Chapter 5

Time Schedule and Cost Estimation

5.1 Time Schedule

The time schedule of the JLC-I project is shown in Fig. 5.1. According to the schedule required by the physics study group, the discovery run should commence around the year 2000. The construction of the straight tunnel for the main linacs is estimated to take three years, which are enough for the parallel construction of the detector-hall and the tunnels for the injector complex. The fabrication of the accelerator components for the startup energy needs four years, excluding the preparatory period for the plant and equipment investment, which match the schedule for the civil engineering. The installation of the machine components will be carried out in parallel with the component fabrication and will be finished no later than two years after the completion of the civil engineering. This schedule assumes that the construction speed is determined not by the funding but solely by technical considerations.

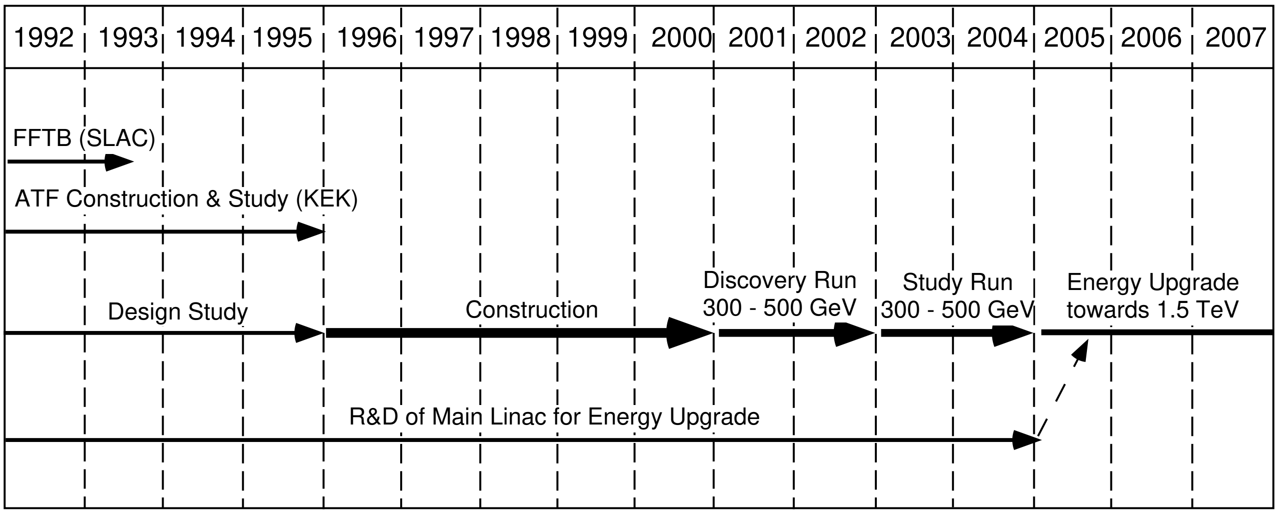

Figure 5.1: The time schedule of the JLC-I project.

5.2 Cost Estimations

The manufacturing process and the component massproduction are the two major factors to determine the required budget for machine construction. At present, however, it is not easy to estimate the cost in the X-band JLC-I case, since the X-band technology is still in a developing stage.

In the case of S-band linacs, however, we know the costs of the 2.5 GeV S-band linac of Photon Factory at KEK and the 1.54 GeV S-band injector linac for the ATF(Accelerator Test Facility) under construction. Taking into account the massproduction effects known by experience, we can thus roughly estimate the total cost of the S-band JLC-I.

As for the C-band JLC-I, we can scale the cost of the S-band linac. The estimated cost turned out to be similar to that of the S-band JLC-I and is listed in Table. 5.1 together with those of the the civil engineering and the detector on the Japanese Yen basis as of 1992.

Table 5.1: Zero-th order cost estimate of JLC-I

CENTER OF MASS ENERGY	300 GeV (Billion Yen)	500 GeV (Billion Yen)
ACCELERATOR TOTAL	**250**	**300**
Particle Sources & S-Band Linac (34 GeV total)	10	10
Polarized Electron Source (1 unit)		
Conventional Sources (2 units)		
Damping Ring Injectors (2 GeV $\times 2$)		
Pre-Accelerators (10 GeV $\times 2$)		
Positron Generator (10 GeV)		
Damping Rings	30	30
Pre-Damping Ring (2 units)		
Main Damping Ring (2 units)		
Bunch Compressors (2 units)		
Beam Transport to main Linac (2 units)		
Main Linacs	150	200
Final Focus system	20	20
Instrumentation & Control System	40	40
DETECTOR TOTAL	**50**	**50**
CIVIL ENGINEERING TOTAL	**100**	**100**
Main Tunnel for Linac	60	60
Tunnel for Approach	10	10
Tunnel for Injector Complex	10	10
Detector Hall	10	10
Other Facilities	10	10
ESTIMATED TOTAL COST	**400**	**450**

Chapter 6

JLC as a spearhead of high technology

6.1 Application as a synchrotron light source

6.1.1 Introduction

In the wide field of experimental studies using “light beam”, it is very important to generate monochromatic and parallel beams with a small spot size, i.e., a high brilliance beam. Needless to say, a laser is the most suitable way to satisfy above requirements. But it is almost impossible to obtain laser beams in the Vacuum Ultra Violet (VUV) and soft and hard X-ray region with the exception of the use of a free electron laser. Another candidate to generate high brilliance beams in this energy region is the synchrotron radiation from high-energy electron and positron accelerators (Fig. 6.1(a)). Recent development of the various types of insertion devices such

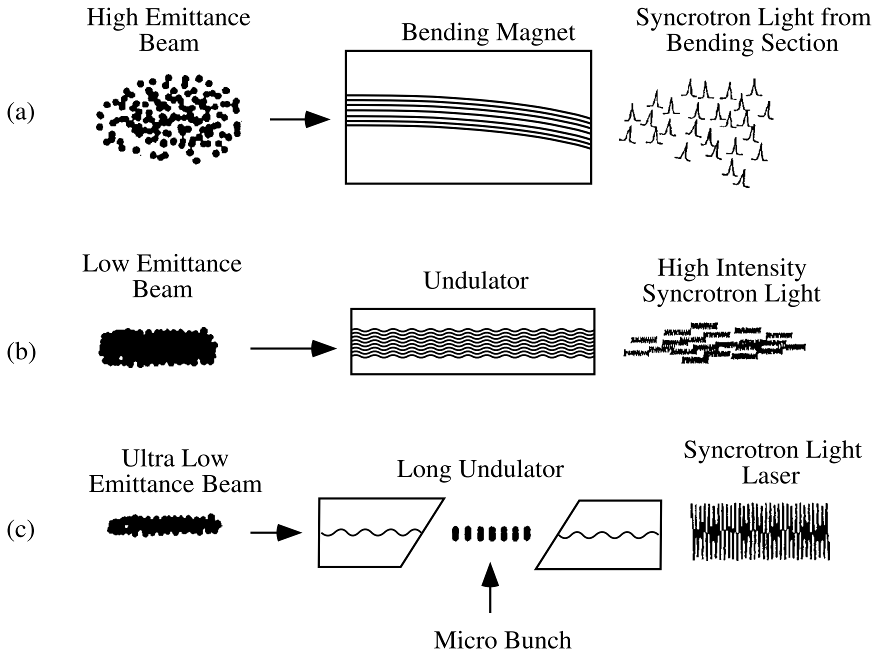

Figure 6.1: A schematic drawing of synchrotron lights (a) from high emittance beam with a bending magnet, (b) from low emittance beam with an undulator and (c) from extremely low emittance beam with a long undulator.

as undulators and wigglers makes it possible to generate a rather monochromatic and intense synchrotron light in the X-ray region as is shown in Fig. 6.1(b) schematically. The radiation from insertion devices in existing accelerators, however, is still inferior to the laser beams from the view points of monochromaticity and brilliance. The characteristics of the synchrotron lights are influenced very much by the quality of the primary electron beam which passes through the insertion device. As a consequence, we must develop an accelerator which can produce a high brightness beam and a long insertion device to obtain high quality synchrotron lights, as shown in Fig. 6.1(c).

The development of world synchrotron radiation facilities has been closely related with high-energy accelerators to explore the energy frontier physics. A typical example is the utilization of the TRISTAN Accumulation Ring (AR) as a synchrotron light source. A multi-pole wiggler and an in-vacuum undulator are used routinely to generate circularly polarized lights for the magnetic Compton experiments and intense X-rays for the Mossbauer experiments, respectively, as a parasite of injecting the beam to the TRISTAN Main Ring (MR). Also, the application of the MR itself is promising for generating ultra high brilliant beams as is shown in Fig. 6.2. The very low emittance of 4×10^{-10} radm is obtained by the MR when it is operated at the

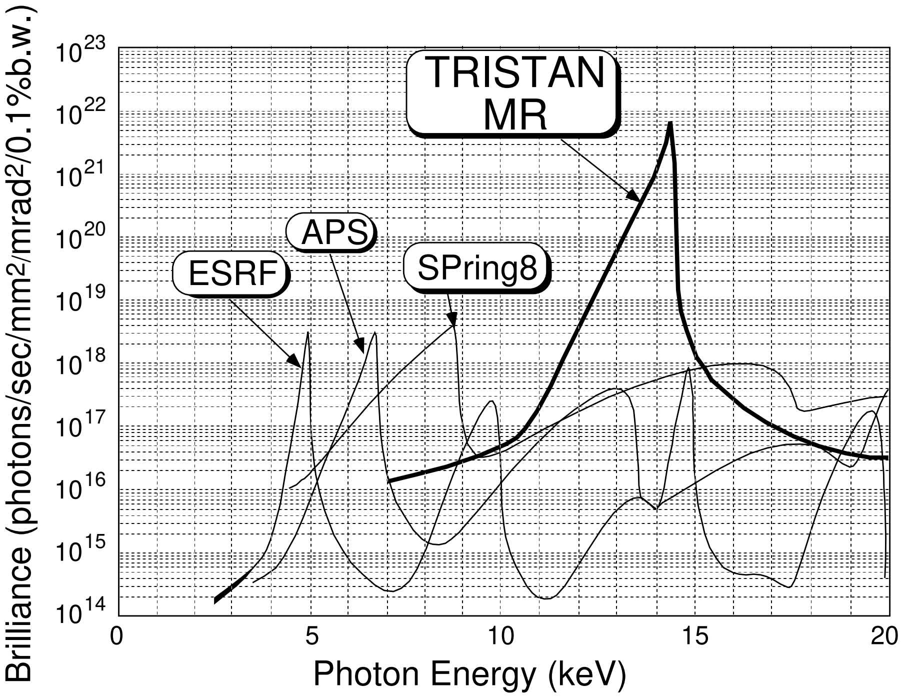

Figure 6.2: Brilliance of synchrotron radiation as a function of photon energy for various facilities.

energy below 5 GeV, with which soft X-ray free electron laser down to $\lambda \sim 1\AA$ can be realized. However, a hard X-ray below $\sim 1\AA$ is not obtainable even with TRISTAN. The only possibility to generate a hard X-ray free electron laser is to use the extremely low emittance beam from JLC.

6.1.2 Hard X-ray laser with JLC

The condition for the beam emittance (ϵ) to generate a synchrotron radiation laser results from the uncertainty principle and is described as

$$\epsilon \leq \lambda,$$

where λ is a wavelength of light. For example, in order to obtain the laser of $\lambda = 500$ Å(VUV region), ϵ must be smaller than 5×10^{-8} radm, which can be realized by operating the Photon Factory Ring (PF) at 0.75 GeV. As is already mentioned above, soft X-ray synchrotron radiation ($\lambda \sim 4\AA$) can be generated by using the MR at 5 GeV, where ϵ of 4×10^{-10} rad m can be achieved.

In order to realize a hard X-ray laser ($\lambda < 1\AA$), the emittance must be smaller than 1×10^{-10} radm which can be achieved only by JLC. The extracted beam from the linac of JLC at the various stages between 7.5 and 20 GeV can generate hard X-rays with the use of long wigglers of 85 $\sim$ 330 m if the peak current is as high as 4 kA as is summarized in Table 6.1. The peak power of 8 $\sim$ 18 GW is obtained for the laser wavelength λ of 0.2 $\sim$ 2.0 Å. These features are summarized in Fig. 6.3.

Table 6.1: Hard X-rays from JLC with long wigglers $\epsilon_{x,y} = 5 \times 10^{-10}$ at 15 GeV, I_p=4kA, $E_{spread} = 3 \times 10^{-4}$

E GeV	Length of Period cm	Length of Magnet m	Field Strength gauss	λ Å	Peak Power GW
7.5	5	85	2600	2.0	18
10.0	4	100	3600	1.0	18
15.0	4	160	3750	0.46	17
20.0	3	330	5000	0.20	8

6.1.3 Application of X-ray laser

The most important application of X-rays is to analyze the structure of materials such as a crystal, amorphous, and liquid, and also to make perspective drawings using the penetrativity. The X-rays from the conventional tube-type sources or from the insertion devices such as those in the PF and AR, however, have no phase correlation between photons: we can make use of the intensity information only. Therefore, for the reconstruction of the three-dimensional structures using the X-ray diffraction, various sophisticated methods are needed such as the heavy atom method.

These complicated problems can be solved easily by using the coherent hard X-rays of $\lambda \sim 1$ Å. The three-dimensional structure of materials can be uniquely obtained by a simple physical method. Thus the impact to the field of solid state physics is drastic.

Solid state physics: As is already mentioned above, the array of atoms in a crystal, amorphous, and liquid can be made visible three-dimensionally in the Å accuracy by the information both in intensity and phase. Moreover, the hard X-ray laser enables us to observe, in real time, the transient (dynamic) phenomena such as the atomic motion during the phase transition and martensitic transformation and that in liquid or melted state.

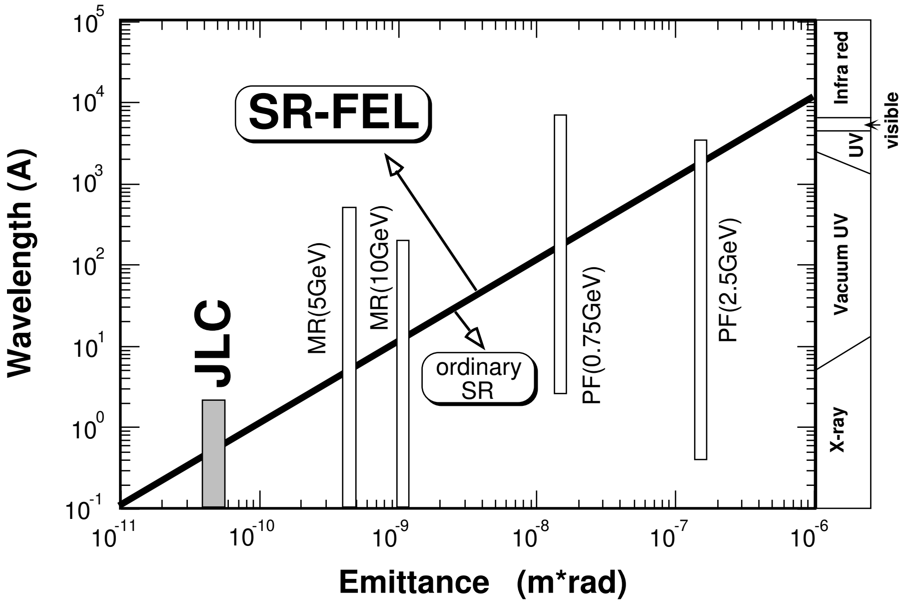

Figure 6.3: Wavelength of synchrotron light as a function of beam emittance

Life science: Up to now, the only method to observe the structure of the biopolymer like the double helical DNA which is the source of life is to use an electron microscope. This method is almost analogous to imagining an active fish in the sea by observing a grilled fish. The application of the hard X-ray laser opens the door to observe the activities of "fresh" microscopic living things such as HIV (AIDS Virus) and cancer cells. It will give rise to a quite clear understanding of the mechanism of breedings or proliferations. These studies are essential in finding out the ultimate weapons to attack such diseases.

The hard X-ray laser is not only useful for the above microscopic level but also for the macroscopic applications. Three-dimensional internal examination of a patient's body can be made easily by taking a holographic picture which is useful clinically.

Manufacturing in nano-meter range: The limit of the accuracy in manufacturing technologies using visible laser beam is the micro-meter range. The X-ray laser in the Årange is a key technology to step into the atomic level. A three dimensional placement and/or removal of individual atoms can be made quite easily. Also, by using the interference phenomena of X-ray lasers, ultra fine manufacturing in the nano-meter range can be realized, which is, for instance, useful to increase the density of computer memories drastically.

ACKNOWLEDGEMENTS

The authors are indebted to the close collaboration with SLAC, without which they would have been suffered from a serious delay particularly in devoloping high power RF technologies. They should also mention the existence of many people, though not presently in the JLC group, who have encouraged and supported the promotion of the JLC project. This work was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education of Japan (No.03302016: Physcs at Linear Colliders).

JLC Group

The JLC group consists of particle and accelerator physicists who have been involved in the feasibility studies for the realization of the JLC project, and those who intend to join forces to further promote the project. This group always welcoms everybody who shares the same goal. The following are the group members as of December, 1992.

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