Report of the
Accelerator Technical Advisory Committee for the
JAERI-KEK Joint Project

May 21-23, 2002
KEK
Tsukuba, Japan

Table of Contents

Page

EXECUTIVE SUMMARY

The Accelerator Technical Advisory Committee (ATAC) for the JAERI-KEK Joint Project (JKJ) held its first meeting over the period May 21-23, 2002 at the KEK laboratory in Tsukuba, Japan.

The JKJ Project combines aspects of the previously proposed Japanese Hadron Facility by KEK and the Neutron Science Project by JAERI. The new project is being undertaken jointly by KEK and JAERI and will be constructed at the JAERI site in Tokai. The project is now approved with a budget of 133.5 billion yen for Phase 1. Construction was initiated in 2001 and Phase 1 is scheduled for completion in 2006. Phase 2 carries an additional 55.5 billion yen and is not yet approved for construction. The committee also notes that the JKJ Project will provide Japan with a preeminent facility in high energy, nuclear, and materials sciences.

The ATAC heard presentations concerned with the technical design and fabrication of the accelerator facilities supporting the project as described in the very complete and detailed Technical Design Report released in April 2002. In addition the committee saw a significant amount of advanced hardware existing on the KEK site. The committee did not specifically review the cost of the facility nor the construction, installation, and commissioning schedule. Presentations and committee discussion concentrated on the Phase 1 project. The committee congratulates the project team on its very excellent progress in developing the design of the accelerator complex and initiating construction.

General Comments

The JKJ Project is comprised of a state-of-the-art proton accelerator complex with associated experimental facilities. The accelerator facility, which was the subject of this review, consists of a 400 MeV linac, a 3 GeV rapid cycling synchrotron, and a 50 GeV synchrotron. The two synchrotrons are designed to provide extremely high average beam power: 1 MW from the 3 GeV ring and 0.75 MW from the 50 GeV ring. This performance is beyond that of any other facilities operational in the world today. Notable pieces of the project that are currently delayed into Phase 2 include an additional 200 MeV of superconducting linac and associated waste transmutation area, an upgrade of the Main Ring energy from ~40 to 50 GeV, and a neutrino beam line supporting long baseline neutrino experiments.

Performance criteria have been established for all the accelerators and advanced conceptual designs are complete. Major components have been prototyped, and in the case of the linac and the 50 GeV Main Ring many are on order.

The accelerator design and construction present a large number of challenges, most of which are associated with the very high average beam power required from the facility. The design, construction, installation, and (ultimately) commissioning are being under taken by a staff numbering approximately 110 people. In the experience of the committee this appears to be a modest number for such an ambitious and complex facility , constructed over a five-year time frame. The committee also notes that a project of this scope comes along only infrequently and presents unique opportunities for the training of young people in the design, construction, and operation of a major accelerator facility—people who become a resource for the future.

The committee heard very little on strategies for commissioning of the accelerator complex. While we did not expect significant discussion at this meeting, the committee suggests that the project team assure that designs choices are made consistent with expeditious commissioning of the facility. Presentations on commissioning strategies will become an appropriate part of future meetings of the ATAC.

Linac

The linac consists of an (H^-) ion source (IS), drift tube (DTL), separated drift tube (SDTL), and annular coupled structure (ACS) linacs. The final energy in Phase 1 is 400 MeV, with a peak current of 50 mA, and a repetition rate of 50 Hz. The design is quite advanced and procurement of the DTL and SDTL has begun. An ion source that nearly meets specified requirements also exists and studies of the source and associated low energy beam transport (LEBT) line are underway. The first DTL tank is assembled and has been aligned successfully. The first two SDTL modules have been processed to approximately three times the required power. R&D aimed at finalizing the ACS is underway. The committee offers the following specific comments and recommendations with respect to the linac:

- The design and hardware assembled to date are basically sound and likely to deliver the specified performance.
- **Pulse-to-pulse energy variation needs to be further understood and communicated to the RCS design group.**
- Analysis of impact of errors and vibrations has been initiated and needs to be continued.
- The committee supports and ***recommends the undertaking a complete end-to-end (IS to RCS) multiparticle simulation, considering realistic conditions, of the linac as soon as possible.***
- The MEBT chopper rise and fall time is a potential source of halo generation. The committee suggests evaluation of solutions to avoid partially kicked bunches propagating through the linac.
- The Cesium seeded filament source meets all project performance tests with the exception of a modest shortfall in lifetime. ***The committee recommends an experiment to determine whether such a source is compatible with RFQ operations.***
- The LEBT assumes effective beam neutralization. This assumption needs to be supported by numerical estimation or simulation.
- The committee encourages further investigation of a design with a tapered gradient in the upstream end of the ACS to shorten a dedicated matching section.

Rapid Cycling Synchrotron (RCS)

The RCS is a state-of-the-art, high power, synchrotron. It is specified as providing a 3 GeV proton beam with 8.3×10^{13} protons per pulse at 25 Hz repetition rate. The total delivered beam power is 1 MW.

Multiturn injection from the linac is utilized in the RCS. Transverse and longitudinal painting, plus a second harmonic cavity, are employed to minimize the impact of space-charge forces within the beam. Acceleration utilizes a novel RF system. The lattice is of the "flexible momentum compaction" type producing a higher transition energy than would be achievable with a more traditional FODO type lattice.

A complete design concept for the RCS exists and there is active R&D on the magnet, power supply, injection, and RF systems. **However, procurements of major RCS components have not yet been initiated and so opportunities still exist for modest design enhancements or modifications.** With this thought in mind the committee offers the following comments and recommendations:

- The committee supports and ***recommend a*** *reexamination of the optics of the linac to RCS* ***transfer lines, in close collaboration with the Linac group,*** with a goal towards improving the acceptance. The committee supports retention of momentum collimation in any modified design.
- The committee ***recommends consideration of lattice modification for the RCS based on the use of regular FODO cells in the arcs***. Such a lattice modification could offer benefits in terms of increased acceptance, increased dynamic aperture, increased dispersion-free free space, and perhaps simpler tuning**. Any such benefits will have to be balanced against complications in the longitudinal match of the RCS to 50 GeV Main Ring transfer.**
- Control of the tunes during RCS acceleration does not exist. The committee believes this could compromise RCS performance and ***recommends the design team think about options for introducing this capability.***
- The committee ***recommends the use of programmable correction dipoles in the RCS***.
- Longitudinal painting is planned to generate bunches with a hole in the longitudinal phase plane. The attention of the project team is drawn to the fact that stability problems have been encountered in the CERN PS Booster under such conditions, especially when combined with dual harmonic operations.
- The RF system is based on very novel, low Q, based resonators. The heavy beamloading in the cavities will be wide-band, which will create a unique stability and beamloading compensation problem. The committee ***recommends studying the problem analytically, and identifying opportunities for experiments in existing accelerators to develop further understanding.***

- The committee ***recommends the development of both tune-shift and impedance budgets for the RCS.*** The committee also requests a comprehensive presentation at next year's meeting on the subjects of impedances, instabilities, and feedback.
- **The committee is not convinced of the necessity for the stranded cable in the RCS dipole magnet.**
- **The ratio between the aperture of the RCS and the collimator set position is smaller than in some comparable machines. The committee suggests communications with ISIS on potential collimator configurations.**

50 GeV Main Ring

The 50 GeV Main Ring is the second state-of-the-art, high power, synchrotron in the project. It is specified as providing 50 GeV proton beam with 3.3×10^{14} protons per pulse with a 0.3 Hz repetition rate. The total delivered beam power is 0.75 MW.

Injection utilizes four beam transfers from the RCS. Beam is either fast or slow extracted from the 50 GeV ring in support of a variety of high energy and nuclear physics experiments. The lattice is of the "flexible momentum compaction" type that allows acceleration of the beam without crossing transition. In phase 1 the energy of the Main Ring is limited to approximately 40 GeV by the absence of an energy storage device required to reduce voltage modulation on the power grid.

A complete design for the 50 GeV Main Ring exists and procurements of magnets and power supply systems have been initiated. R&D continues in parallel on magnet, power supply, and RF systems. The committee offers the following comments and recommendations with respect to the 50 GeV Main Ring:

- The design and hardware assembled to date are basically sound and likely to deliver the specified performance.
- **The duty factor for slow extracted beam seems to be low**. The committee suggests looking at whether the acceleration cycle could be reduced by shortening the ramp down period. It might also be valuable to examine how the duty factor depends on the peak energy.
- The committee ***recommends due consideration is taken of minimizing electron cloud formation, for example using in-situ baking of the vacuum tube, vacuum chamber surface treatment, etc.***
- **Impedances, instabilities, and damper specifications require close attention.** The committee did not receive any input on these topics at this review and requests a comprehensive presentation at next year's meeting. Furthermore, the committee ***recommends the development of both tune-shift and impedance budgets for the 50 GeV Main Ring.***
- The committee encourages consideration of a second harmonic RF cavity in the Main Ring as part of the initial configuration.

- **The committee notes that a unique opportunity may exist for JKJ staff to participate in the commissioning of the slow extraction system for the 120 GeV Main Injector Ring at Fermilab later this year.**

1 INTRODUCTION

The Accelerator Technical Advisory Committee (ATAC) for the JKJ Project held its first meeting over the period May 21-23, 2002 at the KEK laboratory in Tsukuba, Japan. The committee heard presentations from project staff on the 21^{st} through early afternoon on the 22^{nd}, held several closed sessions to discussion reactions and opinions, and presented a verbal report to project management on the 23^{rd}. The meeting agenda is attached as Appendix 3.1.

The ATAC wishes to express it appreciation to KEK and JAERI management for their hospitality during this meeting, and to both the management and staff for their comprehensive presentations.

Committee members in attendance at this meeting included: R. Garoby/CERN, I. Gardner/RAL(deputy chair), S. Holmes/Fermilab (chair), A. Noda/Kyoto, and J. Wei/BNL.

Committee members absent from this meeting included: K. Bongardt/Juelich, D. Gurd/ORNL, T. Roser/BNL, L. Young/LANL. All absent members reviewed the Technical Design Report and provided written input to the full committee in advance of the review. In addition all members participated in the preparation of this report.

This report summarizes the May 21-23 meeting. The body of this report consists of the committee's findings and recommendations related to the major accelerator components of the JKJ Project. Also included are discussions of the control system and beam dynamics topics that span the individual accelerators and allow the complex to operate efficiently as a whole. Because of the absence of significant control system expertise on the ATAC at this meeting, Chapter 2.4 is provided by D. Gurd based on his review of the Technical Design Report.

2 FINDINGS AND RECOMMENDATIONS

2.1 Linac

The Linac part of the JKJ accelerator complex is extensively described in the Technical Design Report that was communicated to the members of the Accelerator Technical Advisory Committee a few weeks before these meetings. This has been supplemented with direct interview of members of the project team and 5 oral presentations on Tuesday 21 and Wednesday 22, May:

- o Project overview by Y. Yamazaki,
- o Linac beam dynamics by M. Ikegami,
- o Linac RF systems by S. Yamaguchi,
- o Linac accelerator components by K. Hasegawa,
- o Beam instrumentation in the Linac by J. Kishiro.

Moreover, we were shown the related hardware available on the KEK site, namely the filament ion source with the LEBT, pre-chopper and 30 mA RFQ, the DTL1, a prototype SDTL tank, a number of 324 MHz klystrons and numerous other remarkable RF equipment. Controls and Vacuum issues were treated collectively with the synchrotrons. This gave us a rather complete overview of the design principles used in the Linac and its components, as well as in the degree of advancement in their construction and test.

Findings

An H- source is needed to provide ~60 mA beam current during the pulses. A filament and an RF driven versions are under development. Using Cesium, the RF driven source has already achieved the required level of performance, except for lifetime which is still too small.

The LEBT, with solenoid focusing, has a pre-chopper to modulate the injection energy into the following RFQ with rise and fall time below 50 ns. The operation with beam of a similar pre-chopper has been demonstrated recently on the HIMAC injector.

Two models of 4 vanes 324 MHz RFQs with pi mode stabilizing loops and electromagnetic quadrupoles are being built. The first one, made for 30 mA beam current, has already been fully characterized. A new one, better optimized for operation at the nominal beam current of 50 mA is presently under construction.

After the RFQ, at 3 MeV, a MEBT equipped with RF deflectors improves the beam time structure. The 15 ns rise and fall times of the field in the deflectors will partly kick a few bunches at the limits of the beam pulse.

At the end of the chopping line, the beam enters a Drift Tube Linac (DTL) structure. Three successive DTL tanks increase the beam energy up to 50 MeV. Low level measurements are presently being made on DTL1. Preliminary measurements have also been made of the mechanical vibrations generated by pulsing the current in the quadrupoles, and deformations have been found to be negligible.

At 50 MeV, the type of accelerating structures is changed to Separated Drift Tube Linac (SDTL). Transverse focusing is also changed from FODO with a 2-beta-lambda period to Doublet with a period of 7-beta-lambda. The RF frequency is kept constant at this transition. The first of these SDTL tanks has already been built and successfully conditioned up to 3 times the nominal input RF power.

Above 190 MeV, Annular Coupled Structures (ACS) operating at 972 MHz are used. A 15.9 m long MEBT2, equipped with buncher cavities is needed for longitudinal matching. The bunch current is tripled inside these third harmonic resonators. The principle of the ACS structure with its bridge coupler has been demonstrated at 1296 MHz. A 972 MHz prototype is under construction.

At 400 MeV the L3BT beam line transports and adapts the beam to the Rapid Cycling Synchrotron (RCS). Energy spread is reduced with a set of two debuncher cavities. Because of the 150 mA bunch current, space charge effects have to be seriously taken into account.

The design of the 324 MHz klystron is fully mastered and a number of units have already been produced. The development of the 972 MHz klystron is progressing satisfyingly.

Waveguide components are designed and prototypes are, or will soon be available.

The transient beam loading at 1.2 MHz induced in the accelerating structures by the chopped beam has been investigated by the project team and the effect found negligible.

The low level RF system of the Linac is specified for stabilizing the field in the RF structures with 1% accuracy in amplitude and 1 degree in phase. Phase stabilized optical fibers are used for distributing the reference 12 MHz signal. Modern digital electronics is employed for I/Q regulation, permitting high performance and sophisticated controls.

Beam instrumentation and controls are in the early stages of development.

Comments

The degree of advancement of the low energy part of the Linac is very convincing. An H- source with useable characteristics has been shown to work, although the use of Cesium raises questions of ageing and degradation of the following RFQ.

Concerning the 3 MeV chopping line and its RF deflectors, we expressed our worries about the particles trajectories in the Linac and the losses due to the partially kicked bunches.

The committee highly appreciates the flexibility provided by the electromagnetic magnets in the DTL.

The experimental tests of the low energy front end that is being assembled at KEK are very important and strongly supported by the ATAC members. In a similar way, the low power measurements of the first DTL tank (accelerating up to 20 MeV) should soon be followed by high power tests.

Preliminary measurements of mechanical vibrations are encouraging, but further investigation on a full size DTL tank have to be planned.

The high gradient capability of the SDTL prototype comfortably exceeds the nominal requirement.

However, the foreseen front-to-end particle tracking simulations are absolutely necessary to validate all design choices, especially in MEBT1 at 3 MeV and in MEBT2 at 190 MeV.

The design of the low level RF system is convincing.

Two subjects could not be treated, and should be reviewed at a later date:

- debunching in the L3BT transfer line where space charge effects are still visible,
- the SC Linac

Recommendations

The detailed design of the main RF components and subsystems of the Linac have already been completed, and prototypes of many of them have been built and tested. Their measured characteristics and the quality of their realization leaves us no doubt that they will perform as expected in their foreseen role. (Good advancement of the ion sources development, remarkable performance of the 30 mA RFQ, conditioning of an SDTL prototype up to 3 times the nominal input power, realization of full performance 324 MHz klystrons, RF deflecting cavities, high quality low level RF electronics, beam instrumentation, etc.).

In the design of the Linac accelerator itself, the explanations we were given let us think that the choices made are workable. However, we consider that some subjects still deserve further analysis, for which we make the following suggestions:

- Experimental tests are needed for a well-informed decision on the operational consequences of operating a high gradient RFQ on the H- beam from a source using Cesium.
- Solutions to avoid partially kicked bunches should be pursued.
- The possibility should be considered of using ACS sections with a progressively increasing gradient to shorten the MEBT2 for the transition at 190 MeV between SDTL and ACS,
- Impact of errors and vibrations, and pulse to pulse energy variation need further investigation,
- As planned by the project team, complete front to end computer simulations of the Linac including the L3BT line are absolutely necessary, including space charge effects and machine imperfections, and using “realistic” particle distributions.

2.2 3 GeV Rapid Cycling Synchrotron (RCS)

Findings/Comments

Lattice

A good description of the RCS lattice and the injection painting scheme was provided. The injection scheme has been well studied and appears to give good flexibility, allowing both correlated and anti-correlated painting. In spite of up to 20 foil hits per proton the predicted foil temperature is low. Multiple foil hits may lead to some beam near the acceptance limits but initial checks do not show this.

However, the H^- beam first passes through the upstream quadrupole of a cell and the extraction of the $H^{o/-}$ is via a downstream quadrupole. This links the injection and ring optics, making a change of the tunes during injection complex. The experience on ISIS is that beam loss is reduced by control of the tunes & closed orbits over injection and early acceleration.

The 7 families of quadrupoles looks complex and while the advantages are given as flexibility in tune value it does not appear possible to change the Q values dynamically throughout the acceleration cycle. This again is an important feature on ISIS and while the space charge tune shift at 0.16 is much less on the RCS it may be worth adding fine tuning control to give +/- 0.2 delta Q over the acceleration cycle.

Acceleration

Restricted straight section space has lead to the use of broadband low Q cavities that achieve considerably higher accelerating fields than ferrite loaded cavities. Promising results are reported from prototypes. However, their use on high intensity beams must be carefully studied along with their use for the provision of combined harmonics. An early test on a high intensity ring would be useful.

Extraction

The extraction system uses 7 kicker magnets and a septum magnet split into 3 sections. Kicker impedance must be considered along with the stray field produced by the section of septum magnet closest to the circulating beam orbit, if this has not already been done.

Magnets

Magnet designs are considered straight forward with the number of quadrupole types kept to 4. The main magnets in the RCS are powered by individual, tracking, resonant ‘White’ circuits. Although stranded aluminum cable is being proposed for the 25 Hz magnets to reduce the eddy currents in the windings it was not clear that this was essential or cost effective. A technique for brazed joins was not explained. The committee notes that B-dot for ISIS and JKJ are similar and ISIS uses plane copper.

Vacuum
A novel design of ceramic vacuum chamber is proposed for the 25 Hz magnets to eliminate eddy current effects. Ceramic sections are joined by a metal braze which is also consistent with attaching metal end flanges to the vessel. Metalization of the ends for attaching these flanges is reported to be inconsistent with the use of a glass frit for joining the ceramic sections. Small magnetic effects from the brazed joints are not expected.

Copper strips deposited on the outer surface of the ceramic vessels provide a RF screen. The RF continuity connections using capacitors have to be designed along with a method of checking their integrity in a radiation area. Low electron emission is achieved on the inside from a TiN coating which will also prevent charge build up on the inside of the vessel. Impedance measurements should be continued.

The method of vessel support in the magnets must be decided bearing in mind the magnet vibration and the method of interconnection between vessels. If bellows are used to relieve strains then RF screens may be necessary in the bellows.

Lost Beam Collectors
Studies of lost beam collection indicate a high efficiency of collection. However, the Apertures and Collimation limits for the Primary, Secondary and Aperture limits are 324, ~385 and 486 pi mm mr which can be compared with those proposed for the ESS Accumulator Rings of 260, 285, 480 pi mm mr.

(Incidentally, the Injection Foil appears to be inside the collimator value of 360 pi mm mr whereas it is normally outside the relevant y or x acceptance of 486 pi mm mr).

Adjustable collectors are the desirable solution and the methods for ensuring the arrival of the lost beam on the collectors should be considered. On ISIS this is achieved by small, dynamic adjustment of the closed orbit corrector magnets away from the settings that provide the minimum closed orbit error. Beam losses are adjusted while the facility is operating at 50 Hz using 1 pulse in 50 with different closed orbit or Q values.

The mechanical design of the collector straight should allow the use of active, but not remote handling, techniques. Interaction between JKJ and ISIS staff may prove fruitful.

General
Further consideration should be given to the methods to be used for commissioning, fault finding and error states. Personnel protection must be given the highest priority and consideration be given to machine equipment protection from lost beam. The use of intercepting or destructive beam monitoring will often flood or overload the machine protection systems but their use is essential.

While the machine shielding must comply with the local regulations a good rule of thumb is to ensure that full beam loss in any area does not create radiation levels of greater than 250 μSv/h in occupied areas.

Adequate room and lifting gear should be provided for the installation of temporary shielding for all accelerator components above the100 MeV point.

Recommendations

Injection
Consideration of a modified lattice (as mentioned in the beam dynamics section) using FODO arcs and matched doublet straights might create longer, free regions in the straight sections and improve the injection scheme.

Tune Control
Consider adding fine tuning control to give +/- 0.2 delta Q over the acceleration cycle.

2.3 50 GeV Main Ring

Findings/Comments

The 50 GeV synchrotron is a long desired machine not only in Japan but also from the world and will have a great impact on particle and nuclear physics when completed. Its design is presented at the Accelerator Technical Advisory Committee held at KEK from the 21st to the 23rd in May. Many remarkable attainments in component development are presented together with elaborate written up proposal for the entire project. Congratulation from the heart is presented at first and then some findings/comments on the 50 GeV main ring are summarized here.

Lattice

The lattice design with three-fold symmetry composed of usual cells of FODO structure plus missing bend cell in addition to straight sections realizes the imaginary γ_t lattice, which is free from the transition energy in the entire energy range to be treated. The idea to adopt the imaginary γ_t is very interesting. The lattice preserves rather long straight sections of 116 m in order to include all the equipments for slow extraction such as an electrostatic septum (ESS), magnetic septa (SM) and bump magnets in the same straight section and results in a low packing factor of the dipole in the circumference, which resulted in a rather high maximum magnetic field as 1.9 T.

The operating point in betatron tune diagram is considered only in rather close region to the extraction resonance of 22.33. In order to make margin to the resonance during injection and acceleration, possibility of moving from appropriately far tune to the resonance after completion of acceleration should also be studied. Even with these flexibilities, the 11 quadrupole families seem to be still too much. Careful studies on this problem is required and reasonable scheme how to adjust these large number of quadrupoles at the commissioning stage based on observed beam parameters should be at least clarified even if the reduction of the number of quadrupole families is not feasible.

Magnet

Judging from the results of the field measurement of radial distribution, it is well anticipated that the iron has already saturated to some extent at the excitation level of 50 GeV. On the other hand, the end cut structure of Rogowski's shape is reported to be difficult to be adopted in order to avoid vibration in the iron core during ramping. Careful consideration on the saturation effect at the higher excitation level is needed so as to realize smooth acceleration up to the top energy.

The measured results of quadrupole magnet with use of the rotating coils should be carefully investigated from the point of view of horizontal useful aperture size. Considering the fact that horizontal useful aperture (132 mm) is a little bit larger than the bore diameter of the quadrupole magnet (130 mm), field measurement system utilizing only the rotating coil system will not provide us enough information to evaluate the homogeneity of the field gradient and its effective length in the whole useful aperture region. Complementary measurement system of the field gradient (G) and its integration along magnet axis(GL) in the entire useful aperture region should be considered at least to evaluate the magnet design even if only the rotation coil is used for the routine measurements of all the quadrupole magnets. Twin translation coils might be one of possible candidates. Radial structure of not only field gradient in the central region, but also the integrated gradient along the beam axis should be paid attention. End cut shape of the quadrupole magnets should be carefully investigated from this point of view with use of the above system.

Septum magnet with opposite field is interesting, but the effect on the circulating beam of the remnant field at injection energy should be carefully investigated in connection to the near by resonance.

Acceleration

The excitation pattern of the magnet should be flexible. The patterns of ramping up and down should be able to be given independently by putting independent timing signals for triggering, which is inevitable to realize flexible change between slow and fast extractions. Possibility of ramping down much faster should also be studied in order to increase the duty factor of the extracted beam. Possibility of enlarging the duty factor for lower beam energy than 50 GeV should also be seriously investigated. Large duty factor of the beam is no less important than high beam intensity for the case of counter experiments.

High field gradient cavity (~40 kV/m) loaded with magnetic alloy (MA) should be carefully studied both theoretically and experimentally from beam dynamical point of view. Beam loading of RF system is very high and feed-forward system should also be carefully studied.

Beam Instability

High proton beam intensity of 3.3×10^{14} per pulse is considered to easily induce coherent instability. Cures for the instabilities with use of 6-pole, 8-pole, feedback damping or any other should be proposed.

Scheme of increasing of the longitudinal emittance is required to be studied. Scheme with use of higher harmonics should be studied in more quantitative way. Study on beam dynamics including beam instabilities and possible single particle resonances should be described much in detail.

Vacuum

Required vacuum pressure should be carefully studied in connection with vacuum instabilities.

During slow beam extraction, the beam will be debunched and becomes sensitive to electron cloud build up. For example, possibility of coating the vacuum chamber with TiN and in-situ baking should be studied.

Proposed chamber thickness of 2 mm needs careful study about the stiffness especially the case when Ti alloy is adopted.

Beam Monitor

Specifications for beam diagnostics seem to be not so clear. Development of beam monitors for such high intensity machine should be described more clearly. The beam profile monitor with use of a sheet beam is very interesting and continuous R&D including the high intensity test at AGS is to be considered.

Beam Extraction

Slow beam extraction assuming zero chromaticity in horizontal direction should require further studies about the transition from finite chromaticity to suppress instabilities at the injection energy. The high voltage of ESS should not increase more than 200 kV if enough turn separation is realized, which might cause problem in feed through of high voltage.

General

Movement of the ring tunnel after magnet alignment is one of the most important issues to be paid attention. Careful studies about the ground motion is required and enough time to wait the shrinkage of the concrete before performing precise alignment should be reserved after the completion of the tunnel.
Role of the abort system of 3 GeV beam in the main ring should be clearly described. Share of the role with 50 GeV abort system should also be presented.

In order to make hands-on maintenance possible, all kickers should be designed without active elements such as Thyratrons or IGBTs in the tunnel. Front end electronics of the beam monitors should also be located outside of the ring tunnel. Location of various equipments should be carefully investigated from the point of view of avoiding the radiation damage and performing hand on maintenance.

Recommendations

1. Effect of the space charge force might become negligible at 50 GeV, but slow beam extraction with such a high average current of 15 μA has not yet been realized. The experience of slow beam extraction at high energy synchrotron as FNAL should be referenced although difference of adopted resonance exists.
2. Tune flexibility during injection and acceleration is worth investigation as well as

commissioning strategy of adjustment of 11 quadrupole families.

3. Further beam dynamics studies on beam instabilities and so on are required.

2.3 Control System

It looks as if the controls team is off to an excellent start. The Technical Design Report is quite comprehensive, the issues identified and understood, and a coherent and workable approach is outlined. Excellent work!!

For successful integration of a complex network of accelerators such as is proposed, it is essential that there be one Controls Group Leader, with responsibility over control of all subsystems (vacuum, power supplies, RF, etc) and all accelerators (linac, RCS, MR). Consideration should be given to including even conventional facilities (power, HVAC, etc), neutron choppers and the spallation target etc as well. This is implied in the brief discussion of organization, but is not explicit.

Although not in the Controls Section, the discussion of the commissioning strategy is valuable, and should inform the control system design. The section (5.1) on "Approach and Philosophy" appears to be well thought out and quite complete. The simple philosophical statement that "All information should be seen in the Control Room" is correct - however it is notoriously difficult to implement in the face of pressures both for cost savings and from groups having independent lower-level systems such as PLCs or intelligent devices. A lesson frequently learned the hard way in accelerator laboratories but not always applied is: "No hidden data." Work hard to enforce this approach.

The idea of using commercial products rather than in-house design wherever possible is common practice in new facilities, and correct here. But the advantage can be lost if care is not take to resist the "too new" – products whose long-term reliability or market endurance is not proven. The layered design approach is the norm today – the only reasonable approach. The choice of EPICS is obvious, and will be beneficial. Remember that one of the principle benefits of EPICS is not technical – it is participation in an active community of shared interest and resource. Don't solve problems that have already been addressed by others – make use of your worldwide EPICS collaborators. I particularly applaud the decision to use Ethernet as a fieldbus wherever possible, and to limit the number of Ethernet controllers. This and other choices of standards will pay dividends, but will require effort and strong management support to make stick.

The discussion of module selection, drivers and driver development is excellent. I would emphasize again however the potential value of tracking what is already available in the EPICS community. For example, the OMS stepping motor driver is widely used in the EPICS community and may meet the needs of this project. The discussion of PLCs and their interfaces is very well done. I believe a statement of when, where and why PLCs will be used – i.e. for what systems and under what circumstances – would be useful. There is a risk of an unnecessary (and costly) PLC layer turning up with subsystems only because the subsystem engineers are suspicious of or unfamiliar with the capabilities of EPICS. A PLC layer should be there only where appropriate, and as a result of an agreement between the controls team and subsystem designers.

Network design appears well thought out, however the bulleted list of “requirements and design criteria” (p5-5) does not really include requirements. Requirements should be stated first in terms of estimated bandwidth and reliability (and possibly security??) before arguing that these requirements can be met using the following design criteria, and then providing the bullets. A case needs to be made for the network redundancy that is assumed. The APS is fully redundant but SNS felt that commercial network equipment is sufficiently reliable, and that the extra equipment needed to provide redundancy might itself compromise reliability. I offer no opinion, but some cost/benefit analysis would be helpful. Perhaps more should be said about security requirements and a plan to meet them. The idea of a separate PLC network was new to me and interesting. The proposed ClassB private IP address space is a common and flexible strategy appropriate for the scale of this project.

The discussion of Tools, Applications and the Operator Interface demonstrates the good understanding of the issues one would expect from this experienced team. The decisions and the decision process are sound. The choice of SADScript, which worked very well for KEKB and played a large role in its early commissioning success, is excellent. Detailed comments on some of these issues have been listed separately.

There is a good discussion of timing system requirements (Section 6) and a preliminary indication of how these could be met (without any discussion of technology.) Nothing is mentioned about line synchronization, although it may be implied in the comments on neutron choppers. Are there challenges relating to the synchronization of line frequency, neutron choppers, RF power and extraction? Feedback is mentioned as a requirement, but there is little discussion of specific requirements (other than for low-level RF feedback, section 3.1.3.6.3 for example). EPICS of course cannot be used for fast feedback – how will any fast feedback requirements be met? The controls interface to the chopper drive is not discussed, but is critical to operating mode selection. The discussion of commissioning strategy touches on the operational modes, and correctly links these to machine protection considerations. The section on machine protection (9.2.3) needs to be expanded, although the initial breakdown into run permit, fast protect auto-rest and fast protect latched seems entirely appropriate. The section on Personnel Safety (Section 8) considers only shielding requirements – there is no mention of access control. Will this be the responsibility of the Controls Group?

There is a very useful discussion of the different databases that will be required, their requirements and a start at considering how they might be implemented. This work should continue at an intense level – the importance of having a coherent database strategy in place very early in the project, with the static database for management in place and being populated as the design proceeds, cannot be stressed too highly. This will require work on the part of the database team, but also commitment on the part of the entire project and strong support from management. The dividends will be enormous.

Congratulations to the controls team for an excellent start.

2.5 Beam Dynamics

Findings

An impressive amount of design and beam-dynamics work has been done for the entire accelerator. Due to the limited time, many subjects were not presented at the review. Excellent work was documented in the Technical Design Report.

The design philosophy and general lattice layout of the accelerator facility have been presented. Structural transitions occur at kinetic energies of 50 keV (Ion source to RFQ), 3 MeV (RFQ to DTL), 50 MeV (DTL to SDTL), 191 MeV (SDTL to ACS), 400 MeV (ACS to RCS), and 3 GeV (RCS to MR). Major changes of transverse focusing type occur at energies of 50 MeV (singlet to doublet) and 400 MeV (doublet to singlet). Major changes of acceleration frequency occur at 191 MeV (324 to 972 MHz) and 400 MeV (972 to 1.23 MHz). The linac contains a transport section (3.0-meter MEBT1 at 3 MeV) for chopping and matching, and a section (15.9-meter MEBT2 at 191 MeV) for matching upon frequency transition. The Linac to RCS transfer line needs special emphasis due to the 150 mA bunch current and 100 kW average beam power. The Rapid-cycling-synchrotron (RCS) lattice is designed with arc achromats containing missing dipoles (six FODO-cells per arc including two missing-dipole cells) to increase the transition energy and synchrotron frequency. The Main Ring lattice is designed with arc achromats containing missing-dipoles to avoid crossing transition during acceleration.

The linac is designed for H- operation at high peak intensity (50 mA). The RCS is designed for a fast ramping (25 Hz) with high intensity (8.3×10^{13} proton per pulse). The Main Ring is designed for a high intensity (3.3×10^{14} proton per pulse) and high brightness (4×10^{12} per eVs at tens of GeV).

Results of beam dynamics studies were presented for linac, RCS, and Main Ring. Various computer-simulation programs have been used for the study of different sections of the accelerator including RFQ, linac, transport lines, and rings. An analysis of expected beam loss and radio-activation was performed for the entire facility.

For the linac and connecting transport lines, single-particle dynamics and 2-D space-charge forces were included in the basic design. Study on beam halo using 3-D space-charge model has been started (MEBT to ACS). Effects of field errors and misalignments have been partially studied. Analysis on pulse-to-pulse beam centroid jitters, in both transverse and longitudinal directions, was not reported in detail. On the linac structure, it was reported that the performance of the present design is superior to the alternative structure with DTL directly connecting to ACS at a higher energy around 100 MeV.

For the Rapid-cycling-synchrotron, the tuning range of the basic lattice, not including injection chicane and bumps, was explored. Separate studies on injection, RF, collimation, and extraction were presented. High collimation efficiency (higher than 98%) was reported. Except for space charge, collective effects were not presented. Optical perturbation from the injection chicane and painting bumps was reported to be 20 – 30%. A significant reduction in dynamic aperture and a large off-momentum beta-beating were reported when the two-family sextupole chromatic correction was applied.

For the Main Ring, a large range of adjustment for the vertical tune and the transition energy was reported. Effects of magnetic errors, misalignments, and space charge were studied. Intensity-dependent matching was reported to be necessary. Effects of beam-environment coupling and electron cloud were not reported.

For the transport lines connecting the rings with linac and experimental facilities, the lattice design is not yet finalized. Beam collimation was planned. The impact of extraction-kicker malfunction is under evaluation.

<u>Comments</u>

Lattice optimization is crucial to the achievement of ultimate low-loss performance of the accelerator facility. There seems to be room for optimization on the lattice design. Detailed study is desirable considering detailed 3-D space charge and lattice perturbations.

1) A long MEBT1 with tight focusing for chopping and anti-chopping at low energy (3 MeV) is a potential source of beam halo generation. It is desirable to reserve the optics capability of bypassing anti-chopping and possibly chopping in MEBT1, and explore a faster LEBT chopping with the goal of a shorter rise/fall time and a low beam-in-gap level. A comparison between the present design and an alternative, shorter MEBT1 (for matching and diagnostics only) with gentle focusing can be beneficial if a realistic initial distribution and a 3-D space-charge model are used for beam-halo investigation.

2) The change of accelerating structure, the transition from singlet to doublet focusing at an energy of 50 MeV, and the three-time frequency jump are sources of possible beam mismatch and halo generation. Detailed study is desirable to ensure adequate acceptance for beam halo.

3) An all-FODO, smooth lattice is desirable for the L3BT line for matching, collimation, diagnostics, and operational robustness. Capability of transverse and momentum collimation is highly desirable.

4) For the RCS ring, an alternative is to use regular FODO cell instead of missing-dipole cell for the arc. Possible advantage can be (a) an increase of the acceptance of the arc by reducing both horizontal and vertical beta-function and the dispersion; (b) an increase in the length of dispersion-free straight sections without significant increase in the total ring circumference; (c) improvement of correction efficiency including both higher-order chromaticity and off-momentum betatron function; (d) allowing chromatic sextupoles to be distributed across the arc to avoid deterioration of the dynamic aperture; and (e) a reduction of power-supply families of the quadrupoles. The disadvantage of such a scheme is the lack of synchrotron-frequency enhancement, whose impact can possibly be minimized by maintaining a high betatron tune. (For example, with a five-cell arc of cell length 11 m, the matched, peak beta-function and dispersion can be reduced by about 30%. The length of each dispersion-free section can be increased from 3 to 4 cells. The reduction in synchrotron frequency can be about 20%.) A long, uninterrupted straight

section possibly realized by a doublet at the cost of increased quadrupole strengths can be advantageous, possibly separating injection from lattice tuning (especially since an accurate phase advance is needed for the vertical painting), reducing chicane perturbation, allowing flexible collimator placement for increased efficiency, and reducing the number of magnets between secondary collimators. The optics and the extraction-channel acceptance need to be designed such that beam loss is tolerable when one kicker misfires, and the beam location on neutron target does not move significantly upon kicker malfunction.

We endorse the design of Main Ring lattice to avoid transition crossing. For both RCS and Main Ring, it is important to ensure adequate adjustability in the transverse (especially horizontal) tunes without compromising injection, collimation, and extraction efficiency. The nominal working points should be optimized considering nearby structure resonances and possible driving harmonics, sensitivity to injection chicane and bump perturbation, sensitivity to collective effects including space charge resonances and instabilities.

It is useful to monitor across the entire acceleration cycle the evolution of key, expected beam and machine parameters including the controlled and uncontrolled beam loss, the transverse and longitudinal acceptances, beam emittances and pulse-to-pulse centroid jitters, to ensure adequate machine protection, tolerable radio-activation, and adequate acceptance-to-emittance ratios. An end-to-end simulation needs to be performed as soon as possible, possibly with measured distribution from the ion source, the expected field errors, and collective effects. Such an end-to-end simulation ensures design consistency across the entire accelerator facility, and can provide valuable insights to the basic design choices.

For the linac, it is necessary to develop a comprehensive "error budget" including field errors, misalignment, and mechanisms (e.g. RF control inaccuracy and mechanical vibrations) leading to pulse-to-pulse centroid variation. Studies should be performed to evaluate sensitivity of beam transmission, emittance growth, and halo generation to key quantities including beam intensity, initial beam condition, and major sources of error. Detailed 3-D simulation with focus on beam halo should be performed, possibly with more than one set of codes for verification (e.g., TOUTATIS and latest PARMTEQ for RFQ, latest PARMILA, IMPACT, and LINSAC for the rest of linac), to ensure satisfaction of stringent beam-loss requirements.

For the RCS and Main Ring, it is necessary to develop a "tune-shift budget" to monitor leading single-particle mechanisms that may compromise machine performance, including space-charge force, chromatic effects, magnetic imperfections (geometrical, saturation, ramp-dependent, and magnet-to-magnet tracking, remnant fields from septa), magnetic fringe field, kinematic nonlinearity, chicane and bump orbit perturbation, magnet misalignments, and electron-cloud neutralization. Efforts need to be made to reduce the impact from the major sources if their impact is significant.

For the RCS and Main Ring, it is necessary to develop an "impedance budget" to monitor leading beam-environment coupling, and for the control of collective effects and instabilities. Efforts need to be made to confirm by measurement, and to reduce impedance of leading sources (e.g. the impedance of the extraction kicker modules and their power supplies) if their impact is significant.

For the RCS, efforts need to be made to ensure an operationally reliable and robust transverse painting, and possible momentum painting with an energy spreader.

Given the physical uncertainty of the regime of ultra-high intensity, efforts should continuously be made develop and compare various computer simulation codes, and to benchmark these codes with experimental machine study.

<u>Recommendations</u>

1. Continue the excellent design optimization, and assess possible advantage of alternative lattice options.
2. Complete and refine end-to-end simulation incorporating realistic conditions.
3. Continue and extend beam-dynamics studies, especially on collective effects, instabilities, and electron-cloud effects.

3 Appendix: Agenda for the 1st ATAC meeting (ver. 5/14/02)

Accelerator Technical Advisory Committee

Meeting Room, Bldg. 3

May 21st (Tuesday)

8:45~9:00	Welcome address:
9:00~9:15	Executive Session
9:15~9:30	(Coffee break)
9:30~10:00	Overview: Y. Yamazaki
10:00~10:45	Linac beam dynamics design: M. Ikegami
10:45~11:30	RCS beam dynamics design: F. Noda, K. Yamamoto
11:30~12:15	MR beam dynamics design: S. Machida
12:15~14:00	(Lunch)
14:00~14:20	Linac RF: S. Yamaguchi
14:20~14:40	Linac accelerator components: K. Hasegawa
14:40~15:10	Ring RF: M. Yoshii
15:10~15:40	RCS Magnet System: N. Tani, Y. Watanabe
15:40~16:10	(Coffee Break)
16:10~16:25	MR Magnets: K. Niki
16:25~16:40	MR Magnet Power Supply: M. Muto
16:40~17:00	Injection/Extraction: I. Sugai, I. Sakai
17:00~17:10	Slow extraction: M. Tomizawa
17:10~17:30	Vacuum: Y. Saitoh
17:30~18:00	Executive Session

May 22nd (Wednesday)

8:45~9:05	Monitor: J. Kishiro, N. Hayashi
9:05~9:25	Control: to be proposed by J. Chiba
9:25~10:00	Beam Loss and Strategies for its Mitigation: Y. Mori
10:00~10:30	(Coffee Break)
10:30~12:00	Executive Session and/or Reserved for the other presentations to be requested by ATAC and/or ATAC Report Write-up
12:00~13:30	(Lunch)
13:30~18:00	ATAC Report Write-up

May 23rd(Thurdsday)

9:00~11:00	Executive Session and/or ATAC Report Write-up
11:00-12:00	Closing meeting with project management
12:00~13:30	(Lunch)
13:30 - 14:30	Executive session

14:30 Adjourn