired beam current output of 100 μA at a 100% duty factory the design requires dc beam accumulator rings for each of the synchrotrons (A for B and C for D) and provides a dc beam stretcher ring to produce a 100% duty factor. The design is ambitious, but should result in a facility with optimal performance. The simultaneous operation of five or more rings is by now well demonstrated and traditional at CERN, DESY, and Fermilab. These experiences point out clearly that for the operation of such an intricate complex, reliability is an extremely important factor. Furthermore, since the KAON Factory will be located in the Pacific coastal fault zone, attention must be paid to make the construction earthquake resistant.

2.2 Individual Components

2.2.1 Ring Lattices and Beam Transfers

The lattices of all five rings are chosen to be the straightforward separate-function FODO cells with straight sections formed by omitting dipoles. With a complex of five rings the ring lattices and the transfers of beam between rings should all be chosen as simple as possible. This has been done. However, it should be checked that the spacings in the lattices are adequate to accommodate transverse and longitudinal beam collimators and to provide for possible unforeseen needs.

The fast extraction and injection of beams for transfers between the rings all employ the simple kicker/septum scheme. Betatron and dispersion matchings are accomplished by all the beam transports in a simple straightforward manner.

The stripping injection into the A-ring and the resonant slow extraction from the E-ring are, by necessity, complicated and difficult. For the H^- stripping injection the concern is the beam scattering and lifetime of the stripping foil and for the slow extraction the concern is the amount of beam loss on the pre-septum. Although these have been demonstrated to be acceptable, we recommend that continued effort be spent to investigate possible improvements on these systems.

2.2.2 Magnets and Power Supplies

There has been a significant development in the level of magnet expertise, as witnessed by the pre-prototypes which have been produced in collaboration with Canadian industry. The time now seems ripe to finalize the designs and launch tender inquiries for production prototypes, with options to continue with the complete production.

A comprehensive magnetic measurement program has been foreseen. This is of particular importance for the B- and D-ring components in order to study the detailed tracking between dipoles and quadrupoles.

The proposed asymmetric excitation waveforms for the D-ring results in very important savings in the amount of rf voltage required.

The proposal to subdivide the energy-storage choke has the advantage that it will be possible to have a spare unit. Once the designs of the ac magnets have been finalized, it is necessary to examine the further subdivision of the resonant circuit, so as to reduce the peak voltage to ground which seems to be too high for the present design. Independent of this voltage, however, the Committee supports the proposal of vacuum impregnating the magnet coils.

2.2.3 Radiofrequency System

The design of the fast cycling B-ring has set very demanding requirements on the rf gradient, frequency range, tuning rate, and cavity impedance. The perpendicular-bias ferrite rf cavity developed at Los Alamos has met the gradient and frequency range requirements, but has not demonstrated the tuning rate or gap impedance. Therefore, we strongly recommend continued development of a fast cycling version of the Los Alamos cavity design. Continued development of feedback systems directed at lowering the cavity gap impedance should also be carried out. Successful completion of these developments is critical to the operation of the B-ring in its presently proposed configuration.

Development of suitably modified versions of the AECL/HERA 53 MHz rf cavity for use in the remaining rings is a reasonable choice. However, it may be necessary to develop an alternative input coupling system for operation above 60 MHz. Such a design should be straightforward.

The number and complexity of the many rf feedback systems proposed for each rf station is very large, but it may not be necessary for all such systems to be operational for initial machine operation at low intensity. Continued development and implementation of these feedback systems will become necessary as beam intensity is increased during the first years of operation. To this end it may be reasonable to consider individual series tube modulators for each cavity rather than the presently proposed individual anode power supplies.

2.2.4 Vacuum System and Beam Instabilities

These inter-related topics have been considered carefully for all five rings of the KAON Factory. Their importance to the full-current operation of the project cannot be overstressed. Both single particle and collective instabilities have been studied in some depth; the various instability mechanisms have been identified, appropriate control systems investigated, and the specifications set for the design of the individual vacuum systems.

Appropriate now would be a review of each loss mechanism, identifying the associated control system hardware and the stage of commissioning when it is likely to be required. Thus, for example, it is important from the early stages of commissioning to have control of the betatron tunes, but installing longitudinal emittance blowup cavities in the C-ring may be deferred until there is some evidence for the existence of the longitudinal microwave instability.

The instability studies have identified the constraints on the vacuum chamber components. In particular, for the B- and the D-rings, the use of ceramic vacuum chambers was proposed for the dipoles and quadrupoles with special radiofrequency shields to provide a low impedance environment to the circulating beam. The Review Committee agrees with this choice. The design goal for the rings is a stable working vacuum in the pressure range 10^{-7} to 10^{-9} Torr. Aside from the B- and D-ring magnets stainless steel chamber is used wherever possible.

2.2.5 Controls and Instrumentation

The Controls Group of the PDS team has done a thorough study in surveying the existing practices in accelerator control of major accelerator laboratories. The approach of the accelerator control system presented reflects the modern trend of recognizing major functional areas and providing support for them on equal basis. These functional areas include Master Timing System, Maintenance Support System, Development Support System, Analog Display System, etc. The design also accords sufficient importance to the role of protocols, standards, and human interfaces. The PDS team realizes the complexity and intricacy of the system requirements and has a fair realistic estimation of the manpower necessary to build such a system.

A generic control system design is presented. It is recommended that the team further develop the concept into concrete realization of the design to meet KAON requirements by actually selecting commercially available products for work stations, local area network, device controller, etc. Only then, the actual performance requirement and limitation can be specified in terms of number of channels, data communication rate, data base structure, etc., and possible improvements and solutions found. For equipment tests and early commissioning, it is useful to provide independent control and operation of individual accelerator systems and partial manual control, if necessary.

The diagnostics group gave a thorough presentation on the requirements and design of the instrumentations for observation of basic beam properties such as: intensity, profile, position, distribution, and losses. They are aware of the state-of-the-art design and utilization of those devices and their performance limitations. However, the adequacy of the instrumentation has to be judged by the operational requirements in terms of emittance measurement, machine function measurements, orbit correction and damping of instabilities, etc. Close discussion with control and operation groups to assess the design requirements of those instruments to develop operation scenarios and specification of control algorithms should be of immediate concern.

Because of the importance and the numbers required of the beam position monitor system, it would be prudent to start the prototyping effort to design, construct, and test several beam position monitors including the mechanical design, vacuum box, data acquisition, and processing electronics. Tests of the linear response, calibration of electrode centerline, and quality of data are all important factors for acceptance of the design. In addition, the cost optimization for mass production must also be considered.

3 PROGRESS ON TECHNICAL PROJECTS

The concentration on the Project Definition Study during the last year resulted in major progresses on many fronts in the design of the project. We list the beam transports between the rings, the injection and extraction systems, the beam chopping reconfiguration of the rings, and the increased effort in the study of the rf systems, just to name a few. Most of these design features were discussed in Section 2 above. Here we will only make some observations of the progress of the R&D projects during the last year.

3.1 Radiofrequency System

The primary rf R&D effort has been the development of a rapid tuning system for the Los Alamos cavity and the development of a suitable higher order mode damping system for this cavity, and presumably for the AECL/HERA cavity as well. Substantial progress is evident toward each of these goals, but each remains to be completed. The high-order-mode damper development has demonstrated the adequacy of the scheme under consideration at lower power level. But the main problem of adapting this damping structure to the cavity in such a way that it will work reliably at high voltage and power levels has yet to be addressed.

3.2 Dual Frequency Magnet Power Supply

The dual frequency asymmetric powering of the D-ring magnets has been demonstrated using four NINA dipoles and an old capacitor bank. The magnets are energized along a half-cycle of a 7.5 Hz sinusoid, and de-energized along that of a 15 Hz sinusoid giving a cycle time of 1/10 second. A new capacitor bank is built to continue the study. The dual frequency mode of excitation reduces the rate of acceleration and hence, eases the requirements on the rf system. The study should be continued to determine the stability and the precision of the excitation and to study the problem of tracking between the quadrupoles and the dipoles.

3.3 Vacuum System

The complete system has been specified for all five rings and, in addition, prototype ceramic chambers have been produced. One prototype has been produced by Rutherford Appleton Laboratory, UK, following the design used previously on ISIS. However, the KAON Factory chamber has a much smaller cross-section and hence, requires a more careful assembly of the individual ceramic sections in the furnace used to produce the glazed bondings. This chamber was satisfactorily completed in January 1990 together with its RF shield and is now being shipped to TRIUMF.

The second prototype is being produced by Science Applications Inc., and involves much longer individual sections, approximately four times those used by RAL. Wall thicknesses have been increased by allowing the inner wall dimensions to follow the maximum beam envelopes. Seven prototypes of one type have met the desired tolerances. A different type of rf shield is proposed, with metallic strips "painted" directly on the ceramic. Further R&D is needed on the SAIC chamber before a full assessment can be made of its potential.

3.4 1 MHz Beam Chopper

A novel type of beam chopper has been proposed for the injection line between the cyclotron and the A-ring. This is an interesting and impressive development project. Low power tests on a full size model have provided a proof of principle. Next, a full high power test is planned and should be completed within a few months.

3.5 H^- Extraction from the Cyclotron

This project is well advanced with proof of principle established. During the PDS, the full extraction line from the cyclotron has been designed, and the expected extracted beam parameters have been estimated through beam dynamics studies. These estimates have allowed the design of the A-ring injection scheme to proceed. The H^- beam has been extracted past the electrostatic strip-septum with good efficiency and good beam quality. Full test of the H^- extraction channel is dictated by the cyclotron's experimental schedule and will not be possible for some time.

4 DEGREE OF READINESS AND FURTHER R&D NEEDS

Typical of all accelerator projects, the evolution and improvement of the design of a component continue until it is necessary to freeze the design to begin production. The measure of readiness is determined by whether a design is available which will produce the minimum required performance. The PDS has established proofs of principle, demonstrated feasibility and resulted in the build up of accelerator expertise in several crucial topics. These include rf systems, beam stabilities, fast pulsed kickers and magnets, vacuum and so on.

Thus, in our opinion, the KAON project is ready for approval. It is expected that continuing development and design modification will further improve the performance and the reliability and perhaps even lower the cost of the component device.

It is also in the nature of an accelerator project that construction staffing and serious industrial support can be forthcoming only after it is funded. These factors will generally produce additional beneficial modifications and improvements on the design. We therefore believe that the KAON project should be funded as soon as possible.

Several R&D projects must be continued or initiated to further define and improve the design before the component production can begin. Among these projects all of which must be pursued with vigor, we suggest the following:

4.1 Prototyping and Studies of Magnets and Power Supplies

This program should be speeded up to check fabrication method (in more industrialized manner), mechanical accuracy, field quality etc. This applies especially to the ramped magnets of the B- and the D-rings. The eddy current losses in the magnet yoke and the coil conductor are uncertain by a factor of 1.5 to 2 and should be checked experimentally. Several prototypes will be needed to fix the design.

The decision of a single-frequency power supply for the B-ring is good, but more R&D should be done to check the stability to develop a feedback system, etc. Tracking between quadrupoles and dipoles should be investigated and resolved. This problem is especially troublesome for the dual frequency case of the D-ring. The separate choke design is good, but possible unequal couplings leading to spurious modes should be checked.

Performance of the accelerators are eventually determined by the aperture available to the beam and the spacings between magnets in the lattice for future installation of unexpected things. All these should be thoroughly investigated.

4.2 Continuing the R&D for Both Perpendicular and Parallel Bias RF Cavities

Between the rf systems of the B- and the D-rings the former is by far the more demanding. Neither the Los Alamos nor the AECL/HERA rf cavity system has been developed to the point where production can begin. Of the two, completion of a working prototype of the Los Alamos cavity is clearly the most pressing problem.

While it is possible to enlarge the B-ring to accommodate a lower voltage gradient set of longer cavities of a more conventional design, the prospect is certainly not a pleasant one. We therefore consider the demonstration of the high gradient perpendicular-bias fast tuning cavity a most urgent matter.

4.3 Studies and Design of Beam Loss Detection and Containment Systems

In a high intensity accelerator beam loss detection, control and containment are essential for avoiding excessive induced radioactivity and damage of machine components by the beam. These affect directly the healthy operation of the machine and the maintenance of components which may be radioactive. For containment of beam loss one employs beam steering and focusing systems, longitudinal and transverse beam collimators and scrapers, and aperture defining blocks. Different types of radiation detectors are placed at various locations in the tunnels to identify regions of high beam loss. Although standard designs of all these instrumentation exist, the use, the type, the amount and the placement of these instrumentation must be designed specifically for individual accelerators. Because of the importance of these systems to the reliable high current operation of the KAON we recommend that a comprehensive program be started for the detailed study of the design, the effectiveness and the efficiency of these systems.

Topics that need to be addressed in this area are the following:

- the design philosophy for the repair of radioactive damaged components; a decision on whether any enlargement of the tunnel is needed in the vicinity of the beam loss points,

- a detailed analysis of beam loss collection schemes, and

- a review of the magnet lattice requirements in the light of these considerations.

Related topics are the degree of expansion required in storage areas and workshop facilities, including those for the handling of radioactive components.

5 COST, SCHEDULE, AND MANPOWER

Based on prototype design the cost of major subsystems has been evaluated in depth. These estimates are in many cases based on quotations and budgetary estimates by industry and they also incorporate the experience of other laboratories which have built and procured similar components in the past. We thus consider the cost estimate of the facility, as presented in the Project Definition Study, to be on a firm footing. However, KAON, is an ambitious project and its realization will require an extension of existing accelerator technologies. Thus as the project progresses this may necessitate changes to the present design. However the committee feels that such eventualities are covered by the listed contingencies which are 10% for the conventional construction, 15% for magnets and power supplies and 20% for the remaining technical systems.

The total in-house effort needed to construct the facility has been estimated to be 1700 man years. In addition another 1000 man years will be required to continue the cyclotron operation, to continue R&D on various accelerator components and for the initial commissioning of the accelerator complex. The TRIUMF management estimates that nearly 50% of the total effort can be met by the existing staff making it necessary to recruit on the order of 300 new staff members. Based on their experience the committee concurs with the estimated total effort. However, note that in parallel to constructing the accelerator complex the laboratory also prepares for a vigorous experimental program. Thus the build-up of new staff might be even higher than estimated by the management.

The proposal schedule calls for the first extracted beam at 30 GeV five years after project approval, followed by the start up of the experimental program six months later. This is an extremely tight schedule and it can only be met provided:

- The present Project Definition Study is followed by an aggressive R&D program aimed at system integration and the construction of prototype components.

- A project leader is designated at the earliest time, even before project approval if possible. The project leader must guide the follow up of the Project Definition Study.

- Full use is made of designs of all systems already existing in other laboratories.
- Recruitment of staff is proceeding in a timely fashion.

Needless to say, this requires continued R&D funding to follow up the PDS. Experience shows that this R&D funding in support of construction is required throughout the construction period. For most accelerator projects the design and R&D manpower at the beginning will develop after commissioning into manpower for the operation, maintenance and future improvement and extension of the facility. It is therefore convenient to set up a parallel R&D/operating budget which continues from the present PDS level and grows into the full operating/maintenance/improvement budget after the facility starts operation.

6 SOME ADDITIONAL OBSERVATIONS

With five rings and six beam transfers, it is imperative that efforts be applied to unify the designs of similar components, such as magnets, power supplies, beam detectors, etc. Otherwise, the number of types of each component will be much too large. Although using the same or similar design for components of different applications will make the component appear over-designed for some applications hence not minimized in cost, the increased cost is likely offset by the savings in multiple engineering, modelling, prototype, tooling, and the reduction in necessary numbers of spare units. More important than cost is the fact that manufacturing larger numbers of identical or similar units will invariably lead to higher quality and greater reliability.

The same reasoning concludes that one should try to derive the maximum benefit from the existing experience available in other laboratories, including copying those time-tested designs. All these will lead to components with high performance and reliability which are of paramount importance for a machine of this complexity.

The committee also notes that although the acceleration of polarized beam will add to the usefulness of the facility, it must be regarded as of secondary priority, e.g., as a future accelerator improvement project.

There are several possible modes of construction staging which will yield at each stage a machine with reduced performance but at a reduced cost and reduced complexity which will nevertheless be capable of future modification and extension into the fully staged five ring machine as designed. As intermediate stages we list the following possibilities.

- Omitting the beam spill stretching E-ring. This is the most easily detached part of the five ring complex and leads to substantial cost savings and even greater reduction in the construction, commissioning, and operating effort needed for the high efficiency slow extraction system. But the reduction in performance is rather severe, one is left only with fast extracted beam directly from the D-ring.

- One may regain a low duty factor, lower intensity slow extracted beam by flat-topping the D-ring.

- One can omit the C-ring and flat-bottom the D-ring to accumulate some pulses from B. This will further reduce the beam intensity at the savings of the cost of the C-ring.

These we mention as possible staging modes for the project if funds or staffing circumstances absolutely necessitate them. But it is obvious that the performance reductions are severe and we do not consider any of these as desirable. In fact, they are to be avoided if at all possible and the full project should be funded ab initio.