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Building a third generation source (invited)

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Through a ten-year period of preparation work, from the feasibility study phase, the conceptual design phase, the engineering design phase, to construction, installation, and, finally, the commissioning phase, the Synchrotron Radiation Research Center (SRRC) celebrated the inauguration of its third generation synchrotron light source, the first of its kind in Taiwan as well as in Asia, on 16 October, 1993. In March 1994, the beam current achieved 450 mA, far exceeding the design goal of 200 mA. In April of the same year, the ring energy had been upgraded from 1.3 to 1.5 GeV. Three high-resolution vacuum ultraviolet photon beamlines were successfully commissioned. Synchrotron radiation experiments have been carried out. The following report will brief on the SRRC facility and concentrate mainly on constructing a successful source in lack of the needed accelerator expertise and experience in Taiwan.

I. INTRODUCTION

The Synchrotron Radiation Research Center (SRRC) was established by the government to design, construct, and operate a 1.3 GeV synchrotron radiation source in the Hsinchu Science-Based Industrial Park, Taiwan, Republic of China. The main objectives of the SRRC construction project are to provide outstanding and organized research opportunities in the frontiers of basic and applied sciences, to stimulate high-caliber industrial research and development, to upgrade local technical ability through involvements with the construction of the machine (e.g., accelerator design, component fabrication, etc.), to provide excellent training for students, and to add a new dimension to international collaboration through synchrotron radiation related activities. This was a major and unprecedented, difficult endeavor, considering lacking of the needed accelerator expertise, manpower, and experience, with significant implications for the future development of science, technology, and ultimately, the economy of Taiwan.

II. HISTORY

1981	Dec	Formation of Feasibility Study Group
1983	Jul	Approval of the SRRC project
	Oct	First board of directors (BOD) meeting in Taipei
	Nov	Establishment of SRRC
1984	Jan	Approval of budget by the Executive Yuan (1 GeV, 250 MeV Linac Injection System, US$44 M)
	Sep	Formation of the Technical Review Committee (TRC)
	Dec	First TRC Meeting at BNL, USA; adoption of full energy injection
1986	Aug	Groundbreaking in Hsinchu
	Dec	Decision on nominal energy of 1.3 GeV
1987	Apr	Adoption of TBA lattice for the storage ring
1988	Jul	Revision of SRRC Construction Plan (1.3 GeV Storage Ring, 50 MeV Linac, 1.3 GeV Booster Synchrotron, US$83 M)
	Aug	Injection system contracted out to Scanditronix AB, Sweden
	Sep	Phase I construction started
1989	Apr	SRRC Design Handbook completed
1990	May	Phase I construction completed; Phase II construction started
	Jun	SRRC entire staff moved in to Hsinchu site
1991	Dec	Commissioning of the injection system started
1992	Mar	Installation of the transport line and the storage ring started
1993	Feb	First turn in the storage ring
	Apr	First beam stored in the storage ring
	Aug	Beam current reached the design goal
	Aug	Commissioning of the three vacuum ultraviolet (VUV) beamlines started
	Oct	Completion of the SRRC Guest House
	Oct	SRRC Dedication Ceremony
1994	Mar	Beam current exceeded 450 mA
	Apr	Ring energy upgraded from 1.3 to 1.5 GeV

III. ORGANIZATION

The SRRC is presently under Executive Yuan and will be reorganized to operate as one of the national laboratories of the National Science Council. A Board of Directors was formed in 1983 to supervise SRRC in its important policy making. Board members include distinguished overseas scientists, Yuan T. Lee (UC Berkeley), Lee C. Teng (FNAL), Samuel C. C. Ting (MIT), Chien-Shiung Wu (Columbia U) and Luke C. L. Yuan (Chairman) (BNL), and leading science administrators, policymakers, and leaders of the local scientific community: Han-Ming Hsia (S&T Advisory Group, Executive Yuan) (retired), Nan-Hung Kuo (newly added member) (NSC), Kuo-Ting Li (Minister Without Portfolio), Yen-

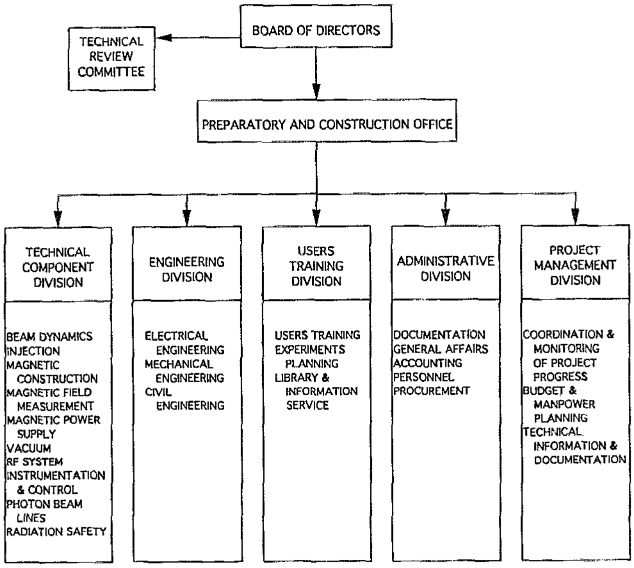

FIG. 1. SRRC organization chart.

Shih Tsiang (General Secretary to the President), Ta-Yo Wu (Academia Sinica) and Chen-Hsing Yen (Atomic Energy Council). A standing Technical Review Committee was established to critically evaluate the design and implementation planning for the facility with world renowned accelerator physicists, scientists, and experimentalists as its members: Matthew Allen (SLAC), Boris Batterman (CHESS) (newly added member), John Blewett (BNL) (retired), Massimo Cornacchia (SLAC), Albert Hofmann (CERN), Kazuo Huke (KEK) (retired), Robert Jameson (LANL), Brian Kincaid (ALS) (newly added member), Gottfried Mulhaupt (ESRF) (retired), Yves Petroff (ESRF), Arie van Steenbergen (NSLS), Herman Winick (SLAC), and Chien-Shiung Wu (Columbia U). Fourteen meetings were held up to date with the following significant issues of concern being brought about by the TRC and effectively dealt with by the SRRC staff: Recommendation to increase the energy of the machine from 1 to 1.3 GeV and to have a full-energy injector; evaluation of alternative lattices for the machine; building of the magnets in Taiwan, the decision on combined function bend magnets, getting the first prototype magnets; development of expertise in the many technical disciplines including magnet measurement, vacuum technology, pulsed injection components, power supplies, survey and alignment; personnel and technology turnover concerns for the I&C system; civil construction-price increases, potential delays; implementation of a radiation safety and general safety program; solution of the septum stray field problem; effective integration/coordination of subgroup activities; development of a user community, training abroad program, in-house laboratories. Under the Preparatory and Construction Office are the Technical Component, the Engineering, the Users' Training, the Administration and the Project Management Divisions. The Technical Component Division consists of ten technical groups, namely, the Beam Dynamics, Injection, Magnetic Construction, Magnetic Field Measurement, Magnetic Power Supply, Vacuum, RF, Instrumentation & Control, Photon

TABLE I. The SRRC manpower list.

Scientists	67 (+15 part time)
Engineers	14
Technicians	38
Administrative staff	28
Total	147 (+15 part time)

Beamlines and Radiation Safety Groups, with top leaders selected from major universities and research institutions. The SRRC organization chart is shown in Fig. 1. These group leaders took charge of each subsystem with the help and advices from well experienced expert consultants from the US, Japanese, and European labs and institutions. These consultants were Thomas Dickinson (NSLS), Jules Godel (NSLS), Hank Hsieh (BNL), Hajime Ishimaru (KEK), Joel Le Duff (LAL), Michel Mayoud (CERN), Charles Pruett (SRC), Heinz Schwarz (SLAC), Andy Soukas (BNL), Ernst Weihreter (BESSY), Bill Weng (BNL), Helmut Wiedemann (SLAC), etc.

IV. BUDGET AND MANPOWER

The total cost for constructing the facility, including the administrative and staff building, booster building, storage ring building, machine shop, utility building, experimental building, the accelerator complex (synchrotron injector and storage ring), the photon beamlines and the end stations, in-house users training, experimentation and promotion, and administrative expenses was around US$94.46 M (civil construction 40%, facility construction 37%, administration 23%). The total manpower is listed on Table I. During the design and fabrication stages, the technical staff were sent to SR labs abroad for training.

V. SITE

SRRC is located in the northwest corner of the Hsinchu Science-Based Industrial Park, about 75 km south of Taipei. The site is triangular in shape with an area of 15 hectares. SRRC is in the vicinity of two prominent technical universities, the National Tsing Hua University and the National Chiao Tung University, and the leading Industrial and Technological Research Institutes.

VI. ACCELERATOR LAYOUT

The accelerating system consists of a 50 MeV preinjector linac, a 1.3 GeV booster synchrotron, a 70-m-long booster-to-storage ring transfer line, and a 1.3 GeV storage ring, as shown in Fig. 2.

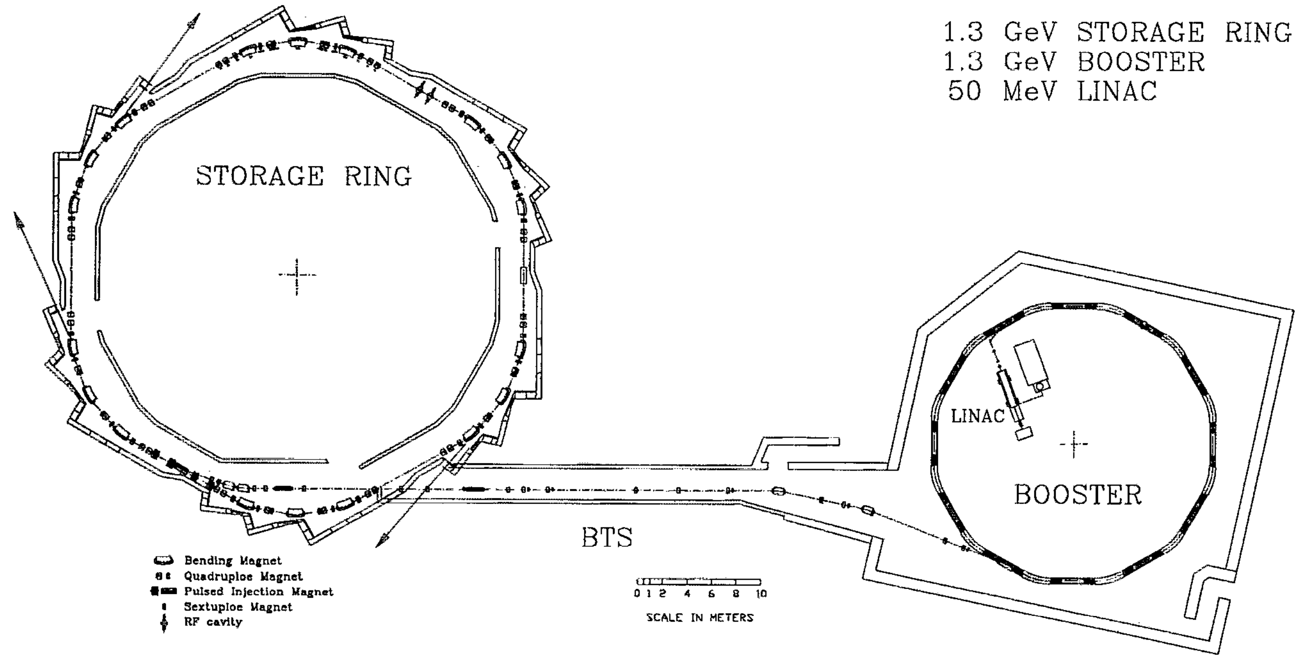

FIG. 2. SRRC accelerator layout.

VII. CONSTRUCTION

Construction of the facility can be divided into three parts: the civil construction, the injection system, and the storage ring. A project summary schedule was made to keep track of the progress of the entire construction work. An overview of the construction project is shown in Fig. 3.

A. Civil construction

Phase I construction including the administration and lab building and the machine shop was completed in May 1990. The entire staff moved into the Hsinchu site in June 1990. Phase II construction took about one and a half years. The booster building was completed in February 1991 just in time for delivery of the injector components. The storage ring building was completed in December 1991.

B. Injection system

Due to the lack of manpower, the electron beam injection system was contracted out to Scanditronix AB, Sweden in August 1988. However, SRRC was fully responsible for the radio frequency (rf) system of the booster synchrotron and the storage ring. Installation of the injector started in May 1991 and beam tests began in January 1992. The performance and reliability of the injector were demonstrated before it was officially turned over to SRRC in July 1992. The major design parameters of the injector are listed in Table II.

C. Storage ring

Construction of the storage ring was the sole responsibility of SRRC. Ten technical groups were formed to make conceptual designs, prototype studies, detailed designs, oversee component fabrication, etc. (see Fig. 1). The lattice structure is a combined-function triple-bend-achromat (TBA) type with sixfold symmetry. There are six dispersion free

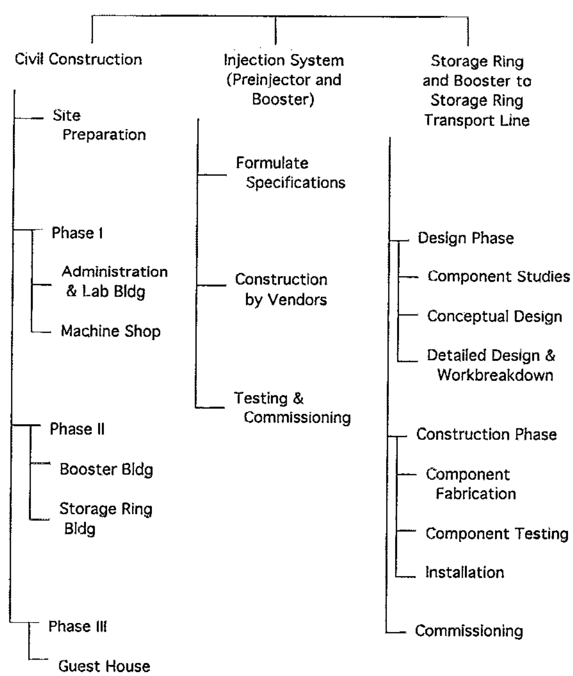

FIG. 3. SRRC construction overview.

TABLE II. Major design parameters of the injector.

Linac energy	50 MeV
Linac current (multibunch mode, average current)	30 mA
Linac rf frequency	299.79 MHz
Booster energy	1.3 GeV
Booster circumference	72 m
Booster rf frequency	500 MHz
Booster natural emittance	1.2×10^{-7} mrad
Booster current (average)	
Multibunch mode	5 mA
Single bunch mode	0.3 mA
Booster repetition rate	10 Hz

long straight sections, each 6 m, for the accommodation of the injection elements, rf cavities, undulators, and wigglers. The major parameters of the storage ring are listed in Table III.

D. Component fabrication and testing

There are 18 dipole magnets powered in series and four families of quadrupole magnets, each with 12 magnets powered in series. Chromaticities are corrected with two families of 24 sextupoles. In addition, there are 24 horizontal and 30 vertical correctors for orbit correction. Several skew quadrupoles were used for coupling adjustment. The magnets were designed, constructed, measured, and analyzed locally. All the magnets installed in the ring were within acceptable tolerances in terms of the multipole errors and integrated fundamental field errors. The pulsed magnets such as the septum and kickers also met the specifications. These pulsed magnets were powered with half-sine waveform with their pulse duration and height of 300 μs, 8.4 kG for the septum and 1.6 μs, 1.29 kG for the kickers, respectively.

Most of the vacuum chambers were made of aluminum. Much care was taken so as to provide an ultrahigh vacuum, low impedance environment. Cleanliness of the material, the tapering of the chamber, the shielding of the bellows, the thermal load, the deformation, rigidity and flexibility of the supporting frame, etc. were seriously considered in order to meet the requirements. The dynamic pressure is about 1.2 nTorr at 200 mA stored beam as of June 1994.

TABLE III. Major design parameters of the storage ring.

Energy	1.3 GeV
Circumference	120 m
Natural emittance	1.92×10^{-8} mrad
Nominal current, multibunch/single bunch	200 mA/5 mA
Natural energy spread, rms	6.6×10^{-4}
Tune ν_x/ν_y	7.18/4.13
Radio frequency	500 MHz
rf cavity gap voltage (nominal)	800 kV
Synchrotron tune	1.15×10^{-2}
Number of dipole, quad, sext	18, 48, 24
Bending field	1.24 T
Damping time τ_x, τ_y, τ_s	10.691, 14.397, 8.708 ms
Critical photon energy in dipole	1.39 keV
Beam size at insertion middle/BM2	
Horizontal	0.45 mm/0.244 mm
Vertical (10% coupling)	0.024 mm/0.033 mm

In one of the long straight sections, two Doris-type cavities purchased from DESY were installed. Each cavity has 60 kW maximum rf power provided by individual transmitters which were purchased from Mountain Technology, USA. The low-level electronic control system was made in SLAC. The rf system of the booster is the same as those in the storage ring. The system can accelerate a 1.3 GeV electron beam of more than 200 mA current in the presence of the insertion devices. The nominal rf frequency is 499.654 MHz. The rf systems, both in the booster and storage ring, have been operating with reliable performance.

Extremely strict requirements on the alignment of the magnets, especially the quadrupole magnets of the ring in both transverse directions, are necessary in order to reduce closed orbit distortions. Acceptable alignment errors in both planes are 0.15 mm rms and the rotation errors are 0.5 mrad rms. The quadrupole magnets were prealigned in the girders and then moved into the tunnel. The final results of the alignments for the dipoles and quadrupoles were 0.14 and 0.12 mm rms in the horizontal and vertical planes, respectively. The tilt errors were 0.2 mrad rms in the dipoles and 0.06 mrad rms in the quadrupoles. As for the sextupoles, the results were 0.20 and 0.15 mm rms in the horizontal and vertical planes, respectively. All the alignment results were within acceptable tolerances. The measured closed orbit distortions were consistent with the simulated results.

There were seven screen monitors for the first turn beam observation in the ring. Among them, two were used for injection launching adjustments in the early commissioning stage. There were forty-seven sets of button-type beam position monitors (BPM). The dynamic range of the BPM electronic was from 50 to 400 μA with resolution of about 50 to 10 μm. Two linear tapered stripline electrodes were installed to measure the transverse motion and the bunch time structure. One excitation electrode station could be used for tune measurements as well as for the transverse instability damping if needed. The fast beam signal, such as the filling structure, could also be measured using the fast current transformer, and the precise beam current was obtained from the Bergoz's parametric current transformer (PCT) with resolution better than 1 μA. Some other elements such as the scraper and photon light monitor were for the machine parameter measurements, etc.

The control hardware architecture adopted was a two-level hierarchical system. Some VAX workstations running the VMS operating system were used to control the computer system. Between the database and the subsystem devices, several intelligent local controllers (ILCs) were implemented. These two-level computers, including that of the booster injector, were linked via the Ethernet work. The control software system was divided into four layers. They were the device access, network access, database access, and the applications. Some friendly graphical user interface (GUI) operation panels were developed. Those GUIs were very useful for the machine commissioning and routine operation.

The radiation safety interlock system was a self-protected subsystem and was also linked to the central control system.

VIII. INSTALLATION

To avoid and solve complications among subsystems, a thorough installation plan was made and strictly followed. A mocked up cell 20-m-long was installed in the machine shop and we gained a lot of practical experience. Technical group and subgroup meetings and the installation team meetings were held regularly. Problems in cabling, cooling system, mechanical support system, survey and alignment, etc. were quickly solved. The installation flow chart, PERT chart, and work breakdown system were worked out. A draft room was erected to cope with the large amount of drawings needed especially during the installation period. A one-sextant installation using real magnets and a vacuum system was simulated in the machine shop. System tests including subsystem tests, intersystem tests, and tests with beams were carried out whenever necessary. Installation of the BTS started in March 1992 and was completed in September 1992 (except for the septum). Installation of the ring began in March 1992. By May 1992, the cabling work and magnet stands installation were completed. The power supplies and all the magnets were installed by October 1992. The vacuum system including the diagnostics elements, rf cavities, and the rf low-level system were installed by end of 1992. In February 1993, we passed a full power test of the magnet power supplies and the ring chambers were connected as a closed form by then. The installation of one rf high-power transmitter and four kicker pulsers were completed in March 1993. Alignment of the magnets reached the acceptable level in March of the same year. Subsystem tests with the control computer and development of the control system software were carried out. The storage ring commissioning started in April 1993 and we got the stored beam very soon.

IX. COMMISSIONING

Due to good quality control in the component fabrication and the installation stage, commissioning of the ring was rather smooth. A commissioning team was formed and regular meetings were held. The BTS beam tests started in August 1992 when the lower level section of the transfer line was completed. By September, the beam reached the septum entrance point. After the pulsed magnets had been installed, the beam passed through the septum and was injected into the ring in January 1993. In February 23, 1993, the beam revolution, for the first time, was accomplished using one kicker for the on-axis injection. The beam was observed on each screen monitor without using any corrector. It showed that the subsystems were basically in good condition. The beam sizes on the screen were consistent with the theoretical values and the alignment errors proved to be barely acceptable in the horizontal plane and extremely good in the vertical plane. Due to the long half-sine base width of 11.6 ms (400 ns revolution time) of the kicker pulse and that there was only one kicker available at that time, a second turn observation was impossible. Not long after the four kickers were available in April, we had several hundred beam revolutions using a few correctors without rf power, and the beam was captured in April 13, 1993 after turning on the rf power with minor adjustments of the magnet settings and rf frequency. The stored beam current was a few mA and beam lifetime was a few minutes under a vacuum pressure of 10^{-7} Torr without turning on the ion pumps. We measured the machine in April and May. In mid-May to end of June 1993, the vacuum chambers were baked and three VUV photon beamlines (1 m SNM, 6 m LSGM, and 6 m HSGM) were installed and tested. We reached the design current on August 12 after the vacuum bakeout. The beam current exceeded 450 mA in the multibunch mode in March 1994. The synchrotron light cleaning was very effective. The accumulated beam dosage as of June 1994 was 150 A h. The average dynamic pressure was about 1.2 nTorr with 200 mA stored beam current. Beam instability has been investigated and improved. At present, the beam lifetime is dominated by the Toushek lifetime. A summary of the storage ring commissioning milestones is given in Table IV.

TABLE IV. Commissioning milestones.

1993	Feb 23	First turn (on-axis injection at 1.3 GeV)
	Apr 2	First few turns
	Apr 13	First beam stored
	Apr 26	Closed orbit measured using BPMs
	Aug 12	226 mA beam current achieved
	Sep 10	300 mA beam current achieved
	Dec	30 mA single bunch achieved
1994	Mar 2	450 mA beam current achieved
	Apr	Ring energy upgraded from 1.3 to 1.5 GeV

X. OPERATION

The machine has been open to outside users since April 1994, however, it is still in a test-run period. The machine time is presently equally shared by users and the machine study group. The run schedule is two shifts (16 h) per day, five days a week. The total machine uptime from October 1993 to June 1994 was 1200 h. At first, failure of the kicker system resulted in a large amount of downtime. Now the system has been improved. In May 1994, 95% of the machine uptime was recorded.

XI. MACHINE PARAMETERS

The machine parameters, such as tunes, betatron, and dispersion function, chromaticity, bunch length, bunch size, broadband impedance of the ring, etc. were measured or deduced. Results were in good agreement with the design values. The closed orbit distortions (COD) were measured and corrected down to 0.23, and 0.13 mm rms in the horizontal and vertical plane, respectively. In the near future, all possible means will be employed to stabilize the electron beam, e.g., the local and global orbit feedback systems, transverse, and longitudinal damping systems, etc.

ACKNOWLEDGMENTS

The author would like to thank the entire SRRC staff for their hardwork and full commitment which made the project a success. Profound gratitudes are also extended to the TRC, consultants and all friends abroad who have given SRRC their invaluable advices and incessant support which are necessary for the project.