Preparatory Survey on The Project for Development of Research Capacity and Human Resources for Advanced Science and Technology in the Kingdom of Thailand

FINAL REPORT (Advanced Release Version)

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JICA

(Japan International Cooperation Agency)

Oriental Consultants Global Co., Ltd. (OCG)

Registered NPO Asia SEED (AS)

Azusa Sekkei Co., Ltd. (AZS)

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Preface

Japan International Cooperation Agency (JICA) decided to conduct the preparatory survey and entrust the survey to the Joint Venture of Oriental Consultants Global Co., Ltd. (OCG), Registered NPO Asia SEED (AS) and Azusa Sekkei Co., Ltd. (AZS).

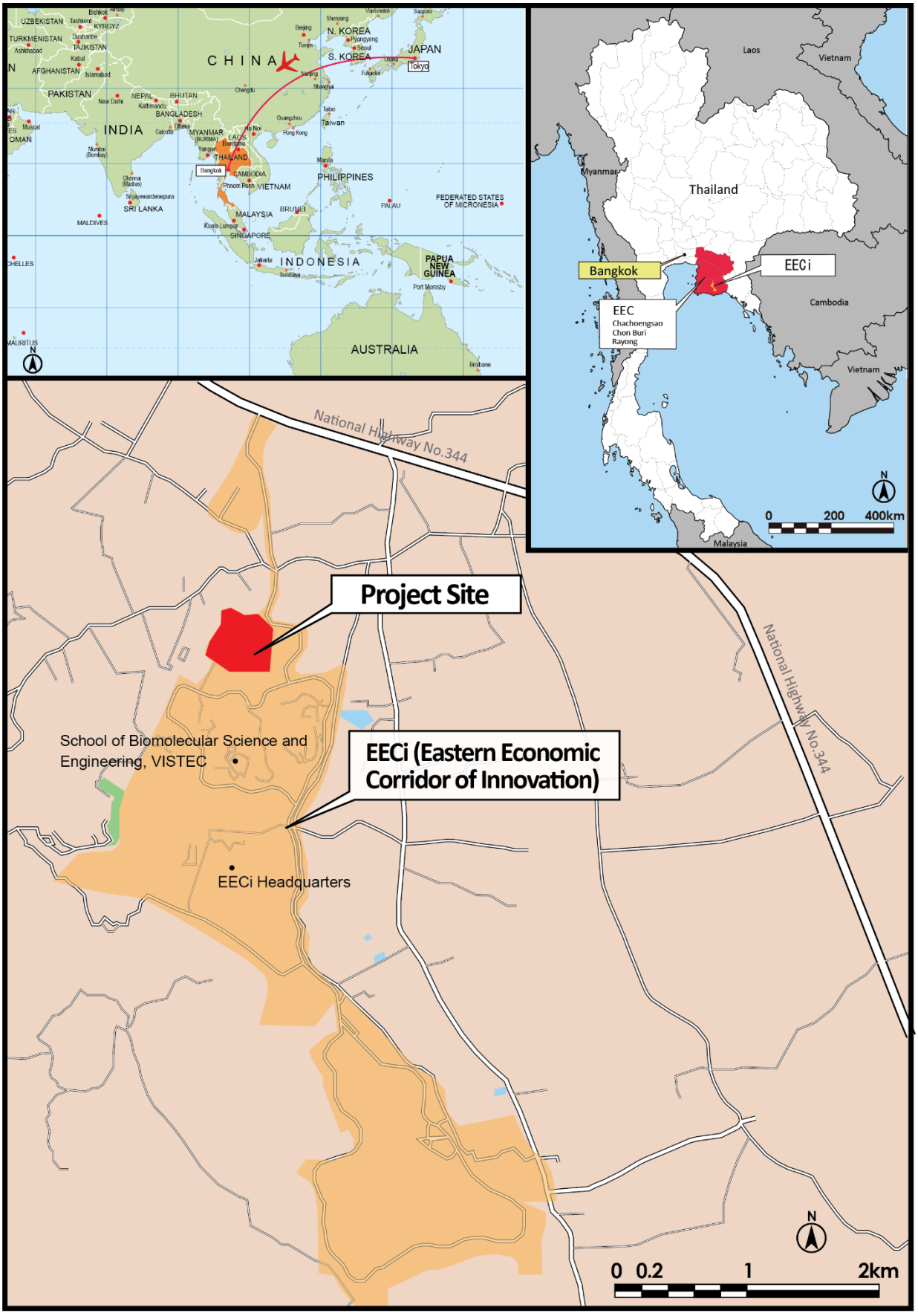
The study team held a series of discussions with the officials concerned of the Kingdom of Thailand, and conducted field investigations. As a result of further studies in Japan, the present report was finalized.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Kingdom of Thailand for their close cooperation extended to the study team.

February, 2026

YONEDA Gen
Director General,
Southeast Asia and Pacific Department
Japan International Cooperation Agency



Projection Site Location Map

Summary

1. Background and Outline of the Project

In the Twelfth National Economic and Social Development Plan (2017-2021) (hereinafter referred to as "12th Development Plan") and the Thirteenth National Economic and Social Development Plan (2023-2027) (hereinafter referred to as "13th Development Plan"), the Government of Thailand (hereinafter referred to as "GOT") has set investment in national Research and Development (R&D) infrastructure as a priority issue necessary to improve international competitiveness by increasing the country's competitiveness of next-generation industries and services in order to become a developed country. In addition, the industrial advancement policy "Thailand 4.0", which consists of improving science and technology research capabilities, industrial sophistication, and Human Resource Development (hereinafter referred to as "HRD") for R&D, is set as the most important strategy. In the Eastern Economic Corridor, the Eastern Economic Corridor of Innovation (hereinafter referred to as "EECi") will be established as a base for R&D in areas e.g. artificial intelligence, robotics, automation, and biotechnology.

The Synchrotron Radiation Facility (hereinafter referred to as "SRF"), which is one of the R&D infrastructures, is a facility for observing extremely small objects with powerful X-rays (radiation) generated by bending accelerated electrons with magnets. It supports cross-disciplinary research, including industrial applications i.e. medicine/ life sciences, environment/geosciences, and material sciences. In Thailand, at the National Synchrotron Research Center (NSRC, later The Synchrotron Light Research Institute (SLRI)) in Nakhon Ratchasima Province, a 2nd generation SRF was built in Japan in the 1990s. An SRF was established with the cooperation from the Government of Japan (hereinafter referred to as "GOJ"). On the other hand, under the circumstances where GOT is promoting further R&D, the need for high-energy, high-intensity and diverse X-rays is increasing from the academic and industrial worlds. This technology was established in the 1980s, and the quality and types of X-rays that can be used at the existing facilities in Thailand are limited. In order to respond to the increasingly sophisticated and diversified needs of synchrotron radiation research in academia and industry, next generation SRF that can irradiate X-rays in micro and nanometer units and enable more advanced and diverse analyzes is required.

Under these circumstances, GOT independently conducted a feasibility study (F/S) for the construction of next generation SRF, which was completed in 2016. Based on the survey, the Thai Cabinet Meeting in 2020 approved a project plan for the development of next generation SRF. After that, in November 2021, GOT also completed a detailed design study (D/D). Recently, Thailand's Ministry of Finance (hereinafter referred to as "MOF") and the Ministry of Higher Education, Science, Research and Innovation (hereinafter referred to as "MHESI") and Synchrotron Light Research Institute (hereinafter referred to as "SLRI") have requested JICA to provide an ODA loan for "next-generation SRF development project", hereinafter referred to as "this Project"). This Project aims to improve the nation's advanced science and technology research capabilities, academia, and industry by developing next-generation SRF and related equipment for advanced science and technology research in the Special Innovation Zone (EECi) located in Rayong Province. It aims to strengthen cooperation with and develop Human Resources (hereinafter referred to as "HR"), and is a high priority indispensable for investment in national R&D infrastructure listed in GOT's

12th Development Plan. In addition, as the first next-generation synchrotron radiation facility in South-East Asia, the use of the facilities by neighboring countries will also be promoted thus collaboration will be strengthened as a regional base for research using synchrotron radiation among ASEAN academic institutions, universities, and companies, and joint research with Japanese academic institutions.

This survey has been conducted for the purpose of collecting additional information necessary for Appraisal of this Project after reviewing the F/S and D/D prepared by GOT.

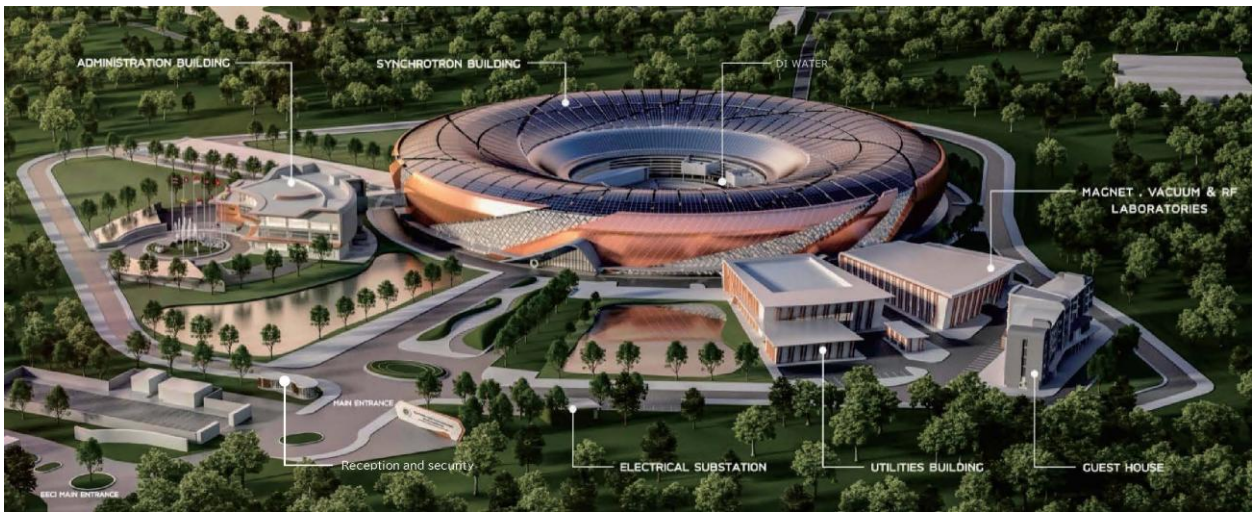
2. Overview and Results of Survey, Project Contents

To develop the next generation SRF and HRD for advanced science and technology research, the Project includes the following components.

1) Procurement of equipment for next generation SRF:
   Injector linac, Booster synchrotron, Electron storage ring (3 billion electron volts: 3.0 GeV), Beam transfer line, Beamlines (7 units)
2) Construction of next generation SRF building
3) Development of related facilities:
   Laboratories, utilities, office building, dormitory building
4) HRD and technology transfer
5) Consulting services: detailed design assistance, bidding assistance, construction supervision, and project management consulting services, etc.

2-1. Design of Facility

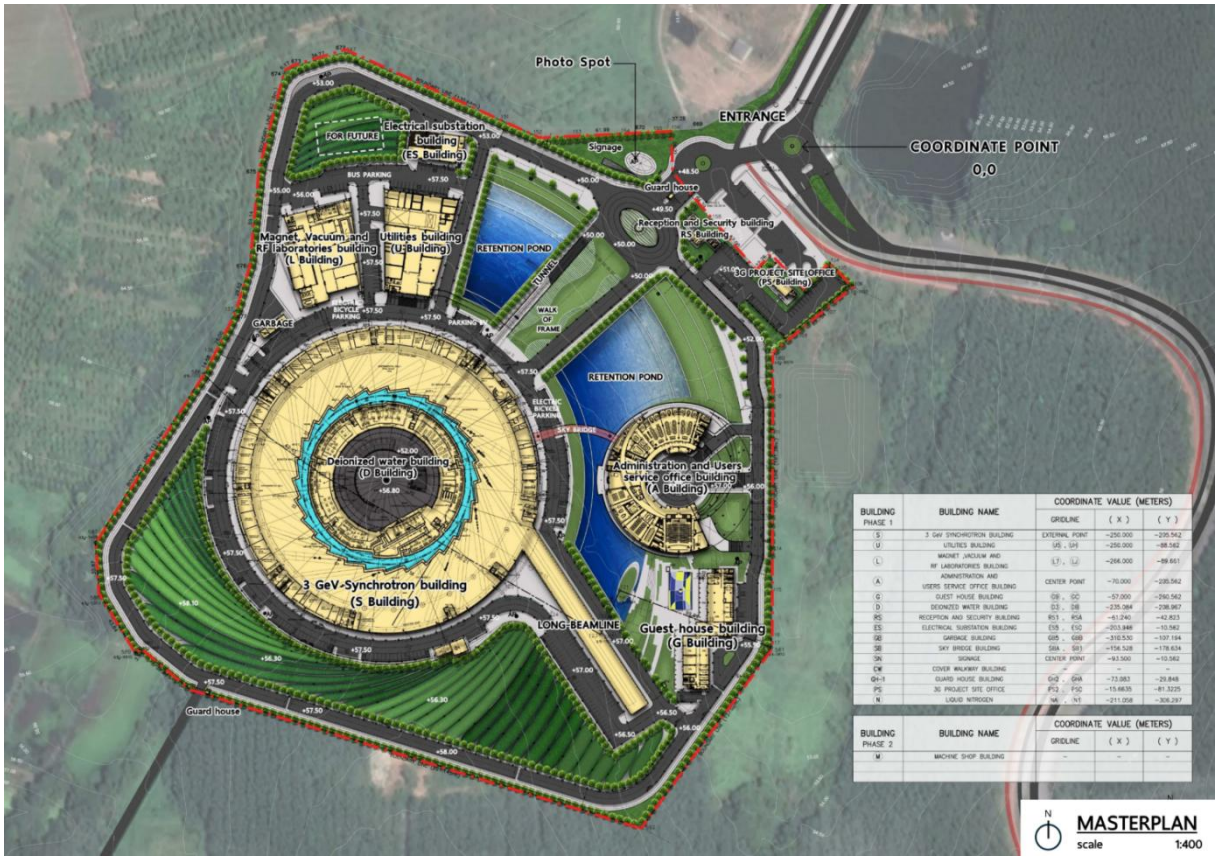
The figure below shows the eight buildings that will be developed sequentially.



Source: SLRI

Figure 1 Siam Photo Source II (SPS-II) Facility Bird-View

The building layout is shown below. The six buildings are planned around the synchrotron building facing approach road, and future extension area (marked in red) for laboratory or administration works are reserved.



Legend: A: Administration Building and User Service Office, D: DI Water Building, G: Guest House, S: 3GeV Synchrotron Building, L: Magnet, Vacuum and RF Laboratories, U: Utilities Building, ES: Electrical Substation, RS: Reception and Security

Source: SLRI

Figure 2 Building Layout

General information regarding each building under the Project is summarized below.

Table 1 List of Buildings

No	Building	Floor Number	Structure	Floor Area (m^2)
1	3 GeV synchrotron building (S Building)	2	Steel frame (storage tunnel is RC)	32,126
2	Utilities building (U Building) for synchrotron light source (including wastewater treatment building)	3	RC	7,214
3	Deionized (DI) water building (D Building)	3	RC	814
4	Magnet, vacuum and RF laboratories building (L Building)	2	RC	2,349
5	Administration and user service office building (A Building)	3	RC	5,805
6	Guest house building (G Building)	3	RC	3,950
7	Reception and security building (RS Building)	1	RC	53
8	Electrical substation 115 kV / 22 kV (ES Building)	1	RC	932
			Total	53,243

Others: Infrastructure work & landscape including garbage storage (91 m^2), signage work

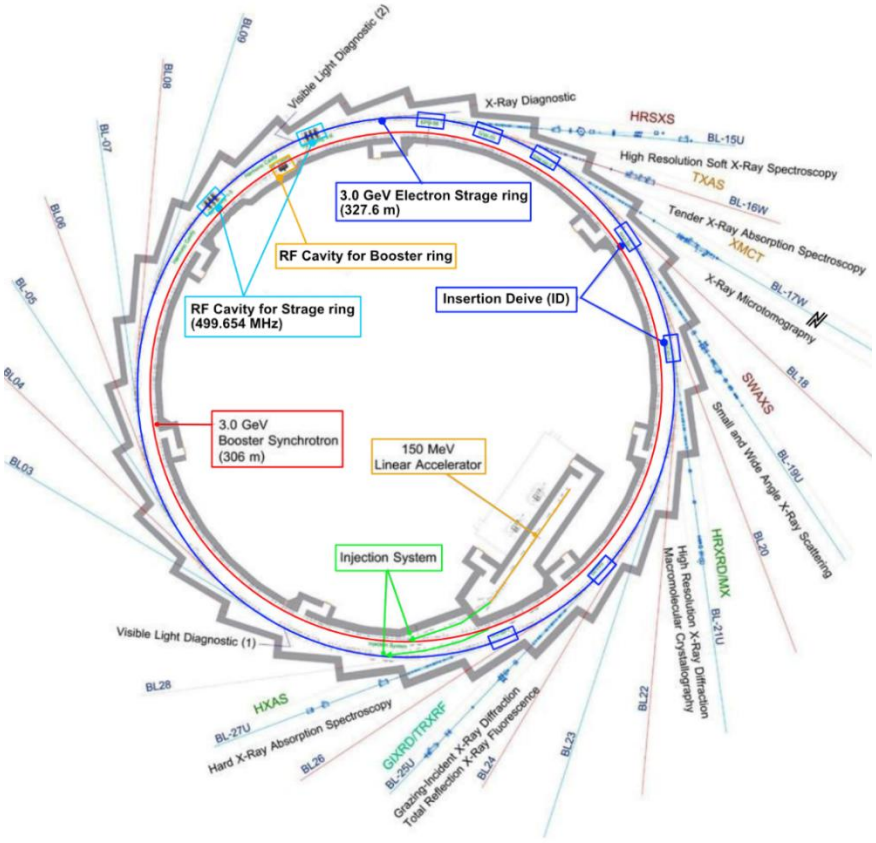
Source: SLRI

2-2. Design of Accelerator

The new synchrotron radiation facility is called the Siam Photon Source II (SPS-II). Its accelerator consists of three main components: a 150 MeV injector linac, a 3.0 GeV booster synchrotron and a 3.0 GeV storage ring.

The injector accelerator consists of a 150 MeV injector linac and a 3.0 GeV booster synchrotron. Electrons accelerated to 150 MeV in the injector linac are transported to the 306.0 m booster synchrotron, which achieves an electron energy of 3.0 GeV and a low-emission electron beam of less than 10 nm-rad for stable injection in top-up operation.

The storage ring will have a circumference of 327.6 m and will be designed to achieve a low emittance beam of 0.97 nm-rad. The frequency of the (RF) system in the storage ring is planned to be 499.65 MHz, and a Double Triple Bend Achromat (DTBA) lattice is adopted as the grating design. The DTBA lattice will allow 14 standard straight sections and 14 central straight sections to be formed in the SPS-II storage ring and is designed to accommodate up to 21 light sources in the future.

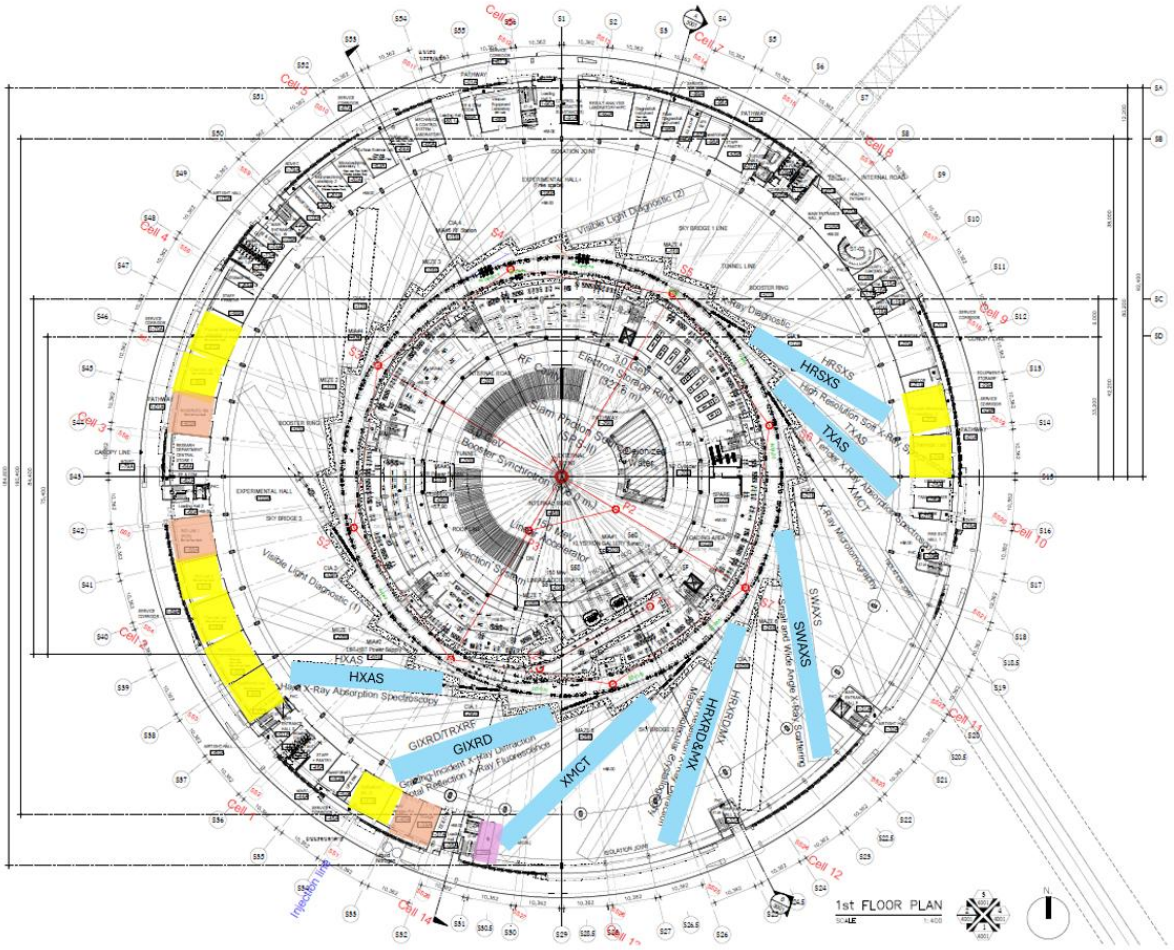


Source: SLRI

Figure 3 Schematic Diagram of the SPS-II Accelerator

2-3. Design of Beamline

Figure below shows a schematic layout of the planned beamlines in SPS-II. The SPS-II storage ring is designed to accommodate a total of 21 insertion devices (IDs), consisting of 11 long straight sections (corresponding to standard straights) and 10 short straight sections (corresponding to center straights). In addition, the figure indicates that 2 diagnostic beamlines and 10 bending-magnet beamlines are also available.



Source: SLRI

Figure 4 Schematic Diagram of Beamline Layout in SPS-II

In Phase I of SPS-II, a total of seven beamlines are planned for installation. Their lineup is shown in the table below. These beamlines have been planned based on the results of a needs survey conducted among existing SPS users, prospective researchers, and industry stakeholders. As shown in the table, the SPS-II beamlines will consist of 5 hard X-ray beamlines, 1 soft X-ray beamline, and 1 grazing-incidence X-ray scattering/fluorescence detection beamline.

Table 2 Proposed Beamline for SPS-II (1st Phase)

Beamline	Technique	Energy range
HRSXS	High resolution soft X-ray spectroscopy	90.0 eV – 2.5 keV
TXAS	Tender X-ray absorption spectroscopy	1.8 -13.0 keV
HXAS	Hard X-ray absorption spectroscopy	6.0-35.0 keV
XMCT	X-ray microtomography	10.0-60.0 keV
HRXRD/MX	High resolution X-ray diffraction & Macromolecular crystallography	9.0 – 27.0 keV
SWAXS	Small & wide-angle X-ray scattering	8.0-20.0 keV
GIXRD/TRXRF	Proposed beamline: Grazing-incidence X-ray Scattering and Total Refection Fluorescence	8.0 – 28.0 keV

Source: SLRI

2-4. Procurement Method/ Procurement Plan (Non-Disclosure)

(This section is concealed for a certain period.)

2-5. Project Implementation Schedule

The Project implementation schedule has been confirmed as follows.

Table 3 Project Implementation Schedule

Key Milestones	Schedule
Signing of Loan Agreement	April 2026
Procurement of Consultant (PMC) (Package 4)	March 2026 – November 2026
Bidding for Building Construction (Package 1)	December 2026 – February 2028 (14.5 months)
Bidding for Accelerator Equipment (Package 2)	October 2026 – January 2030 (39.5 months)
Bidding for Beamline Equipment (Package 3)	January 2027 – April 2030 (39.5 months)
Building Construction (Package 1)	March 2028 – April 2031 (38 months)
Defect Notification Period	May 2031 – April 2032 (12 months)
Procurement of Accelerator Equipment (Package 2) (Including 12-month warranty period)	October 2027 – April 2034 (79 months)
Procurement of Beamline Equipment (Package 3) (Including 12-month warranty period)	March 2028 – November 2033 (69 months)
Beamline Installation	February 2033 – October 2033
First beam (without IDs (Insertion Device))	March 2033
Beamline Commissioning Including Final Machine Commissioning	November 2033 – July 2034
Project Completion Date – Start of Beam Services (1st Phase Operation)	August 2034
Completion of Consulting Services (Package 4)	August 2034

Note 1: The planned period for Procurement of Consultant and Bidding has been set in accordance with the standard implementation period set by JICA.

Note 2: Detailed design by SLRI needs to be adjusted to fit the project implementation schedule.

Source: JST

2-6. Project Cost (Non-Disclosure)

(This section is concealed for a certain period.)

2-7. Scope of GOT's Portion (Non-Disclosure)

(This section is concealed for a certain period.)

3. Project Evaluation (Non-Disclosure)

(This section is concealed for a certain period.)

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List of Abbreviations

12th Development Plan	The Twelfth National Economic and Social Development Plan (2017-2021)
13th Development Plan	The Thirteenth National Economic and Social Development Plan (2023-2027)
ADB	Asian Development Bank
AFM/STM	Atomic Force Microscope/ Scanning Tunneling Microscope
AI	Artificial Intelligence
Aichi SR	Aichi Synchrotron Radiation Center
AJCCST	ASEAN-Japan Cooperation Committee on Science and Technology
ALARA	As Low As Reasonably Achievable
AOFSRR	Asia Oceania Forum for Synchrotron Radiation Research
APRIS	ASEAN-EU Programme for Regional Integration Support
ASEAN	Association of Southeast Asian Nations
ASTNET	ASEAN Science and Technology Network
B/C	Benefit-Cost
B/D	Basic Design
BD	Combined-Function Dipole Magnets
BIOTEC	Bioscience and Biotechnology (research institute under NSTDA)
BOI	Board of Investment of Thailand
BOQ	Bill of Quantities
BPM	Beam Position Monitor
BS	Booster Synchrotron
BSE	School of Biomolecular Science and Engineering (VISTEC)
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CDI	Coherent Diffraction Imaging
CEDAW	Convention on the Elimination of Discrimination against Women
CIRAD	The French Center for International Cooperation in Agricultural Technology
CIT	Corporate Income Tax
CNC	Computer Numerical Control
CO2	Carbon dioxide
COST	Committee on Science and Technology
COSTI	Committee on Science, Technology, and Innovation
COVID-19	Coronavirus disease of 2019
CP Group	Charoen Pokphand Group
CPF	CP Food Lab
CPGE	Committee to Promote Gender Equality

CS	Construction Supervision Consultant
CU	Chulalongkorn University
CU iHub	Chulalongkorn University Innovation Hub (startup management supporting unit of Chulalongkorn University)
D/D	Detailed Design
DBA	Double Bend Achromat
DCM	Double Crystal Monochromator
DECTRIS Ltd.	A Swiss company producing photon counting X-ray detectors
DI water	Deionized water
DIP	Department of Intellectual Property
DMM	Double Multilayer Monochromator
DTBA	Double Triple Bend Achromat
DXL	Deep X-ray Lithography
E/N	Exchange of Notes
EbA	Ecosystem-based Adaptation
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EDD	Energy-Dispersive X-Ray Diffraction
EEC	Eastern Economic Corridor
EECa	Eastern Airport City (EEC Special Zones)
EECd	Digital Park (EEC Special Zones)
EECi	Eastern Economic Corridor of Innovation
EECmd	Medical Hub (EEC Special Zones)
EHIA	Environmental Health Impact Assessment
EIA	Environmental Impact Assessment
EIRR	Equity Internal Rate of Return
ENPV	Economic Net Present Value
ENTEC	Energy Technology (research institute under NSTDA)
EPICS-IOC	Experimental Physics and Industrial Control System – Input/Output Controller
EPU	Elliptical Polarization Undulator
ESE	School of Energy Science and Engineering (VISTEC)
ESRF	The European Synchrotron Radiation Facility
ESS	European Spallation Source
EU	European Union
EV	Enterprise Value
EVA	Economic Value Added
F/S	Feasibility Study

FAR	Floor Area Ratio
FDA	Food and Drug Administration
FEL	Free-Electron Laser
FIRR	Financial Internal Rate of Return
FLUKA	Fluktuierende Kaskade (German for Fluctuating Cascade)
FNPV	Financial Net Present Value
FRC	Frontier Research Centre (VISTEC)
FTIR	Fourier Transform Infrared Spectroscopy
FXI	Full Field X-ray Imaging
GDP	Gross Domestic Product
GERD	Gross domestic expenditure on research and experimental development
GHG	Green House Gas
GISTDA	Geo-Informatics and Space Technology Development Agency
GIWAXS	Grazing-Incidence Wide-Angle X-ray Scattering
GIXRD	Grazing-Incidence X-Ray Diffraction
GNSS	Global Navigation Satellite System
GOJ	Government of Japan
GOT	Government of Thailand
GUI	Graphical User Interface
HAII	Hydro and Agro Informatics Institute
HAPS UAV	High Altitude Pseudo-Satellite Unmanned Aerial Vehicle
HAXPES	Hard X-Ray Photoemission Spectroscopy
HEPS	High Energy Photon Source (China)
HMBA	Hybrid Multi-Bend Achromat
HOM	Higher-Order Mode
HQ	Headquarter
HR	Human Resources
HRD	Human Resources Development
HRSXS	High Resolution Soft X-Ray Spectroscopy
HRXRD	High Resolution X-Ray Diffraction
HXAS	Hard X-Ray Absorption Spectroscopy
ICB	International Competitive Bidding
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ID	Insertion Device
IEE	Initial Environmental Examination

ILO	International Labour Organization
INT	Institute for Technology and Innovation Management (startup management supporting unit of Mahidol University)
IOT	Internet of Things
IR	Infrared
ISMI	Infrared Spectro / Microscopy
IST	School of Information Science and Technology (VISTEC)
IWRM	Integrated Water Resources Management
JAEA	Japan Atomic Energy Agency
JAERI	Japan Atomic Energy Research Institute
JASRI	Japan Synchrotron Radiation Research Institute
JASTIP	Japan-ASEAN Science, Technology, and Innovation Platform
JETRO	Japan External Trade Organization
JICA	Japan International Cooperation Agency
JICA Climate-FIT	Jica Climate Finance Impact Tool
JST	JICA Study Team
KKU	Khon Kaen University
KMITL	King Mongkut's Institute of Technology Ladkrabang
KMUTT	King Mongkut's University of Technology Thonburi
KRIS	KMITL Research and Innovation Services (startup management supporting unit of KMITL)
KVIS	Kamnoetvidya Science Academy
KX	Knowledge Xchange for Innovation (startup management supporting unit of KMUTT)
L/A	Loan Agreement
LCB	Local Competitive Bidding
LED	Light-Emitting Diode
LIB	Limited International Bidding
LiMiNT	Lithography for Micro- and Nanotechnology
Linac	Linear Accelerator
LN2	Liquid Nitrogen
MAI	Market for Alternative Investment
MAX-IV	A Swedish national laboratory providing scientists with the most brilliant X-rays for research with Lund University as the host university
MBA	Multi-Bend Achromat
MBM	Multi-Bunch Mode
MEP	Mechanical, Electrical, Plumbing
MHESI	Ministry of Higher Education, Science, Research, and Innovation

MNRE	Ministry of Natural Resources and Environment
MOC	Memorandum of Cooperation
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
MOU	Memorandum of Understanding
MPW	Multi-Pole Wiggler
MSE	School of Molecular Science and Engineering (VISTEC)
MTEC	Material and Manufacturing Technology (research institute under NSTDA)
MTHB	Million Thai Baht
MX	Macromolecular Crystallography
MXT	Multiple X-ray Techniques
NANOTEC	Nanoscience and Nanotechnology (research institute under NSTDA)
NARIT	National Astronomical Research Institute of Thailand
NBS-SURF	The National Bureau of Standards – Synchrotron Ultraviolet Radiation Facility
NDC	Nationally Determined Contribution
NECTEC	Electronics and Information Technology (research institute under NSTDA)
NEQA	National Environmental Quality Act
NESDB	Office of the National Economic and Social Development Board
NIMT	National Institute of Metrology Thailand
NQI	National Quality Infrastructure
NRCT	National Research Council of Thailand
NSLS-II	National Synchrotron Light Source II (USA)
NSRC	National Synchrotron Research Center *(previous name of SLRI)*
NSRRC	National Synchrotron Radiation Research Center of Taiwan
NSTDA	National Science and Technology Development Agency
NXPC	National Higher Education Science Research and Innovation Policy Council
NXPO	Office of National Higher Education Science Research and Innovation Policy Council
O&M	Operation and Maintenance
OAP	Office of Atoms for Peace
OCSC	Office of the Civil Service Commission
ODA	Official Development Assistance
OHEC	Office of the Higher Education Commission
OJT	On-the-Job Training
ONEP	Office of Natural Resources and Environmental Policy and Planning
OPEX	Operation Expenditure
OPS	Office of the Permanent Secretary

OSL	Optically Stimulated Luminescence
OSR	Open Space Ratio
P/Q	Prequalification
PAL	Pohang Accelerator Laboratory (South Korea)
PCIT	Phase Contrast Imaging and Tomography
PDF	Pair Distribution Function
PDMO	Public Debt Management Office
PEEM	Photoemission Electron Microscopy
PES	Photoemission Spectroscopy
PF	Photon Factory
PF-AR	Photon Factory Advanced Ring
PFE	Particulate Filtration Efficiency
PIU	Project Implementation Unit
PLS II	Pohang Light Source II (South Korea)
PMC	Project Management Consultant
PMU	Project Management Unit
PS	Power Supply
PSC	Project Steering Committee
PSD	Power Spectral Density
PSU	Prince Songkla University
PTT	(formerly known as) Petroleum Authority of Thailand
PVD	Prefabricated Vertical Drain
QCBS	Quality- and Cost-Based Selection
QD	Defocusing Quadrupole Magnets
QF	Focusing Quadrupole Magnets
QST	The National Institutes for Quantum Science and Technology (Japan)
R&D	Research & Development
RAMS	Radiation Area Monitoring System
RC	Reinforced Concrete
RF System	Radio Frequency System
RFR	Request for Reimbursement
RIKEN	A National Research and Development Agency of Japan
RIXS	Resonance In-elastic Spectroscopy
RO water	Reverse Osmosis water
RSC	Radiation Safety Committee
RSO	Radiation Safety Officer

S&T	Science & Technology
SAGA	UNESCO's global STEM and Gender Advancement
SAGA-LS	SAGA Light Source, a compact 3rd generation SRF in Tosu City, Saga Prefecture, Kyushu, Japan.
SAXS	Small Angle X-ray Scattering
SBM	Single-Bunch Mode
SCF	Standard Conversion Factor
SCG	Siam Cement Group
SD	Defocusing Sextupole Magnets
SDR	Social Discount Rate
SEA	Strategic Environmental Assessment
SEDA	Student Entrepreneurship Development Academy (startup management supporting unit of Suranaree University of Technology)
SERI	SERI™ products are researched and fabricated using Thai silk fibroin protein solutions as drug/vaccine-controlled release carrier and artificial tissue
SES	SPRING EIGHT SERVICE
SET	Stock Exchange of Thailand
SF	Focusing Sextupole Magnets
SHB	Sub-Harmonic Buncher
SINS	Surface, Interface, and Nanostructure Science
SINS EUV	Surface, Interface and Nanostructure Science Extreme ultraviolet
SLRI	Synchrotron Light Research Institute
SLS	Swiss Light Source
SME	Small and Medium-sized Enterprise
SMPW	Superconducting Multi-Pole Wiggler
SOLEIL	Source optimisée de lumière d'énergie intermédiaire du LURE (LURE optimised intermediary energy light source), LURE meaning Laboratoire pour l'utilisation du rayonnement électromagnétique (Soleil means "Sun" in French, an SRF in France)
SOP	Standard Operation Procedure
SPL	Siam Photon Laboratory
SPS-I	Siam Photon Source I (existing SRF)
SPS-II	Siam Photon Source II (new SRF)
SPSRMS-II	Siam Photon Source Radiation Monitoring System-II
SRC	Steel-Reinforced Concrete
SRF	Synchrotron Radiation Facility
SRI	Siam Research and Innovation Company Limited
SSLS	Singapore Synchrotron Light Source

SSRF	Shanghai Synchrotron Radiation Facility
STEM	Science, Technology, Engineering, Mathematics
STeP	Science and Technology Park (startup management supporting unit of Chiang Mai University)
STI	Science Technology and Innovation
STR	Storage Ring
SUV	Soft X-ray – Ultraviolet
SWAXS	Small and Wide Angle X-Ray Scattering
SYNAPSE	Synchrotron for Neuroscience – an Asia Pacific Strategic Enterprise
TAS	Thailand Academy of Science
TBA	Triple Bend Achromat
TBIR	Thailand Business Innovation Research
TCELS	Thailand Center of Excellence for Life Science
TEM	Transmission Electron Microscope
TEY	Total Electron Yield
THB	Thai Baht
TINT	Thailand Institute of Nuclear Technology
TISTR	Thailand Institute of Scientific and Technological Research
TPS	Taiwan Photon Source
TRXAS	Time-Resolved X-ray Absorption Spectroscopy
TRXRF	Total Reflection X-Ray Fluorescence
TSMC	Taiwan Semiconductor Manufacturing Company Limited
TSRI	Thailand Science Research and Innovation
TUIPI-TUBI	Center of Intellectual Property and Business Incubator (startup management supporting unit of Thammasat University)
TXAS	Tender X-Ray Absorption Spectroscopy
UHV	Ultra High Vacuum
UK	United Kingdom
UMC	United Microelectronics Corporation
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UPS	Uninterruptible Power Supply
USA	United States of America
USTDA	US Trade and Development Agency
VAT	Value Added Tax
VISTEC	Vidyasirimedhi Institute of Science and Technology
WAXS	Wide Angle X-ray Scattering

WBS	Work Breakdown Structure
XAFCA	X-ray Absorption Fine structure for catalysis
XAFS	X-ray Absorption Fine Structure
XAS	X-ray Absorption Spectroscopy
XDD	X-ray Development and Demonstration
XFI	X-ray Fluorescence Imaging
XMCD	X-ray Magnetic Circular Dichroism
XMCT	X-ray Microtomography
XMD	X-ray Magnetic Diffraction
XPS	X-ray Photoelectron Spectroscopy
XRD	X-ray Diffraction
XRF	X-ray Fluorescence
XRR	X-ray Reflectometry
XRT	X-ray Topography
XTM	X-ray Tomographic Microscopy

1 Introduction

1.1 Background of the Study

In the Twelfth National Economic and Social Development Plan (2017-2021) (hereinafter referred to as "12th Development Plan") and the Thirteenth National Economic and Social Development Plan (2023-2027) (hereinafter referred to as "13th Development Plan"), the Government of Thailand (hereinafter referred to as "GOT") has set investment in national Research and Development (R&D) infrastructure as a priority issue necessary to improve international competitiveness by increasing the country's competitiveness of next-generation industries and services in order to become a developed country. In addition, the industrial advancement policy "Thailand 4.0", which consists of improving science and technology research capabilities, industrial sophistication, and Human Resource Development (hereinafter referred to as "HRD") for R&D, is set as the most important strategy. In the Eastern Economic Corridor, the Eastern Economic Corridor of Innovation (hereinafter referred to as "EECi") will be established as a base for R&D in areas e.g. artificial intelligence, robotics, automation, and biotechnology.

The Synchrotron Radiation Facility (hereinafter referred to as "SRF"), which is one of the R&D infrastructures, is a facility for observing extremely small objects with powerful X-rays (radiation) generated by bending accelerated electrons with magnets. It supports cross-disciplinary research, including industrial applications i.e. medicine/ life sciences, environment/geosciences, and material sciences. In Thailand, at the National Synchrotron Research Center (NSRC, later The Synchrotron Light Research Institute (SLRI)) in Nakhon Ratchasima Province, a 2nd generation SRF was built in Japan in the 1990s. An SRF was established with the cooperation from the Government of Japan (hereinafter referred to as "GOJ"). On the other hand, under the circumstances where GOT is promoting further R&D, the need for high-energy, high-intensity and diverse X-rays is increasing from the academic and industrial worlds. This technology was established in the 1980s, and the quality and types of X-rays that can be used at the existing facilities in Thailand are limited. In order to respond to the increasingly sophisticated and diversified needs of synchrotron radiation research in academia and industry, next generation SRF that can irradiate X-rays in micro and nanometer units and enable more advanced and diverse analyzes is required.

Under these circumstances, GOT independently conducted a feasibility study (F/S) for the construction of next generation SRF, which was completed in 2016. Based on the survey, the Thai Cabinet Meeting in 2020 approved a project plan for the development of next generation SRF. After that, in November 2021, GOT also completed a detailed design study (D/D). Recently, Thailand's Ministry of Finance (hereinafter referred to as "MOF") and the Ministry of Higher Education, Science, Research and Innovation (hereinafter referred to as "MHESI") and Synchrotron Light Research Institute (hereinafter referred to as "SLRI") have requested JICA to provide an ODA loan for "next-generation SRF development project", hereinafter referred to as "this Project"). This Project aims to improve the nation's advanced science and technology research capabilities, academia, and industry by developing next-generation SRF and related equipment for advanced science and technology research in the Special Innovation Zone (EECi) located in Rayong Province. It aims to strengthen cooperation with and develop Human Resources (hereinafter referred to as "HR"), and is a high priority indispensable for investment in national R&D infrastructure listed in

GOT's 12th Development Plan. In addition, as the first next-generation synchrotron radiation facility in South-East Asia, the use of the facilities by neighboring countries will also be promoted thus collaboration will be strengthened as a regional base for research using synchrotron radiation among ASEAN academic institutions, universities, and companies, and joint research with Japanese academic institutions.

This survey has been conducted for the purpose of collecting additional information necessary for Appraisal of this Project after reviewing the F/S and D/D prepared by GOT.

1.1.1 Purpose of the Project

The purpose of this Project is to develop the next generation SRF and human resources, for advanced science and technology R&D and HRD in the Special Innovation Zone (EECi) in eastern Thailand, thereby strengthening the foundations of science and technology research and industrial development in Thailand, thereby contributing to sustainable economic growth.

1.1.2 Outline of the Project

To develop the next generation SRF and HRD for advanced science and technology research.

1) Procurement of equipment for next generation SRF:
   Injector linac, Booster synchrotron, Electron storage ring (3 billion electron volts: 3.0 GeV), Beam transfer line, Beamlines (7 units)[1]
2) Construction of next generation SRF building
3) Development of related facilities:
   Laboratories, utilities, office building, dormitory building
4) HRD and technology transfer
5) Consulting services: detailed design assistance, bidding assistance, construction supervision, and project management consulting services, etc.

1.1.3 Project Site

Rayong Province, Thailand (Eastern Economic Corridor (Special Innovation Zone))

1.1.4 Executing Agency and Implementing Agency

Executing Agency/ Implementing Agency: Synchrotron Light Research Institute (SLRI)[2]

[1] Only Phase 1 Beamline is included in the Yen Loan project. Additional beamlines will be developed in Phase 2 and later.
[2] SLRI will be fully responsible for its own design, assembling, test and commissioning as well as integration of next generation synchrotron facility in the Project. However, it is the first time for SLRI to design and construct a synchrotron radiation facility on its own, SLRI expects to establish a system for obtaining advice from the Advisory (external team consisting of experts from RIKEN and NSRRC) concerning baseline design, detailed design, prototyping, commissioning, and etc.

1.2 Purpose of the Study

This study has been conducted after reviewing the F/S and D/D prepared by GOT for this Project. The purpose of the study is to conduct a supplementary survey necessary for the Project formulation and the JICA's Appraisal of ODA Loan.

1.3 Scope of the Study

This study is to verify the necessity and validity of the Project, and to conduct a supplementary study necessary for the Project Appraisal, i.e. the Work Plan and rough Project cost, in which Project outline is shown in 1.1.2 above. Accordingly, this report has been prepared based on the discussion result with GOT.

1.4 Method of Study

This study has been conducted with the methods as follows:

1) Review of preliminary survey result (F/S and D/D) conducted by Thailand side
2) Collection of supplementary information and analyze the collected information for the Project formulation
3) Discussion with the related counterparts in Thailand for the JICA's Appraisal

2 Background and Needs of the Project

2.1 Development Plans in Thailand and International Trends

In the 12th Development Plan and 13th Development Plan, GOT has identified investment in national R&D infrastructure and human resource development as priority issues necessary to improve Thailand's international competitiveness to become a leading country. GOT has also identified "Thailand 4.0" as the most important strategy for industrial upgrading, and as one of the specific measures to promote the development of R&D hubs through industry, government, and academia, it is currently developing a special innovation zone (EECi) in the Eastern Economic Corridor (EEC) that will serve as a hub for R&D.

2.1.1 National Economic and Social Development Plan

To set out development directions and strategies to achieve the objectives of "Security, Prosperity, and Sustainability", National Economic and Social Development Plan is prepared by Office of the National Economic and Social Development Council, and Office of the Prime Minister.

The 12th Development Plan has prioritized **investment and development of national research and development infrastructure** to increase Thai competitiveness as a step towards being a developed country. The aims of the 12th Development Plan are consistent with the targets of the 20-Year National Strategy (2017–2036). The 13th National Economic and Social Development Plan (2023-2027) has been made public in October 2022.

Table 2-1 Important Issues Raised in the 12th and 13th Development Plan

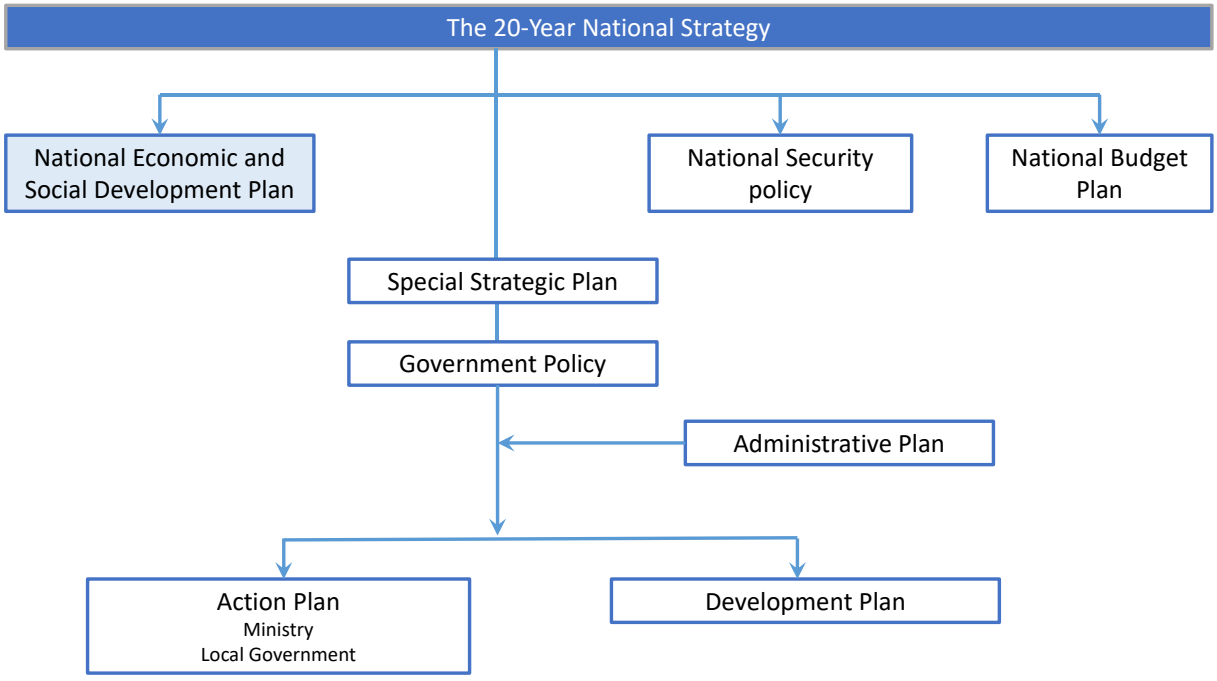
12th National Economic and Social Development Plan (2017-2021)	4.8 Strategy for the Development of Science, Technology, Research, and Innovation *The previous phase of Thailand's economic development has largely depended on the country's pool of labor, stocks of natural resources, and ready-made technology imported from abroad rather than using collective knowledge in order to develop its own technology. This has allowed the foreign providers of technology to benefit from the value-added by technology, and to gain market share.* ***Research and development (R&D) investment in Thailand has been insufficient to drive innovation within the country.*** *Therefore, the development strategy in the ensuing period will emphasize strengthening Thailand's science and technology sectors, and increasing the capability to apply scientific knowledge, technology, and innovation in order to* ***enhance competitiveness in the agricultural, industrial, and service sectors,*** *and improve the quality of life of citizens.* (Source: Summary of the 12th Development Plan (2017-2021))
13th National Economic and Social Development Plan (2023-2027)	Five Key Areas: • *Narrowing income disparities and poverty reduction through innovation;* • ***Creating a knowledge-based economy and value-added development;*** • *Human resource development to meet demand in a digital economy;* • *Environmental conservation to deal with climate change, and;* • *Advanced preparations to deal with changing global economic and social environments.*

Source: JST

2.1.2 Thailand 4.0

Thailand 4.0 is an ambitious vision of accelerating economic growth and becoming a developed country in line with the "National Strategy" toward an economy and society that sustainably creates added value, with "innovation," "productivity," and "trade in services" as keywords. While ensuring political and social stability and promoting the process of transition to civilian rule, GOT has also embarked on national reconstruction, including long-term economic and social development policies, names as "National Strategy (*Yuththasartchat*)," and was positioned as the top-level national plan stipulated in the new Constitution.

The relationship between the National Strategy and the various plans is shown in the figure below.



Source: NESDB (2016)

Figure 2-1 Relationship Among National Strategy in Thailand

The 20-Year National Strategy will be the upper level of the National Economic and Social Development Plan and will govern the 12th Development Plan (2017-2021) through the 15th Development Plan (2032-2036). The National Strategy also sets the framework not only for development planning, but also for national security policy and the national budget, which influences the formulation and implementation of central, administrative, and local government plans through the Special Strategic Plan.

The Policy Committee is chaired by the Prime Minister, and its vice-chairmen are the two deputy prime ministers, the Supreme Commander of the Armed Forces, the commanders of the Army, Navy, and Air Force, the Chairman of the National Defense Council, representatives of the Thai Chamber of Commerce, the Federation of Thai Industries, the Thai Bankers Association, the heads of large corporations such as PTT, SCG, CP Group, and NESDB are the member of policy committee.

2.1.3 International Policy on Science and Technology and within ASEAN

(1) ASEAN Committee of Science, Technology and Innovation, ASEAN-COSTI

ASEAN Science and Technology Network (ASTNET) was identified as a flagship project of ASEAN Committee on Science, Technology, and Innovation (COSTI) and Committee on Science and Technology (COST). ASTNET aims to create an ASEAN-wide electronic based technology information network which will also be a gateway to interconnect ASEAN Science and Technology (S&T) information resources to internal S&T and industrial databases.

The support from ASEAN-EU Program for Regional Integration Support (APRIS) was also provided on the redesigning of ASTNET to improve its performance and services. ASTNET is expected to be a comprehensive, information-rich and vibrant infrastructure set up by the COSTI that is envisioned to underpin:

- Good governance, wise policy and proactive planning for its regional cooperation programs;
- Competitive basic and applied research and development;
- Widespread basic, tertiary and continuing education;
- Human resource development; and
- Technology transfer.

(2) Japan-ASEAN Science, Technology and Innovation Platform (JASTIP) - Promotion of Sustainable Development Research

Recognizing the importance of demonstrating Japan's presence in ASEAN, discussions were held on S&T policies and the direction of cooperation between Japan and ASEAN at the Japan-ASEAN Science and Technology Cooperation Committee Preparatory Meeting held in 2008. In 2009, the first ASEAN-Japan Cooperation Committee on Science and Technology (AJCCST) was held in Bali, Indonesia. Since then, it has basically been held every year in conjunction with the holding of the ASEAN Committee on Science, Technology and Innovation (COSTI), an intra-ASEAN meeting.

(3) Synchrotron for Neuroscience – an Asia Pacific Strategic Enterprise (SYNAPSE)

SYNAPSE is an international cooperation project whose main objective is the use of synchrotron-based imaging at different facilities in a parallel and coordinated fashion to complete the first full map of human brain at a cellular level. The collaboration of synchrotron facilities including Pohang Light Source (Korea), Shanghai Synchrotron Radiation Facility, SPring-8 (Japan), Singapore Synchrotron Light Source, Taiwan Photon Source and Australia Synchrotron under the Asia Oceania Forum for Synchrotron Radiation Research (AOFSRR), with support from the local synchrotron, neurobiology and computing communities.

Table 2-2 Executive Board of SYNAPSE Prior to 30 November 2022

Executive Board Members

Giorgio MARGARITONDO	Ecole polytechnique fédérale de Lausanne, Switzerland	(Chairman)
Zhentang ZHAO	Shanghai Synchrotron Radiation Facility Advanced Research Institute, China	(Member)
Tetsuya ISHIKAWA	RIKEN Spring-8 Center, Japan	(Member)
Jung Ho JE	Pohang University of Science and Technology, Korea	(Member)
Chian-Ming LOW	National University of Singapore, Singapore	(Member)
Yeu-Kuang HWU	Academia Sinica, Taiwan	(Member)
Anton STAMPFL	Australia's Nuclear Science & Technology Organization, Australia	(Member)

Source: https://synapse-sg.org/

From 30th November to 2nd of December 2022, SYNAPSE held an Executive Board Meeting in Phuket, Thailand, where an MOU between SLRI and SYNAPSE was signed, effective from 30 Nov 2022, without an end date. Currently SLRI is an associate member of SYNAPSE and 10% of SPS-I's X-Ray Tomographic Microscopy annual beamtime is tentatively reserved to SYNAPSE-related activities. As of October 2024, the use record is as follows:

Table 2-3 SYNAPSE's Use Record of X-Ray Tomographic Microscopy in SPS-I

No	Year	Project Name	Principle Investigator	Beamtime Period	No. of Experiments	No. of Shifts
1	2021	High resolution tomography of animal brains	Professor, Yeukuang Hwu Hwu	1-7 Apr 2021, 4-8 Dec 2021	2	22
2	2023	Detector System Installation and System Test	Dr. Catleya Rojviriya	11-13 Jul 2023	1	6
3	2023	SYNAPSE: High resolution tomography of animal brains	Professor, Yeukuang Hwu Hwu	4-8 Dec 2023	1	10
4	2024	SYNAPSE: Development of high-resolution x-ray tomography imaging for brain research	Dr. Catleya Rojviriya	6-9 Mar 2024	1	8

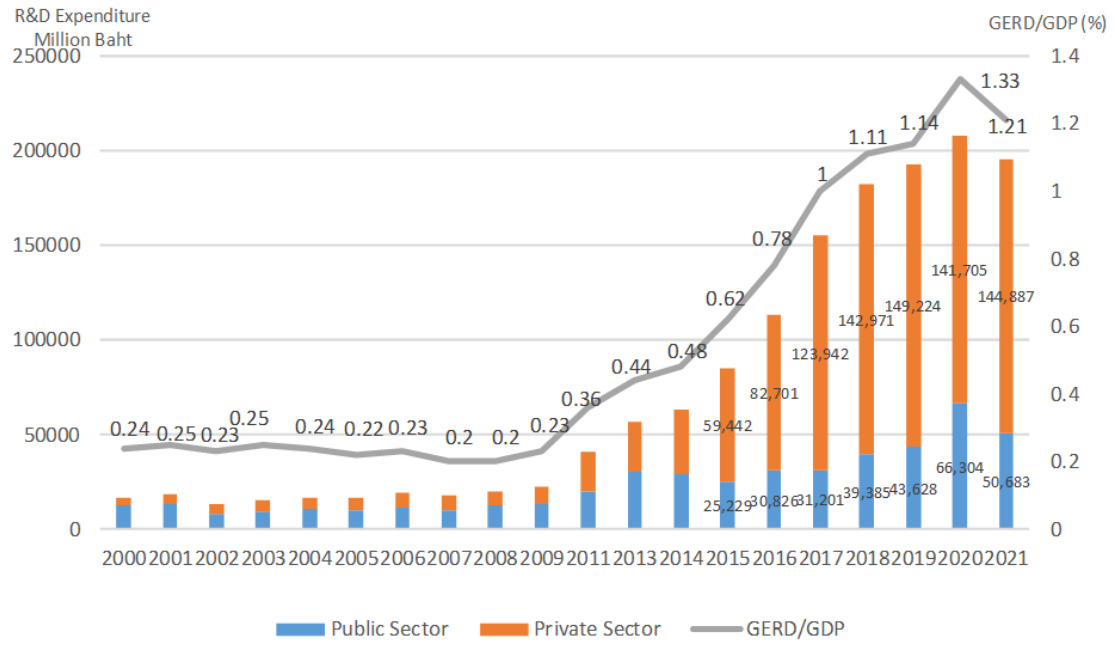
Source: SLRI

2.1.4 Overview of Science and Technology Policy in Thailand

(1) R&D Expenditure and Share of GDP in Thailand

Since the Asian currency crisis in 1998, GDP in Thailand has been steadily increasing and the ratio of R&D expenditure against GDP has also continued to increase, even faster growth than GDP growth after 2010. This is a kind of effect of the government's S&T priority policy.

The following table shows R&D Expenditure and the ratio of R&D expenditure against GDP (GERD/GDP) from 2000 to 2021.



Source: UNESCO Institute for Statistics and NXPO, prepared by JST (no data in 2010 and 2012)

Figure 2-2 R&D Expenditure of GDP and GERD/GDP

The ratio of total R&D expenditure of GDP was 0.24 in 2000 and the ratio reached 1.00 in 2017. The ratio of 2019 was marked at 1.14 whereas the R&D expenditure was 192.8 billion THB. Of this amount, 43.6 billion THB (23%) was contributed by the public sector and 149.2 billion THB (77%) by the industry (see Figure 2-2).

Compared with other ASEAN countries in 2021, Thailand (1.21%) is lower than Singapore (2.16% in 2020) and higher than Malaysia (0.95% in 2020), Vietnam (0.43%) and Indonesia (0.28% in 2020).

Table 2-4 GERD of Main ASEAN Countries

Country	2015	2016	2017	2018	2019	2020	2021
Indonesia		0.25	0.24	0.23	0.27	0.28	
Myanmar			0.04	0.06	0.09	0.15	0.15
Malaysia	1.28	1.42		1.04		0.95	
Singapore	2.17	2.07	1.9	1.81	1.89	2.16	
Thailand	0.62	0.78	1	1.11	1.14	1.33	1.21
Vietnam	0.44		0.53		0.53		0.43

Source: UNESCO Institute for Statistics, prepared by JST

The following figure shows the forecast of R&D expenditure by GOT. During 2020 (2563) to 2022 (2565), it is forecasted that both R&D expenditure and the ratio decreased compared with the ones of 2019 due to COVID-19. After 2026, it is forecasted to increase and to reach 1.46 in normal growth, reaching 2.00 as a target in 2027.

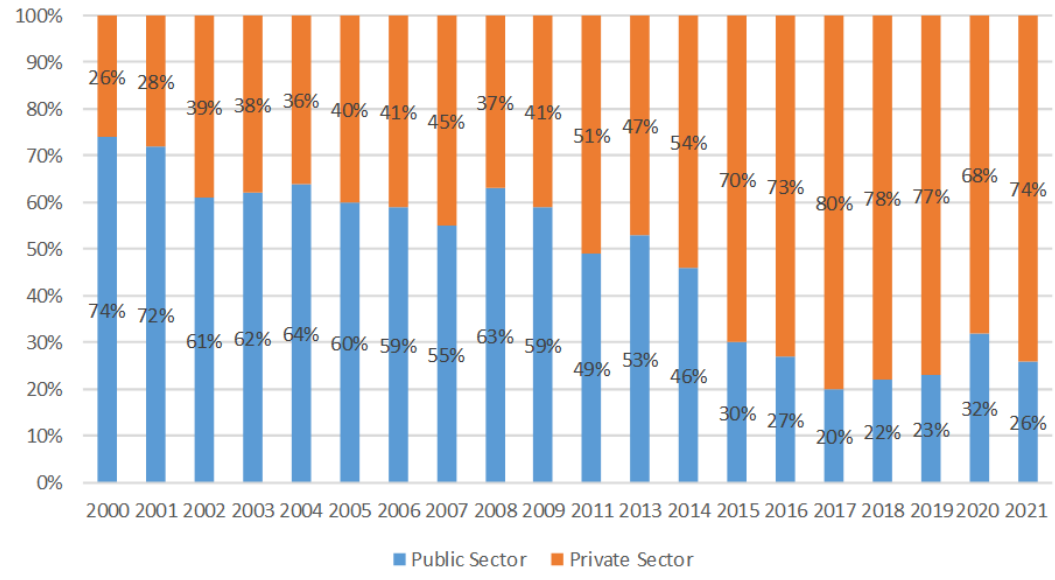


Source: https://www.nxpo.or.th/th/7929/

Figure 2-3 Forecast of R&D Expenditure during 2020 to 2027

(2) R&D Expenditure by Sector

In order to promote innovation in S&T, GOT has set a major goal of increasing the ratio of R&D investment to GDP, whereas to raise the level of R&D investment throughout the country, GOT will increase the amount of R&D funding based on the Thailand 4.0 Plan. On the other hand, the Thai Board of Investment (BOI) has implemented tax incentives to attract more private investment. As a result, the public sector (government) contributed 51% and the private sector (industry) contributed 49% in 2013, but the public sector contributed 26% and the private sector 74% in 2021.



Source: NXPO, prepared by JST (no data in 2010 and 2012)

Figure 2-4 R&D Expenditure of GDP by Sector

The following table summarizes amounts of R&D expenditure by sector during 2011 to 2021.

Table 2-5 R&D Expenditure 2011 – 2021

Amount: MTHB

Year	2011		2013		2014		2015		2016	
Sector	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
Public	20,186	49	30,270	53	29,045	46	25,229	30	30,826	27
Private	20,684	51	26,768	47	34,445	54	59,442	70	82,701	73
Total	40,870	100	57,038	100	63,490	100	84,671		113,527	100

Year	2017		2018		2019		2020		2021	
Sector	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
Public	31,201	20	39,385	22	43,628	23	68,304	32	50,683	26
Private	123,942	80	142,971	78	149,224	77	141,705	68	144,887	74
Total	155,143	100	182,356	100	192,852	100	208,009	100	195,570	100

Source: NXPO, prepared by JST

During this period, total R&D expenditure increased by 4.8 times from 40.8 billion THB to 195.6 billion THB. The public sector has grown 2.5 times from 20.2 billion THB to 50.7 billion THB while the private sector has grown 7 times, from 20.7 billion THB to 144.9 billion THB contributing to increased R&D expenditure.

Table 2-6 Top 3 Industry for R&D Investment in 2019

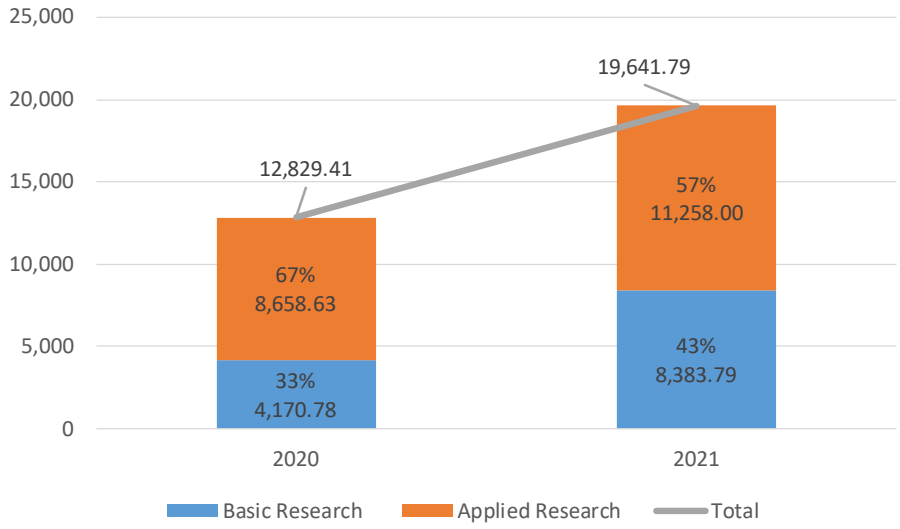
Category of Industry (amount of investment for R&D)	Reason and Contents for / of Investment
Food industry (THB 32,321 million)	Research Infrastructure Investment for Food Innovation Center R&D on Food Waste Reduction and Recycle New Product Development and Renew of Existing Product Development to satisfy End-user's requirements
Petroleum industry (THB 11,958 million)	New Product and New Process Development for Productivities, Cost, and other outcomes R&D for competitiveness, market share, and new business. Strengthen Infrastructure, Scale-up, and Research capability
Finance and Insurance industry (THB 11,579 million)	R&D on Mobile Banking Platform, Online business system, Cyber security, and Customer's needs R&D on new business for replenishment the business which has been removed by Digital Disruption

Source: NXPO, prepared by JST

(3) R&D Budget Allocation by Activities Classified by Type of Research

Regarding allocation classified by type of research, basic research and applied research, in Thailand, as mentioned, recently, the R&D expenditure in the private sector has been more than one in the public sector. From this point, applied research is presumed to be the mainstream in Thailand since R&D expenditure in the private sector is focused on applied research more than basic research.

Regarding R&D expenditure in the public sector, the figure below shows classification of research fund by basic science and applied science[3], which is provided by the Thailand Science Research and Innovation (TSRI) in 2020 and 2021.



Source: TSRI, prepared by JST

Figure 2-5 Research Fund of TSRI Classified by Type of Research

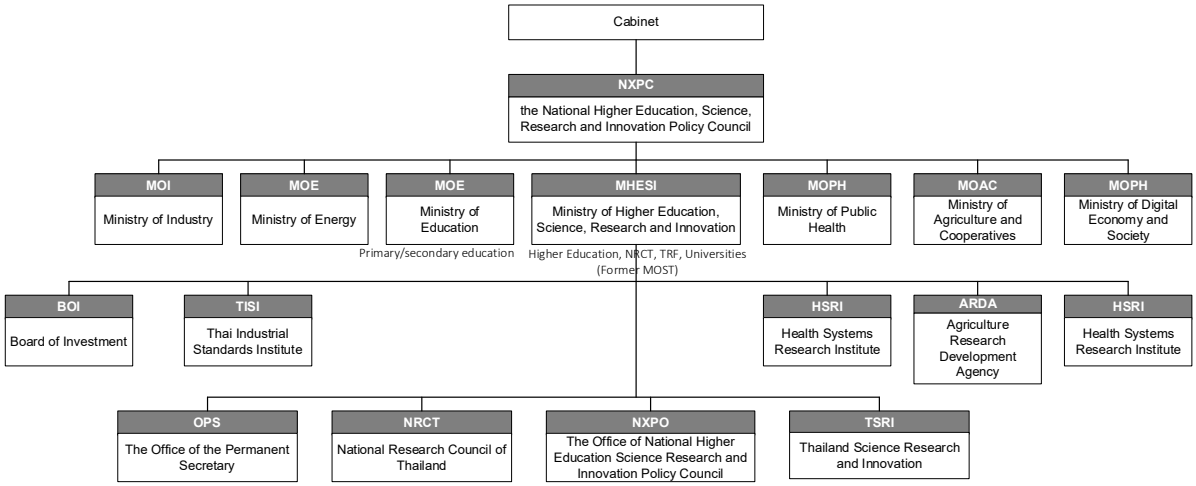
As referred by the above figure, it is understood that applied research accounts for more than 50% of research fund of TSRI.

2.1.5 Organization Structure of R&D in Thailand

Ministry of Higher Education, Science, Research and Innovation (MHESI) is the center player of S&T development policy, which was established in 2019 by the integration of Ministry of Science and Technology (MOST), the Office of the Higher Education Commission (OHEC) of Ministry of Education, and Office of the National Research Commission under the Prime Minister.

For cross-cutting planning and implementation of S&T development policy, National Higher Education Science Research and Innovation Policy Council (NXPC) is organized under the cabinet, which is chaired by the prime minister. Two vice-chairman consists of one of deputy prime minister and the minister of MHESI and the Office of National Higher Education Science Research and Innovation Policy Council (NXPO) is set under the MHESI as function of secretariat for this Council.

[3] In original data, according to literal translation, it is translated as "Strategic support fund" and is interpreted as "Fund for applied science".



Source: Center for Research and Development Strategy Japan Science and Technology Agency

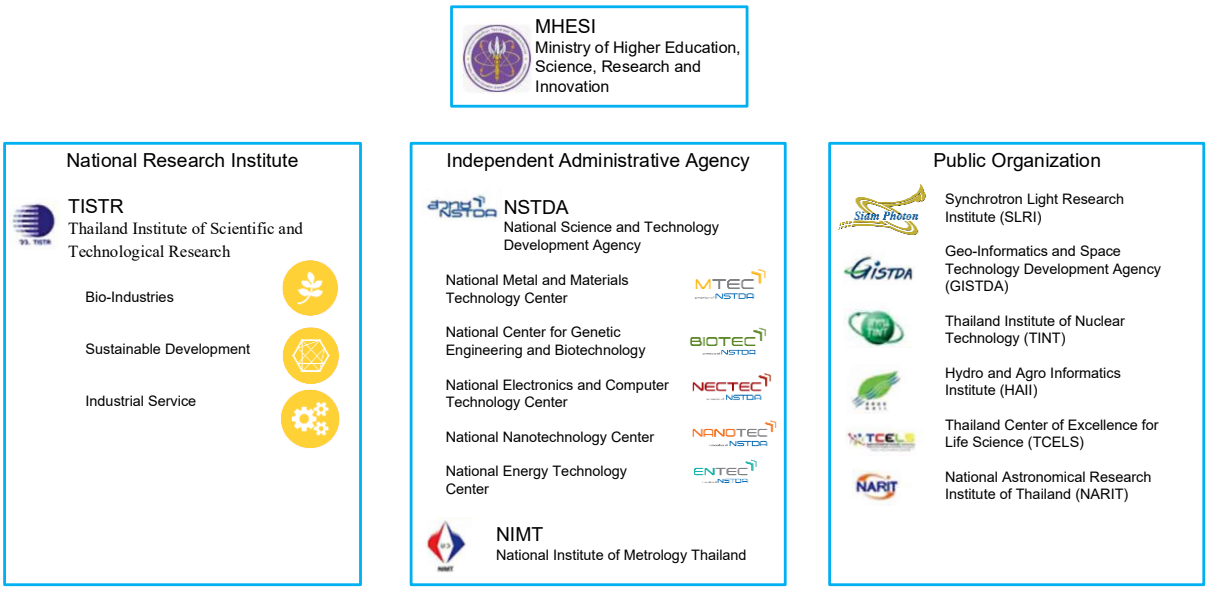
Figure 2-6 Organization Structure of Science and Technology Development Policy in Thailand

Under MHESI, there are 4 main organizations on policy and funding (institutes):

- Office of the Permanent Secretary (OPS)
- National Research Council of Thailand (NRCT)
- Office of National Higher Education Science Research and Innovation Policy Council (NXPO)
- Thailand Science Research and Innovation (TSRI)

(1) Public Research Institute under MHESI

Under the control of MHESI, there are three types of legal entities for public research institutes; 1) National Research Institute, 2) Independent Administrative Agency, and 3) Public Organization



Source: MHESI and others, prepared by JST

Figure 2-7 Research Institutes under MHESI

Thailand Institute of Scientific and Technological Research (TISTR) under the category of "National Research Institute" is a state enterprise whereas institutes and organizations categorized under both

"Independent Administrative Agency" and "Public Organization" are public organization and the difference between the two categories lies in the legal basis upon which they were established. In other words, the ones under "Independent Administrative Agency" were established with a specific act such as NSTDA Act[4] and the ones under "Public Organization" were established by royal decree of the 1999 Act[5].

1) National Research Institute

TISTR belongs to this legal entity category. TISTR was established in 1963 as the first national S&T research institute. After the establishment of NSTDA, both TISTR and NSTDA are in completion and the difference is that NSTDA focuses on advanced S&T, while TISTR focuses on solving social problems.

TISTR's fields of research are food, health-related, medical equipment, alternative energy, environment, and railway-related. There are 3 research and service groups;

- Bio Industries
  - Expert Centre of Innovative Agriculture
  - Expert Centre of Innovative Health Food
  - Expert Centre of Innovative Herbal Products
  - Biodiversity Research Centre
- Sustainable Development
  - Expert Centre of Innovative Clean Energy and Environment
  - Expert Centre of Innovative Materials
  - Expert Centre of Innovative Industrial Robotics and Automation
  - Sakerat Environments Research Station
- Industrial Services
  - Industrial Metrology and Testing Service Centre
  - Material Properties Analysis and Development Centre
  - Railway Transportation System Testing Centre
  - Thai Packaging Centre
  - Office of Certification Body

2) Independent Administrative Agency

- National Science and Technology Development Agency (NSTDA)

NSTDA was established with the mission to contribute to utilize S&T for national economic and social development. NSTDA is an organization which does not only promote basic and application research but also a various activities e.g. support for startup, technology transfer, industry-academia-government

[4] https://po.opdc.go.th/file/reader/Y3x8MjIxOHx8ZmlsZV91cGxvYWQ
[5] Bureaucracy Development Commission (opdc.go.th)

collaboration, and HRD. Compared with National Research Institute, NSTDA has more freedom on its operations including personnel and salaries.

Under the control of NSTDA, there are 5 research institutes: Bioscience and Biotechnology (BIOTEC), Nanoscience and Nanotechnology (NANOTEC), Electronics and Information Technology (NECTEC), Material and Manufacturing Technology (MTEC) and Energy Technology (ENTEC).

In an attempt to create a place or environment and interactive ground that generates, attracts and nurtures technology companies, NSTDA established infrastructure to support research and innovation with conducive ecosystem. NSTDA currently manages Thailand Science Park and Software Park Thailand and oversees establishing EECi. There are 4 innovation platforms within EECi:

- ARIPOLIS: An innovation platform for automation, robotics and intelligent systems
- BIOPOLIS: An innovation platform for life sciences and biotechnology.
- SPACE INNOPOLIS: An innovation platform for aerospace and aviation.
- FOOD INNOPOLIS: An innovation platform for food industry.

■ National Institute of Metrology Thailand (NIMT)

NIMT was established in 1998 in order to spread international standard of metrology widely in Thailand. NIMT is the only research institute that is responsible for primary standard of metrology such as length, time/frequency, mass-related quantity, electricity/magnetism, temperature measurement, quantity of matter, photometric radiometry, acoustic/ultrasonic/vibration, etc. Recently, it has begun to strengthen its activities such as chemical analysis.

3) Public Organization

Under this legal entity category, 6 research organizations including SLRI are categorized as shown in the table below. Compared with the other 2 legal entries previously explained, these research institute has more autonomy on their operations such as personnel and salaries.

Table 2-7 Public Organization

Name of Institutes	Remarks
Synchrotron Light Research Institute (SLRI)	Established in 1996 Location: HQ in Nakhon Ratchasima Province Installed secondhand SRF provided from Japan R&D: Synchrotron radiation and related researches Number staff: 212 (2022)
Geo-Informatics and Space Technology Development Agency (GISTDA)	Established in 2000 Location: HQ in Bangkok (Bangkhen, etc.) R&D: Remote sensing, GIS, satellite technology development Number of staff: 311 (2020)
Thailand Institute of Nuclear Technology (TINT)	Established in 2006 Location: Bangkok, Nakornnayok, Pathum Thani R&D: Nuclear energy research in medicine, agriculture, biotechnology, material, chemistry, etc. Number of staff: 327 (2021)
Hydro and Agro Informatics Institute (HAII)	Established in 2009 R&D: applying science and technology knowledge for agricultural and water resource management Number of staff: 132 (2021)
Thailand Center of Excellence for Life Science (TCELS)	Established in 2004 R&D: Pharmaceuticals, biomedical engineering for medical robots devices, advanced Medical services for cell/gene therapy, automated cell/tissue production Number of staff: 65
National Astronomical Research Institute of Thailand (NARIT)	Established in 2008 R&D: Astronomy and Astrophysics Research Field Number of staff: 168 (2021)

Source: the website of each organization, prepared by JST

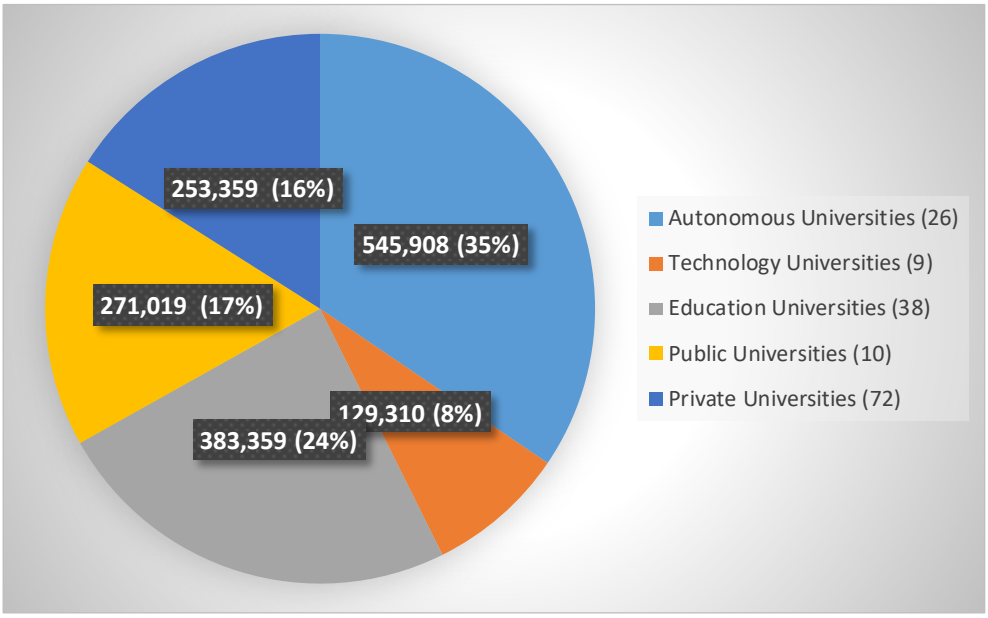
(2) University

The university entrance rate in Thailand is 49.3% (UNESCO, 2019), which is ranked at 67th out of 152 countries and at the 2nd position in ASEAN countries next to Singapore (88.9%). The ration of Japan is 63.6%.

There are 155 universities in Thailand; 83 national and public universities and 72 private universities (MHESI, 2021). 83 national and public universities are divided into following 4 categories:

- Autonomous universities (26 universities)
- Technology universities (Rajammangala Univ. of Technology / 9 universities)
- Education universities (Rajabhat University / 38 universities)
- Public universities (10 universities)

Universities with high research capacity are mostly National Universities and most of them are categorized as Autonomous universities. In total, 1,582,955 students are enrolled in 155 universities (MHESI, 2021).



Source: MHESI and others, prepared by JST

Figure 2-8 Number of Students by Type of University

545,906 students belong to 26 Autonomous universities, which is 35% of the total number of students. The universities in the following table summarizes the representative universities recognized for their high research capacity in Thailand.

Table 2-8 Summary of Main Universities in Thailand

Name of university (Establish year / Type / QS Asia Rank)	Main faculty/school	Number of students	Number of academic staff
Chulalongkorn University 1917 Autonomous 36 (Asia 2022)	20 faculties and 23 research institutes and colleges Main. Science, Engineering, Medicine, Pharmaceutical, Education, Law, MBA, etc.	Total: 37,280 BS: 25,643 MS/PhD: 10,849 Engineering: 3,155/1,383 Science: 3,111/1,053	Total: 7,861 Engineering:282 Science: 417
Mahidol University 1888 Autonomous 43 (Asia 2022)	16 faculties and 23 research institutes and colleges Main. Science, Engineering, Medicine, Public Health, Pharmaceutical, etc.	Total: 29,412 Undergrad: 21,882 Graduate: 7,530 Engineering: 2,014 Science: 2,648 (Annual Report 2021)	Total: 3,963 Engineering: 149 Science: 296
Vidyasirimedhi Institute of Science and Technology (VISTEC) 1888 Private (established by PTT)	Only Graduate school 4 academic schools; Biomolecular Science and Engineering (BSE), Energy Science and Engineering (ESE), Information Science and Technology (IST), Molecular Science and Engineering (MSE)	Total: 225	Total: 36

Name of university (Establish year / Type / QS Asia Rank)	Main faculty/school	Number of students	Number of academic staff
King Mongkut's University of Technology Thonburi (KMUTT) 196 (Asia 2022)	8 faculties and 7 research institutes and colleges Main. Science, Engineering, Information Technology, Industrial Education and Technology, etc.	Total: 13,726 Undergrad: 11,640 Graduate: 2,086 Engineering: 5,337/653 Science: 1,497/176	Total: 659 Engineering: 212 Science: 107
King Mongkut's Institute of Technology Ladkrabang (KMITL) 281-290 (Asia 2022)	11 faculties and 7 research institutes and colleges Main. Science, Engineering, Information Technology, Industrial Education and Technology, etc.	Total: 26,975 Undergrad: 23,789 Graduate: 3,186 Engineering: 6,455//913 Science: 3,136/443	Total: 1,176 Engineering: 317 Science: 156
Chiangmai University 88 (Asia 2022)	21 faculties and 16 research institutes and colleges Main. Science, Engineering, Medicine, Agriculture, etc.	Total: 37,350 Undergrad: 31,393 Graduate: 5,957 Engineering: 3,788/661 Science: 2,424/497	Total: 2,274 Engineering: 168 Science: 321
Khon Kaen University 133 (Asia 2022)	19 faculties and 5 research institutes and colleges Main. Science, Engineering, Medicine, Agriculture, etc.	Total: 38,249 Undergrad: 32,559 Graduate: 5,690 Engineering: 3,002/530 Science: 2,416/439	Total: 2,363 Engineering: 151 Science: 188
Suranaree University of Technology 351-400 (Asia 2022)	8 institutes and 1 research institutes and colleges Main. Science, Engineering, Agriculture, etc.	Total: 16,350 Undergrad: 14,793 Graduate: 1,557 Engineering: 3,000/866 Science: 476/331	Total: 435 Engineering: 159 Science: 85
Kasetsart University 138 (Asia 2022)	18 faculties and 4 research institutes and colleges and 3 local campus Main. Science, Engineering, Forestry, Agro-Industry, Fisheries, etc.	Total: 70,056 Undergrad: 61,768 Graduate: 8,288 Engineering: 10,669 Science: 13,247	Total: 3,530 Engineering: 252 Science: 303

Source: JST

As representative universities among the above table, Chulalongkorn University and Vidyasirimedhi Institute of Science and Technology (VISTEC) are described below.

1) Chulalongkorn University (CU)

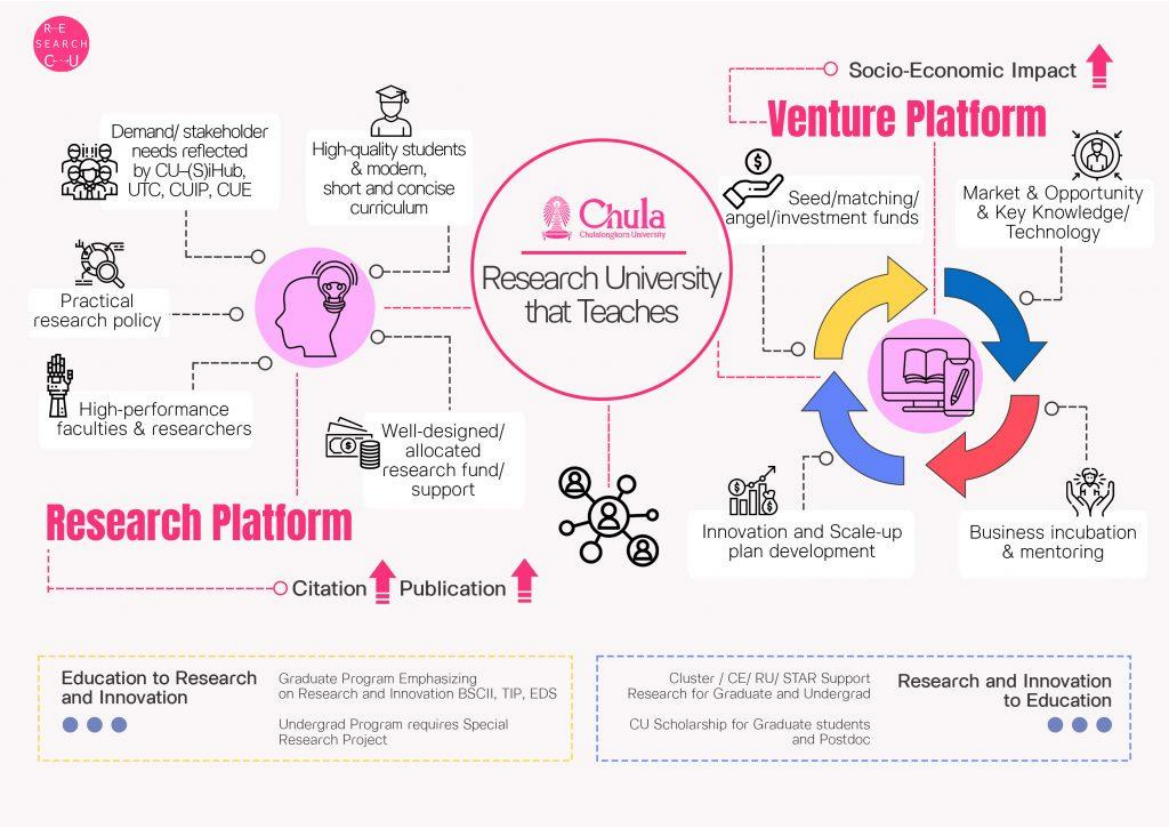
Chulalongkorn University is a public and autonomous research university in Bangkok, Thailand. The university was originally founded during King Chulalongkorn's reign as a school for training royal pages and civil servants in 1899 at the Grand Palace of Thailand. It was later established as a national university in 1917, making it the oldest institute of higher education in Thailand.

Chulalongkorn University is a comprehensive and research-intensive university. It is ranked as the best university in Thailand in many surveys quality of students, quality of research, quality in particular

subjects, university reputation, and environmental management systems. According to QS World University ranking 2022, CU is placed 215th in the world, 36th in Asia, and 1st in Thailand.

Chulalongkorn University was established with 4 faculties in 1917: Arts and Sciences, Public Administration, Engineering, and Medicine and currently consists of consists of 20 faculties, 3 colleges, one school and many institutes which function as teaching and research units.

The following figure shows recent educational and research vision of Chulalongkorn University.



Source: Chulalongkorn University (RESEARCH AND INNOVATION FOR SOCIETY), https://www.research.chula.ac.th/)

Figure 2-9 Educational and Research Vision of Chulalongkorn University

Focused Research Area: Advanced Materials, Aging, ASEAN, Bio-refinery, Climate Changes and Disaster Management, CU Cannabis, Energy, Energy Storage, Food and Water, Frontier Biotechnology in Emerging Diseases, Genomic Medicine, Health, Labour and Workforce, Microplastic and Plastic Waste, One Health, Smart City, Innovation in Arts and Culture, Tele-health, and Tropical Medicine

2) Vidyasirimedhi Institute of Science and Technology (VISTEC)

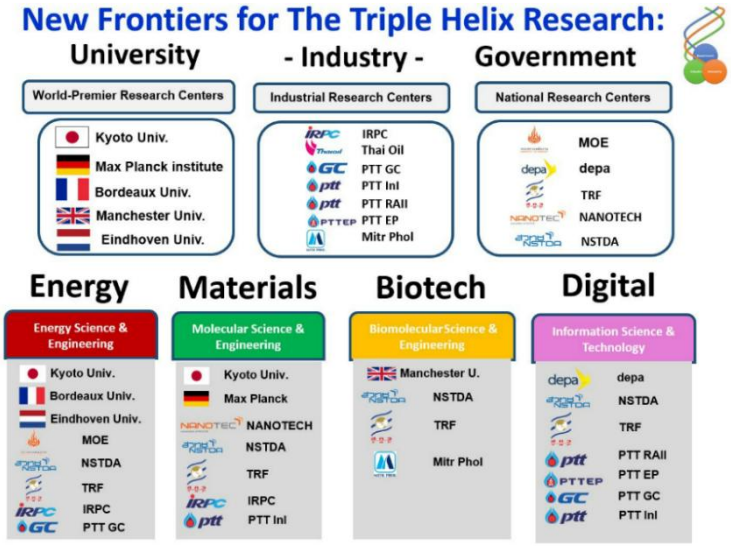
VISTEC is a private post-graduate university established by PTT Public Company Limited (PTT) in 2015, which is the only Thai company ranked among the top 100 companies in the world by Fortune magazine. VISTEC is located at the heart of EECi in Wangchan Valley, Rayong. VISTEC strives towards world-class research excellence by creating advanced knowledge and cutting-edge innovation to address national demands and global challenges. Its mission is to become an internationally-

recognized university; to foster passionate faculty and talented students; to actively pursue high-quality, high-impact, frontier research, and to enhance Thailand's competitiveness via research and innovation for the sustainable development of the society.

4 schools have been established to focus on the four interdisciplinary areas of future key technologies.

- School of Molecular Science and Engineering (MSE)
- School of Energy Science and Engineering (ESE)
- School of Biomolecular Science and Engineering (BSE)
- School of Information Science and Technology (IST)

In addition to the above schools, Frontier Research Centre (FRC) has been established with state-of-the-art facilities such as Transmission Electron Microscope (TEM) and Nuclear Magnetic Resonance Spectroscopy. FRC aims at the focal point for research collaborations with both academic and industrial partners from around the world.



Source: VISTEC, https://www.vistec.ac.th/about/collaboration.php

Figure 2-10 Research Collaboration of VISTEC

(3) Private (Industrial) Sector

Thai Industry has long played a role as the world's factory; however, transformation to Industry 4.0 or Thailand 4.0 is the proposition nowadays, in other words, the private sector needs to be transformed from labor-intensive industry to knowledge-intensive industry based on research and development. The Thai industry needs to be changed from being a technology follower to a technology leader to be able to develop innovative and high value-added products to the market.

Amid this trend, many of the companies driving the Thai industry have continued to invest in their research and development divisions. For example, the Cement-Building Materials Business Unit of the SCG group established a research and development company named Siam Research and Innovation Company Limited (SRI); PTT Group restructured a research center named the PTT Innovation Institute; CP ALL Group

established a research and development company named CP Food Lab (CPF); and CPF has a R&D oriented company named CPF Food Research & Development Center.

Macroscopic data has also shown this trend. One of the examples is data shown by the Figure 2-2 in the previous section, during period from 2009 to 2019, GERD/GDP dramatically increased from 0.23 to 1.14 and the driving force of this improvement is the private sector. In 2009, the total R&D expenditure was THB22,655, in which the public sector accounts for 59% with THB13,319 while the private sector accounts for 41% with THB9,336. In 2019, the total R&D expenditure was THB192,852, in which the public sector accounts for 23% with THB43,628 while the private sector accounts for 77% with THB149,224. During this period, the R&D expenditure of the private sector increased by about 16 times which the public sector increased by 3.3 times.

Table 2-9 R&D Expenditure by Sector 2009 to 2019

million Baht

Sector	2009		2011		2013		2014		2015		2016		2017		2018		2019	
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
Public	13,319	59%	20,186	49%	30,270	53%	29,045	46%	25,229	30%	30,826	27%	31,201	20%	39,385	22%	43,628	23%
	times:1.0		times:1.5		times:2.3		times:2.2		times:1.9		times:2.3		times:2.3		times:3.0		times:3.3	
Private	9,336	41%	20,684	51%	26,768	47%	34,445	54%	59,442	70%	82,701	73%	123,942	80%	142,971	78%	149,224	77%
	times:1.0		times:2.2		times:2.9		times:3.7		times:6.4		times:8.9		times:13.3		times:15.3		times:16.0	
Total	22,656	100%	40,872	100%	57,040	100%	63,492	100%	84,673	100%	113,529	100%	155,145	100%	182,359	100%	192,855	100%
	times:1.0		times:1.8		times:2.5		times:2.8		times:3.7		times:5.0		times:6.8		times:8.0		times:8.5	

Source: UNESCO and NXPO, prepared by JST

JST interviewed 16 companies for the survey, and the R&D costs of those companies and whether they have used SPS-I in the past are summarized in the table below.

Table 2-10 Summary of Interviews on R&D Costs

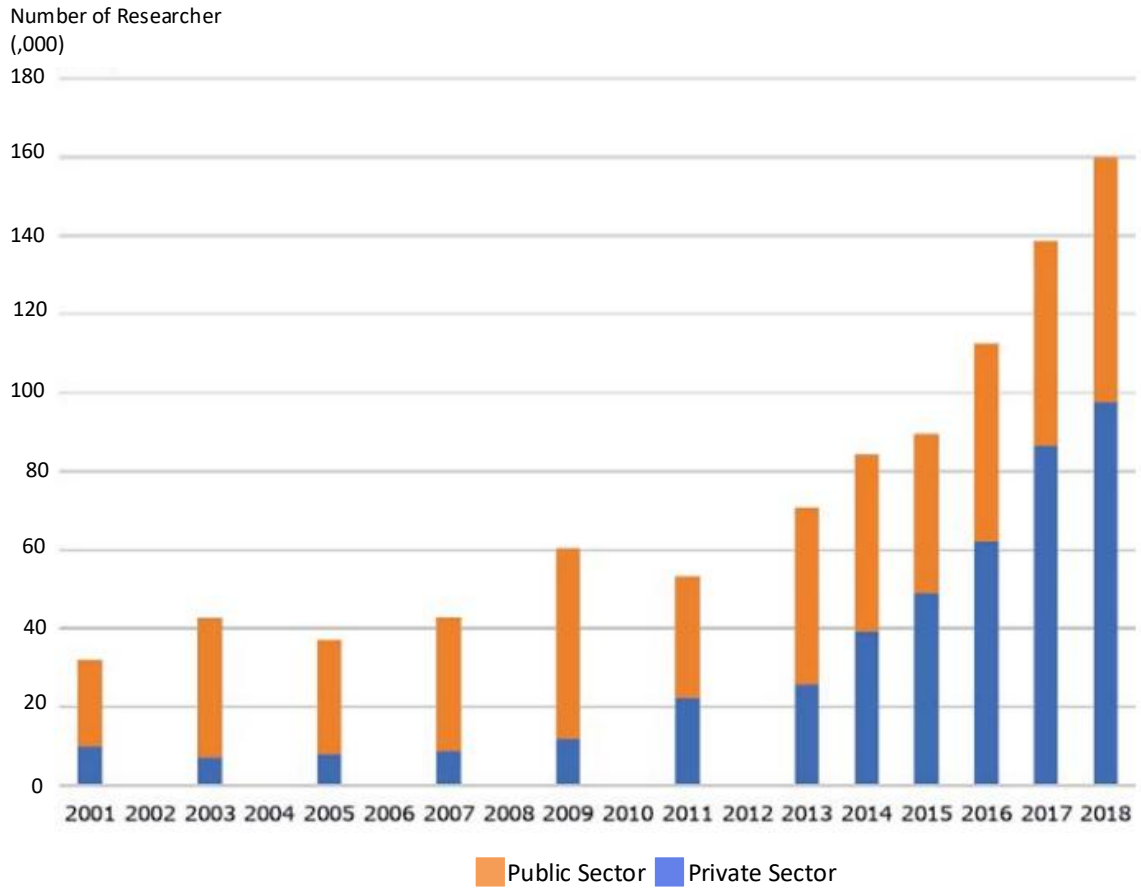
Business Scale/Type	Product	Total Revenue (Approx-MB)	Net Profit (Approx-MB)	R&D expenditure (Approx-MB)	SLRI Users	Beamline
Large Enterprise	Foods/ Retail	545,000.00	17,000.00	30.00	NA	
Large Enterprise	Feeds/ Farms/ Foods	545,000.00	19,000.00	500.00	yes	BL4.1: IR
Large Enterprise	Fuel/ Petrochemical products	153,000.00	53,900.00	501.00	yes	
Large Enterprise	Petrochemical products	499,000.00	19,400.00	890.00	yes	BL1.2 XTM; BL1.3W-SAXS; BL8-XAS
Large Enterprise	Building Materials	205,000.00	3,800.00	2,680.00	NA	
Large Enterprise	Petrochemical products	237,000.00	5,900.00	1,600.00	yes	BL1.2 XTM; BL1.3W-SAXS; BL8-XAS
Large Enterprise	Packaging	146,000.00	5,800.00	510.00	yes	
Large Enterprise	Steel	26,000.00	(100.00)	200.00	yes	BL3.2Ub: PEEM; BL5.2: XAS; BL5.3: XPS
Large Enterprise	Foods	25,000.00	3,800.00	9.00	yes	BL4.1: IR
Japanese affiliated	Cosmetics/ Consumers	14,000.00	700.00	25.00	yes	BL1.2W: XTM; BL1.3W: SAXS/WAXS; BL4.1: IR
SME	Chemical product	1.00	0.01	1.00	yes	NA
SME	Land	1.98	0.77	5.00	yes	NA
SME	Chemical product	-	(0.15)	0.20	yes	NA
SME	Chemical Lab	480.23	81.30	project based	yes	BL4.1: IR
SME	Medical Equipment	0.00	(0.01)	1.50	yes	BL6: DXL
SME	Cosmetics	2,960.20	82.20	upon request	yes	BL4.1: IR

Source: JST

2.2 R&D Human Resources in Science and Technology

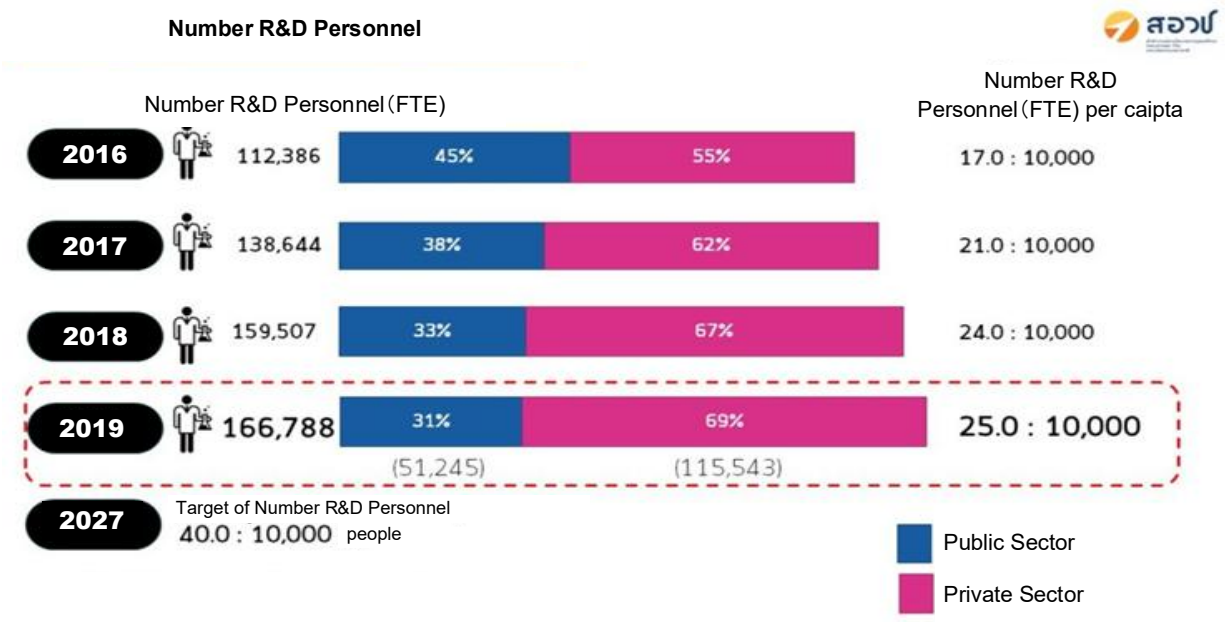
2.2.1 R&D Human Resources in Thailand

The number of R&D researchers in Thailand has grown steadily over the past decade because the number of private researchers has been increasing, mainly due to the increase in private R&D expenses while the number of researchers at government agencies has been almost flat or slightly increased. In 2017, the number was 138,644 (full-time equivalent), but in 2018 it increased by 15% to 159,507 people. The breakdown is 67% in the private sector and 33% in the public/government sector, equivalent to 24 per 10,000 people. In the STI Policy Plan (2012-2021) prepared by the National Science, Technology and Innovation Agency, the number of researchers as of 2012 was 9 per 10,000 people and targeted to increase 25 per 10,000 people by 2021, which increase 2.7 times of the one in 2012. GOT targets to increase to 40.0 per 10,000 people by 2027.



Source: NXPO, prepared by JST

Figure 2-11 Number of Researcher by Sector

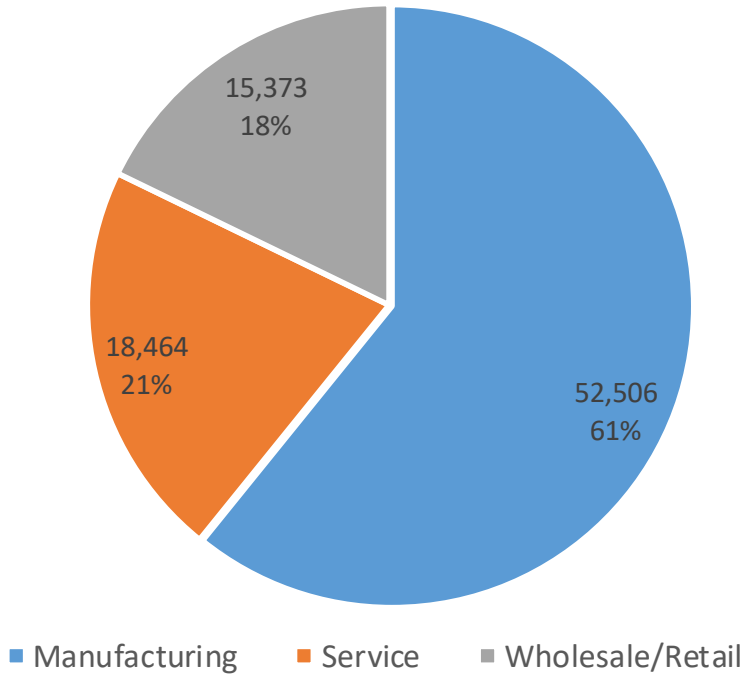


Source: https://www.nxpo.or.th/th/7929/

Figure 2-12 Target of R&D Personnel

Breakdown of the private sector

The number of R&D personnel in the private sector in 2017 was 86,343. Out of 86,343 researchers, manufacturing sector is 52,506 (61%), service sector is 18,604 (21%) and wholesale/retail is 15,373 (18%).



Source: NXPO, prepared by JST

Figure 2-13 Number of R&D Personnel by Business Sector in the Private Sector in 2017

The following table shows the number of R&D personnel by more detailed business field under the manufacturing sector.

Table 2-11 Number of R&D Personnel by Year

Field of Business	2013	2014	2015	2016	2017
Food products and beverages	3,373	4,648	5,536	8,996	10,281
Motor vehicles	1,048	893	2,290	5,404	6,840
Chemicals and chemical products	3,536	3,872	3,985	5,736	6,135
Electrical machinery and apparatus	1,531	747	1,415	1,429	4,528
Refined petroleum products	541	728	426	4,445	4,291
Basic metals and fabricated metal products	990	742	2,187	797	3,097
Other non-metallic mineral products	1,318	1,829	1,803	2,565	2,894
Machinery and equipment	1,389	2,344	3,721	1,975	2,732
Office, accounting and computing machinery	-	415	1,470	1,981	2,289
Rubber and plastic products	808	1,741	4,011	2,038	1,711
Recycling, electricity, gas and water supply	626	750	337	613	1,629
Furniture	275	1,229	2,815	2,619	1,284
Radio, television and communication equipment and apparatus	1,348	1,219	980	1,014	939
Agriculture	-	769	203	623	909

Field of Business	2013	2014	2015	2016	2017
Paper and paper products	210	282	1,301	769	669
Other transport equipment	233	327	268	714	442
Textiles	272	564	307	308	439
Wearing apparel	711	330	557	528	382
Leather products and footwear	432	328	554	398	368
Mining and quarrying	50	162	52	113	296
Wood and wood products	357	363	142	194	123
Printing	102	205	495	136	117
Medical, precision and optical instruments, watches and clocks	97	225	45	129	101
Tobacco products	3	8	10	10	10
Total	19,250	24,720	34,910	43,534	52,506

Source: NXPO, prepared by JST

GOT aims not only to increase the number of researchers, but also to improve their quality. The success of Thailand 4.0, which emphasizes STI requires more than just the total number of researchers but also the number of highly skilled industrial HR and postdoctoral researchers. The number of researchers with the doctoral degree was 9.5 per 10,000 people in 2014, and targeted increase 80 per 10,000 people in 2036 in the 20-year plan (Thailand 4.0).

GOT has set up scholarships for studying abroad to promote human resource development through overseas study. In 2022, a total of 2,296 students, consisting of 1,710 government-sponsored scholarships and 586 other scholarships, started their studies at higher education institutions in foreign countries. The table below summarizes the number of students studying abroad through government scholarships and other scholarships from 2018 to 2022.

Table 2-12 Number of Scholarship by Source and Year

	Government Scholarship	Other Scholarship	Total
2018	2,166	715	2,881
2019	2,054	723	2,777
2020	1,710	586	2,296
2021	1,756	647	2,403
2022	1,782	654	2,436
Total	9,468	3,325	12,793

Source: OCSC, prepared by JST

From 2020 to 2022, the impact of the coronavirus pandemic was clearly visible, and in 2020 there was a significant decline in the number of international students. Since then, there has been a gradual recovery trend in 2021 and 2022, but it is taking time to return to pre-coronavirus levels, but it is expected that the number of international students will recover further in the future.

The chart below shows the study destinations by country from 2018 to 2022.

Table 2-13 Number Scholarship by Country

Country	2018		2019		2020		2021		2022		Total	
UK	1244	43.2%	1260	45.4%	1049	45.7%	1106	46.0%	838	34.4%	5499	43.0%
USA	925	32.1%	848	30.5%	723	31.5%	812	33.8%	989	40.6%	4298	33.6%
Japan	145	5.0%	157	5.7%	137	6.0%	139	5.8%	182	7.5%	760	5.9%
Germany	145	5.0%	90	3.2%	78	3.4%	66	2.7%	69	2.8%	448	3.5%
Australia	94	3.3%	102	3.7%	74	3.2%	54	2.2%	79	3.2%	403	3.2%
Netherlands	64	2.2%	58	2.1%	40	1.7%	44	1.8%	52	2.1%	258	2.0%
China	54	1.9%	53	1.9%	47	2.0%	36	1.5%	57	2.3%	247	1.9%
France	45	1.6%	35	1.3%	26	1.1%	23	1.0%	28	1.1%	157	1.2%
Canada	21	0.7%	17	0.6%	15	0.7%	18	0.7%	15	0.6%	86	0.7%
New Zealand	21	0.7%	23	0.8%	15	0.7%	11	0.5%	10	0.4%	80	0.6%
Taiwan	5	0.2%	9	0.3%	12	0.5%	10	0.4%	18	0.7%	54	0.4%
South Korea	8	0.3%	9	0.3%	8	0.3%	5	0.2%	12	0.5%	42	0.3%
Other	110	3.8%	116	4.2%	72	3.1%	79	3.3%	87	3.6%	464	3.6%
Total	2881	100%	2777	100%	2296	100%	2403	100%	2436	100%	12797	100%

Source: OCSC, prepared by JST

The top two study abroad destinations are the UK and the US every year, with the share of both countries exceeding 75% throughout the period. Japan ranks third, but its share is just under 6%.

Regarding research and study fields by government-scholarship students for three years from 2018 to 2020, the top 20 fields are shown in the table below.

Table 2-14 Top 20 Fields of Government Scholarship Students

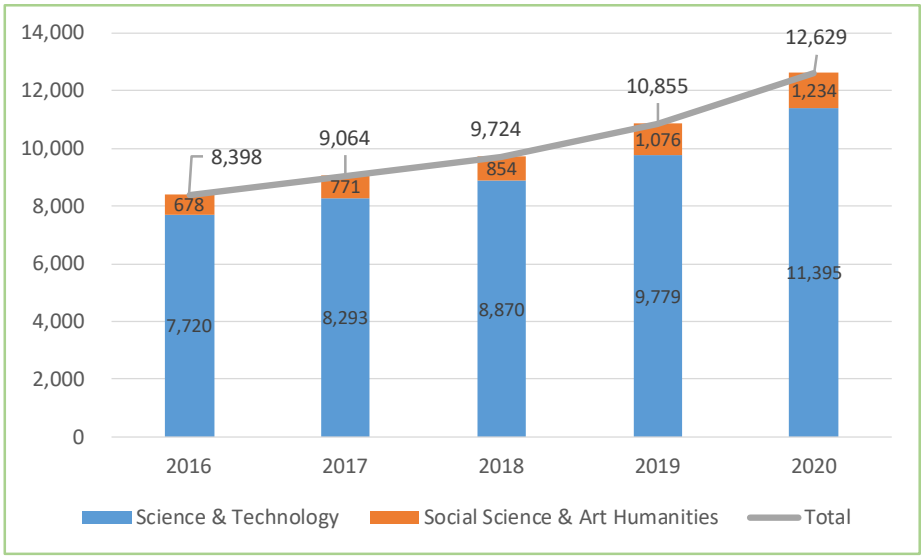
	2018		2019		2020	
	Field	(%)	Field	(%)	Field	(%)
1	Engineering	22.5	Engineering	22.2	Engineering	23.3
2	Biology	7.9	Computer Science	7.7	Computer Science	8.7
3	Computer Science	7	Biology	7.2	Physics	7.4
4	Physics	6.9	Physics	6.5	Biology	6.8
5	Mathematics	6.3	Mathematics	5.7	Mathematics	6.4
6	Chemistry	5.4	Chemistry	5.5	Chemistry	6.3
7	Science	3.9	Science	4.6	Science	4.9
8	Business Administration	3.5	Law	3.4	Economic	2.5
9	Law	3.2	Business Administration	3.2	Law	2.5
10	Economic	2.6	Economic	3.1	Business Administration	2.5
11	Medicine	2.4	Political Science	3	Food Science and Technology	2.3
12	Linguistics	2.3	Food Science and Technology	2.4	Medicine	2
13	Political Science	2.3	Medicine	2	Language	1.8
14	Food Science and Technology	2.1	Management	1.6	Nursing	1.6
15	Nursing	1.7	Linguistics	1.6	Pharmacy	1.6
16	Pharmacy	1.6	Nursing	1.6	Political Science	1.5
17	Environmental studies	1.5	Pharmacy	1.5	Geology	1.5
18	Social Science	1.4	Geology	1.4	Management	1.3
19	Geology	1.3	Social Science	1.4	Linguistics	1.3
20	Management	1.1	Environmental studies	1.3	Environmental studies	1.2
	Others	13.1	Others	13.1	Others	12.6

Source: OCSC, prepared by JST

Science & Technology-related fields such as Engineering, Computer Science, Biology, Phocis, Chemistry, etc. occupy the top positions every year, and it is highly expected that they will become the core human resources who will play a role in Thailand's R&D in the future.

2.2.2 Research Paper

The figure below shows the transition in the number of submissions to international journals by Thai researchers (2016 to 2020).



Source: Thomson Reuters Web of Knowledge, prepared by JST

Figure 2-14 Number of Papers Submitted to International Journals in Thailand

The table below shows the number of researchers, the number of papers and the number of papers per researcher in major Asian countries in 2020.

Table 2-15 Comparison of Paper and Per Researcher in Asia

Country	Number of Researcher	Number of Paper			Number of Paper per Researcher		
		S&T	Social	Total	S&T	Social	Total
Singapore	44,800	15,066	3,227	18,293	0.336	0.072	0.408
Malaysia	83,800	13,802	2,345	16,147	0.165	0.028	0.193
South Korea	525,700	68,653	8,809	77,462	0.131	0.017	0.147
China	4,800,800	515,422	41,307	556,729	0.107	0.009	0.116
Taiwan	271,600	28,485	5,485	33,970	0.105	0.020	0.125
Japan	903,400	88,179	7,038	95,217	0.098	0.008	0.105
Philippines	27,800	1,972	582	2,554	0.071	0.021	0.092
Thailand	166,800	11,395	1,234	12,629	0.068	0.007	0.076
Indonesia	74,900	5,032	1,192	6,224	0.067	0.016	0.083

Source: Thomson Reuters Web of Knowledge, prepared by JST

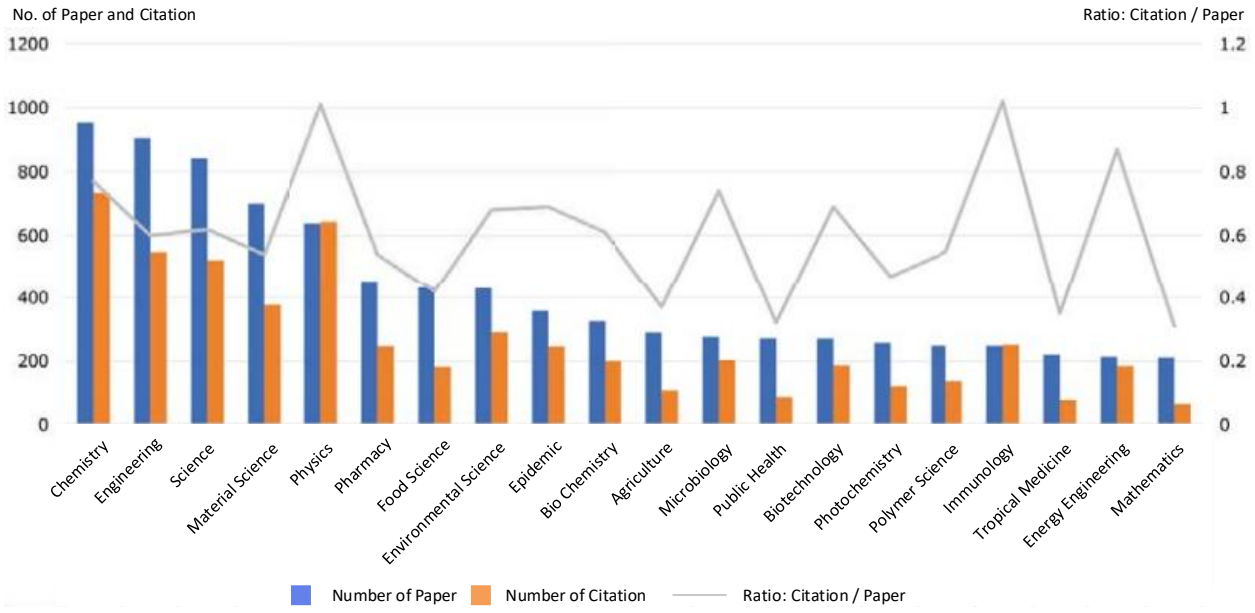
The number of papers per researcher in Thailand is 0.068, which is on the same level as the Philippines and Indonesia. The table below summarizes the number of papers and the number of papers per 1,000 population in major Asian countries.

Table 2-16 Comparison of Paper and Per 1,000 People in Asia

Country	Population	Number of Paper			Number of Paper per 1,000		
		S&T	Social	Total	S&T	Social	Total
Singapore	5,680	15,066	3,227	18,293	2.652	0.568	3.221
Malaysia	32,366	13,802	2,345	16,147	0.426	0.072	0.499
South Korea	51,269	68,653	8,809	77,462	1.339	0.172	1.511
China	1,439,324	515,422	41,307	556,729	0.358	0.029	0.387
Taiwan	23,561	28,485	5,485	33,970	1.209	0.233	1.442
Japan	126,476	88,179	7,038	95,217	0.697	0.056	0.753
Philippines	109,581	1,972	582	2,554	0.018	0.005	0.023
Thailand	69,800	11,395	1,234	12,629	0.163	0.018	0.181
Indonesia	273,524	5,032	1,192	6,224	0.018	0.004	0.023

Source: Thomson Reuters Web of Knowledge, prepared by JST

The number of papers in the Science and Technology field per 1,000 people in Thailand is 0.163, which is lower than Malaysia and China, but higher than the Philippines and Indonesia. The figure below shows the number of papers, citations, and the ratio of citations/papers by research field in Thailand in 2020.



Source: NXPO and others, prepared by JST

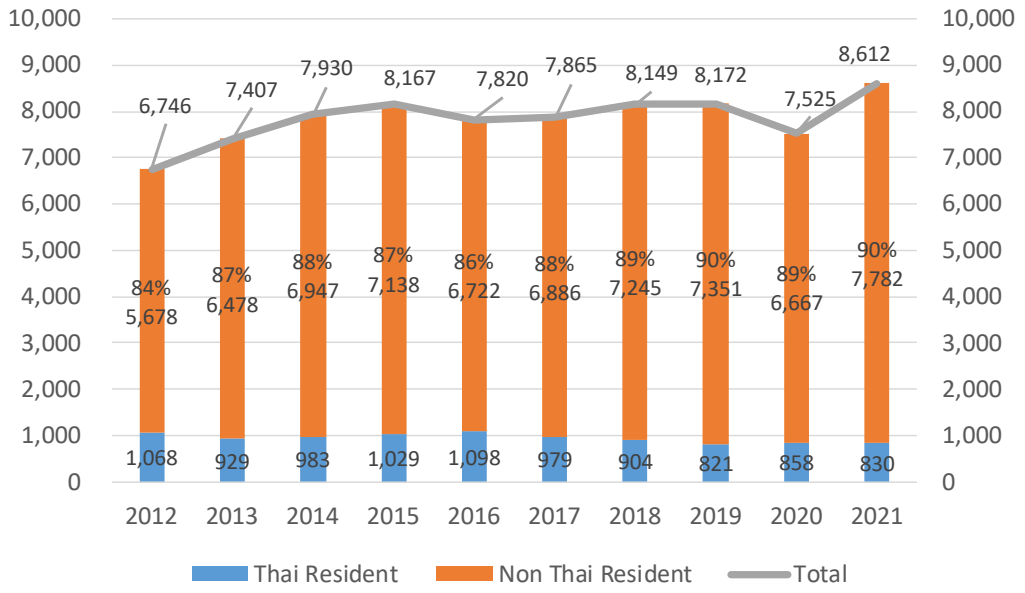
Figure 2-15 Number of Paper/ Citation by Research Field

The field of chemistry has the highest number of papers and citations.

2.2.3 Patent

In Thailand, intellectual property rights including patent are governed by Department of Intellectual Property (DIP) under the Ministry of Commerce. Patent, Petty Patent (similar with "Utility Model" in Japan) and Design are legalized by Patent Act (1979, 1992 and 1999). One of characteristics of Thai patent applications is that more applications are by non-residents than by Thai- residents.

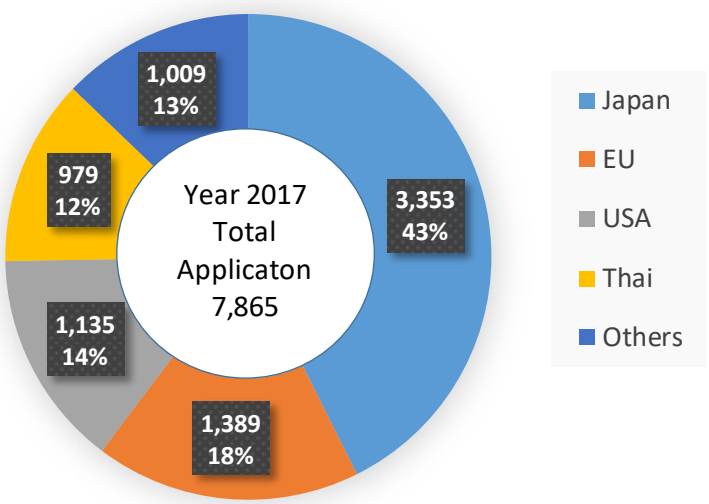
As referred by the following table, in the past decade the total number of applications in Thailand has slightly increased and the ratio of number of applications by Non-Thai Resident to total applications has stayed in high level around 80-90%.



Source: Department of Intellectual Property, https://www.ipthailand.go.th/th/, prepared by JST

Figure 2-16 Number of Patent Applications by Thai Resident and Non-Thai Resident

As shown in following figure, the number of patent applications from Japan accounts for 43%of the total, while Thailand accounts for 12%.



Source: JETRO Bangkok, prepared by JST

Figure 2-17 Breakdown of Patents Applications in 2017

The table below summarizes the number of international patents in Asia-Pacific countries.

Table 2-17 Number of Applications to International Patent in Asia-Pacific Region

Country	2017	2018	2019	2020	2021
China	1,257,702	1,306,019	1,460,244	1,327,847	1,441,085
Japan	453,640	460,660	460,369	452,130	423,254
South Korea	233,625	226,568	232,020	248,427	260,610
India	25,795	27,985	30,036	34,015	37,880
Australia	11,679	11,656	12,261	12,568	11,906
Singapore	6,684	6,950	7,415	7,354	7,946
Malaysia	1,929	2,148	2,060	2,122	1,923
New Zealand	3,062	3,182	3,039	2,173	2,377
Indonesia	52	2,320	1,451	3,141	1,358
Thailand	503	1,611	1,685	1,766	1,512
Vietnam	632	663	749	838	1,133
Philippines	554	508	736	674	630
Mongolia	114	128	83	90	70
Brunei	5	19	25	21	10
Cambodia	4	-	10	2	11
Laos	5	-	1	1	8
Myanmar	2	3	1	1	-

Source: World Intellectual Property Organization, prepared by JST

The number of international patents in Thailand in 2021 was 1,512, which is the third largest number among ASEAN countries after Singapore and Malaysia.

2.2.4 Industry-Government-Academia Collaboration Project

One of the keys to free Thailand from the middle-income trap is to employ technology and innovation to create high-value goods and services to drive an innovation-based economy and society. As the industry is an essential player in the development of innovation-driven economy, it is necessary to empower enterprises to innovate and create technology that will bring about commercially viable products and services. Industry, government, and academia should work together to address this issue.

From the standpoint of jurisdiction over higher education and research activities, MHESI has launched two programs as Industry-Government-Academia Collaboration Project.

Higher Education Sandbox: to nurture human resources to meet with demands from the industry.

Thailand Business Innovation Research (TBIR): to provide research fund aiming at encouraging local enterprises to engage in research demanded by the government sector.

Higher Education Sandbox

The Higher Education Sandbox is a higher education system launched by MHESI based on Article 69 of the Higher Education Law B.E.2562 with the aim of innovatively improving the conventional higher education curriculum and program to meet the human resource development needs of the industry. Higher education programs under this system are required to develop a curriculum in collaboration with industry. It is possible to develop a curriculum without being bound by the conventional school period (4 years of bachelor's degree) or curriculum and syllabus requirement, which enables to develop more practical and innovative curriculum which meets the needs from the private sectors.

Thailand Business Innovation Research (TBIR)

TBIR is a funding program aimed at encouraging local industries to engage in research demanded by the government sector. The program consists of the following actors:

1) Government – Government agencies mainly provide funding and take on the risk of research and innovation. They identify needs for technology and innovation that will enable them to either fulfill their mission or solve current social problems or create economic impact. They will also serve as initial users of such technology and innovation before connecting to other potential users.
2) Enterprises – Enterprises play a role of inventors of technology and innovation demanded by government agencies. In addition to creating innovation, enterprises also increase their potential through TBIR.
3) Universities – Universities provide R&D support and mentorship to enterprises.

TBIR comes with a mechanism to promote government-university-industry-academia collaboration through joint research, technology/knowledge transfer and access to research facility, thus ensuring that all resources are directed towards the creation of innovation in firms. With a large number of SMEs in Thailand, TBIR is expected to drive the growth of SMEs by acting as a financing facility providing research grants to SMEs and startup companies. By allowing enterprises to own intellectual properties derived from the

research grant, thus expediting the commercialization process, this program helps turn SMEs and startups into innovation-driven enterprises which are the primary engine to fuel an innovation-driven economy.

2.2.5 University-Originated Venture Company

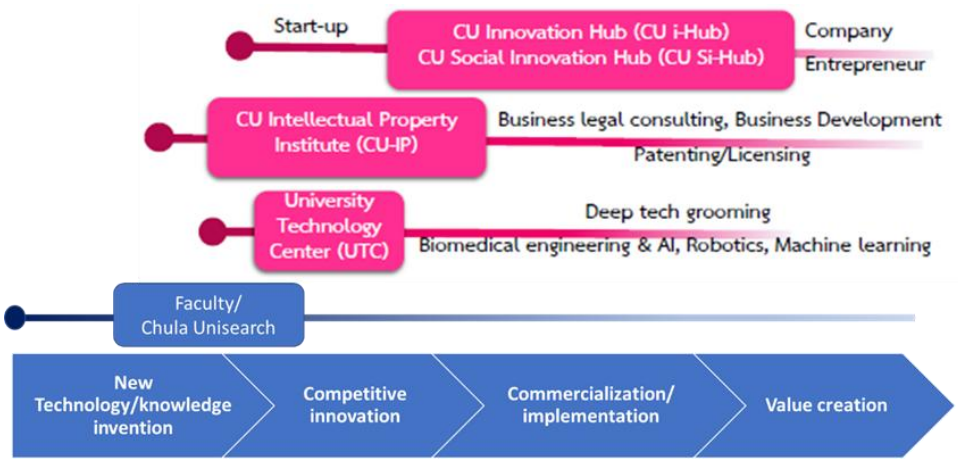
University-originated ventures are highly expected to be "leaders of innovation" that aim to create new markets by discovering latent university research results and creating new markets with highly novel products. As mentioned above, transforming to an innovation-based economy and society is an important task for Thailand, so, to foster university-originated ventures is highly expected. For this issue, MHESI has launched the aforementioned TBIR as a program to support research funding for startup companies and SMEs. Some universities have established a system that specializes in supporting university-originated ventures, separate from organizations that support industry-academia collaboration. The table below shows the list of universities and their startup management supporting units.

Table 2-18 Startup Management Supporting Units

University	Startup Management Supporting Units
Chulalongkorn University	CU Innovation Hub (CU iHub)
Mahidol University	Institute for Technology and Innovation Management (INT)
King Mongkut's Institute of Technology Ladkrabang	KMITL Research and Innovation Services (KRIS)
King Mongkut's University of Technology Thonburi	Knowledge Xchange for Innovation (KX)
Khon Kaen University	Technology and Innovation Management Center (KKU-INNOPRISE)
Suranaree University of Technology	Student Entrepreneurship Development Academy (SEDA)
Thammasat University	Center of Intellectual Property and Business Incubator (TUIPI-TUBI)
Prince Songkla University	PSU Science Park
Chiang Mai University	Science and Technology Park (STeP)

Source: JST

Chulalongkorn University has setup relevant on-campus research supporting units throughout the innovative business stages for startup companies. Their roles and responsibilities are shown in the following figure.



Source: Churla Research Affairs

Figure 2-18 On-Campus Research Supporting Units

Chulalongkorn University established the CU Innovation Hub (CU iHub) to support university-originated startup companies. Below is a summary of the center's activities.

CU iHub was established to support university-originated startup companies in 2017, which is mainly to promote and support the creation of innovations that will usher the Thai society into a new way of life, learning, and creativity; to produce graduates of top talent who will become the leaders of the future, to see new business opportunities via technology and intellectual properties and dare to create a disruptive change in conventional industries, challenge the traditional mindset in the workplace.

The startups under the iHub umbrella focus on creating outstanding innovations for society in five key areas:

1) Health/Aging,
2) Education,
3) Bio-Circular Green Food & Agriculture,
4) Sustainable Society,
5) Deep Tech Supercluster.

Startups under CU iHub include Baiya Phytopharm, Co., Ltd producing COVID-19 vaccine from tobacco leaves, and ViaBus mobile application that facilitates commuters on public transport which was selected as Consumer Technology 30 Under 30 by Forbes Asia in 2021. The following table summarizes representative startups under CU iHub.

Table 2-19 Startups under CU-iHub

Startup name	Affiliation/ Research Field	Innovative Product	Description	Achievements
Baiya Phytopharm	Pharmaceutical Sciences	Biopharmaceutical products COVID-19 vaccine	Focused on strengthening health security for all people, such as vaccines and anti-cancer products	The first plant-based cGMP facility for human in Asia

Startup name	Affiliation/ Research Field	Innovative Product	Description	Achievements
ViaBus	Computer Engineering	Real-time Transit Application	A real-time public transport bus tracking and navigation application around Bangkok Metropolitan	Consumer Technology 30 Under 30 (2021 Forbes Asia)
sPace	Mechanical Engineering	Dynamic Artificial Prosthetic Feet	A high-quality dynamic prosthetic feet made from carbon fibers which are flexible and bendable and can store energy with each step.	Petty patent, ISO 10328 strength standards, ISO 13485 for quality, and Food and Drug Administration (FDA) certified
Cure	Metallurgy Engineering and Material Science	Cure Air Filter	High Efficiency Filtration Technology	Sub-micron Particulate Filtration Efficiency (PFE) at 0.1 Micron, Design Excellent Award 2021
Nabsolute	Pharmaceutical Sciences	Mask Shield+ Protecting Spray	Nano-modification of biopolymer (Hy-N Technology) to unlock the limitation of new healthcare material development	Patented technology improving stability and efficacy of cosmetics, food, pharmaceutical products
PhytFoon	Pharmaceutical Sciences	Dust Reduction Spray	For Allergic and PM2.5 protection which derived from natural compounds	Human Repeat Insult Patch Test, Hypoallergenic Test
Enginelife	Bio-medical Engineering	SERI products for Drug/Vaccine controlled release systems and Tissue engineering	R&D of Thai silk protein for medical application. The focused applications are drug-controlled release carrier and artificial scaffold for tissue regeneration	SERI Cleanroom Laboratory with ISO 14644-1 Standard
Mineed	Pharmaceutical Sciences	Mineed's Detachable Dissolvable Microneedles	Detachable Dissolvable Microneedle Technology: quick, convenient, and painless administration with dose precision	Taiwan patent granted
Tann D	Allied Health Sciences	Tann D Inno-Food (Eggyday)	Demon Protein Albumen Food	CU petty patent
Enrez	Information Technology and Computer Engineering	Enrez: IoT and AI based Building Health and Energy Monitoring	24Hrs Real-Time Monitoring and Analysis using IoT and AI Technology	DEPA Accelerator Program (ASEAN's First Smart City Accelerator Winner (2019)
Kollective	Information Technology and Marketing Technology	Integrated Influencer Marketing Optimizer	Redefine "Influencer Marketing" in a non-traditional way for maximum performance and efficiency	5 winners in Startup Competitions
Biom	Biotechnology Sciences	Microbial Biostimulants	Innovative "microbial" detoxification accumulated residual in the soil	Patent Pending
Crystallyte	Nanotechnology Engineering	Crystallyte: CO_2 converter into Carbon Nanomaterials	Negative CO_2 emission carbon production from natural oxygenic organic compounds via zero thermal energy CO_2 capture/regeneration process	MOU with Department of Intellectual Property

Source: Chulalongkorn University, prepared by JST

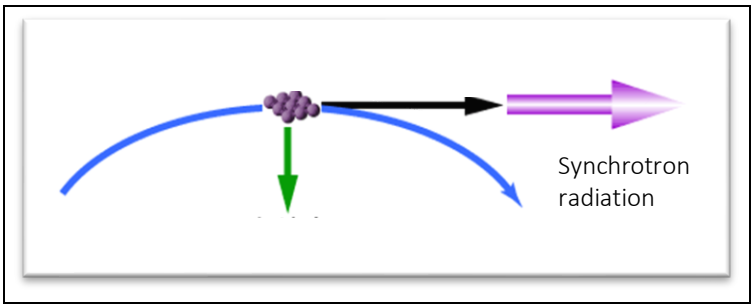
2.3 Outline (Mechanism) and Features of SRF

2.3.1 Mechanism of SRF

(1) Principle

Electromagnetic waves generated when electrons traveling straight ahead at nearly the speed of light are changed in their direction of motion by a magnet or other means are called synchrotron radiation. The higher the energy of the electrons, the brighter and more directional the synchrotron radiation becomes, and the higher the energy of the electrons and the greater the change in direction of motion, the more light of shorter wavelengths such as X-rays is included.

Electrons create an electric field around them. When high-energy electrons are bent by a magnetic field, the virtual photons are shaken off and emitted as real photons, which are synchrotron radiation.



Source: SPring-8 website

Figure 2-19 SRF Mechanism

(2) Magnets for Generating Synchrotron Radiation

There are two types of magnets used to change the direction of electrons: bending magnets, which are necessary to rotate electrons in a ring-shaped accelerator, and insertion devices, which are specific combinations of magnet rows. Insertion devices are further divided into two types: undulators and wigglers, each of which produces a unique type of synchrotron radiation.

- Bending magnets: Light of continuous wavelengths from infrared to X-rays can be obtained.
- Undulators: When the magnetic field is relatively weak, Produce extremely bright light of a specific wavelength by periodically meandering electrons in a small pattern and causing interference with the synchrotron radiation generated by each meandering motion.
- Wigglers: When the magnetic field is relatively strong, by meandering electrons in a large number of large meanders, brighter light of continuous wavelengths can be obtained in a short wavelength range than bending magnets.

(3) Areas of Application

Synchrotron radiation can be used for the following purposes.

- To understand the types, structures, and properties of materials in detail
- To study in detail the structure and properties of materials under various environmental conditions and their changes over time

- As a driving force to unravel the mechanisms for chemical reactions and material changes.

Synchrotron radiation is useful for basic and applied research in a wide range of fields as follows, as well as for industrial applications.

Life science: 3D structural analysis of protein macromolecules, small-angle scattering of non-crystalline biomaterials, drug design, new drug development, etc.

Material Science: Atomic and electronic structures of advanced materials, material properties under extreme conditions, evaluation of industrial materials, creation of new materials and material modification, etc.

Chemistry: Dynamic behavior of catalytic reactions, X-ray photochemical processes on surfaces, atomic and molecular spectroscopy, ultra-trace element analysis and chemical state, archaeological research, etc.

Geoscience: Structure and state of deep Earth materials, physical properties under extreme conditions, structure of meteorites and cosmic dust, etc.

Environmental science: Analysis of environmental pollution trace elements in biological samples, local structure analysis of high-performance battery materials, analysis of catalysts for environmental purification, etc.

Medicine: Observation of tumor blood vessels by micro angiography, tomography, observation of respiratory diseases by refraction contrast imaging, etc.

Industry: Evaluation of new oxide materials for semiconductors, evaluation of nanomaterials, trace element analysis, tomographic observation of materials, analysis of strain distribution in materials, etc.

The main research fields in each energy region are as follows. In the high-energy region, structural studies using diffraction and scattering are the main research fields, while electronic structure studies using spectroscopy are the main research fields in the low-energy region.

Hard X-ray region:

- Light with a short wavelength of 0.2 nm or less
- Research for microscopic structural analysis such as atomic-level imaging and crystal structure analysis

Soft X-ray region:

- Light from 0.2 nm to 10 nm
- Acts on "inner-shell electrons" of the element. Enables selective measurement of local electron and span states around specific elements.
- Overlaps with the electron-binding energy region of light elements such as beryllium to potassium and captures element-specific electronic states.

Vacuum ultraviolet region:

- Light from 10nm to 300nm
- Acts on the "valence electrons" of the elements. It is possible to observe the valence electron state of a material as a whole.
- Possible to investigate the valence electron structure related to the scientific bonding state and magnetism of materials, and to induce photo-induced structural phase transitions, etc.

The table below organizes the energy domains and measurement methods.

Table 2-20 Energy Domains and Measurement Methods

	Diffraction/Scattering	Imaging	Spectrum	Inelastic Scattering
Hard X-ray (no vacuum required)	Structural analysis, stress measurement, strain measurement, diffuse scattering, small angle scattering	Radiograph, topograph, X-ray microscope, X-ray CT	EXAFS, X-ray fluorescence analysis, photoelectron spectroscopy	Compton, inelastic scattering, resonant inelastic
Soft X-ray (vacuum required)	resonant scattering	Soft X-ray microscope, soft X-ray CT	Absorption spectroscopy, emission spectroscopy, photoelectron spectroscopy	Resonance inelasticity
Vacuum ultraviolet (vacuum required)			Absorption spectroscopy, emission spectroscopy, photoelectron spectroscopy	

Source: SPring-8 website, prepared by JST

(4) Name and Function of Each Facility of the Synchrotron Radiation Facility

An SRF basically consists of the facilities listed in the table below.

Table 2-21 Facility in an SRF

Equipment Name	Function
Electron gun (injector)	Electrons are generated. An electron gun draws a beam of electrons from a tungsten electrode.
Accelerator	Accelerate electrons. Accelerate the electron beam to almost the speed of light.
Storage Ring	The electron beam is kept at high energy and orbited. During this process, synchrotron radiation is emitted by bending magnets and insertion devices (undulators).
Beamline	X-rays are irradiated onto the sample. At the beamline, X-rays with wavelengths appropriate for experimental purpose are extracted from the synchrotron radiation by means of a monochromator and focusing mirror and irradiated onto the sample at the experimental hutch.
Laboratory	Analyze the data. The data is analyzed by reading X-rays emitted after irradiating the sample, changes in the sample itself, and secondary emissions of light and electrons from the sample using a detector.

Source: SPring-8 website, prepared by JST

(5) Features of SRFs by Generation

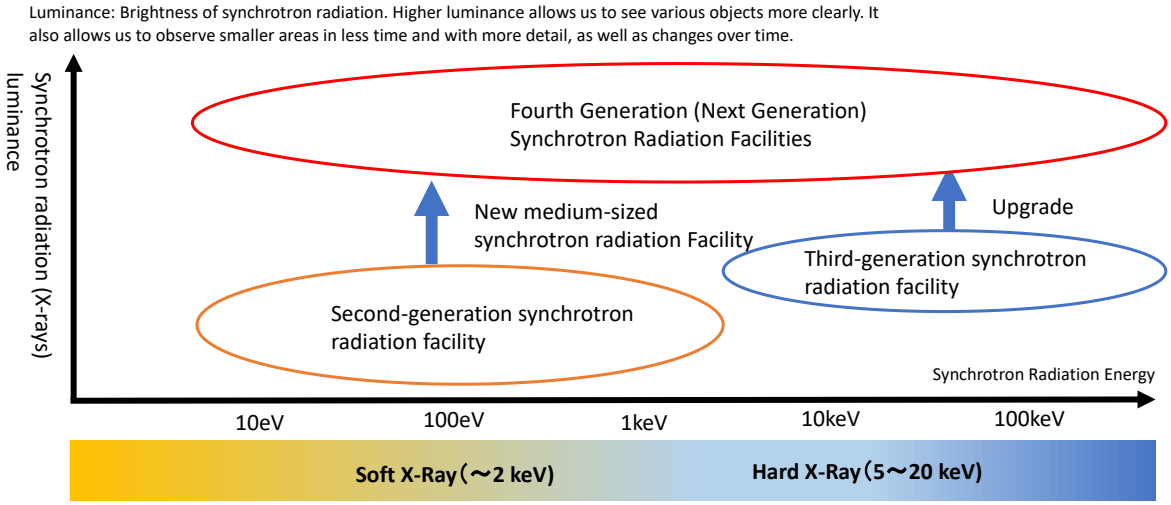
The table below summarizes how SRF was created and developed in each generation.

Table 2-22 Features of SRF by Generation

Generation name	Features of SRF	Representative Facilities/Organizations
1st generation (1940-1960)	This is not a dedicated SRF, but an accelerator built for particle physics research in the era when synchrotron radiation was used. Only the wavelength range of vacuum ultraviolet radiation is available.	Cornell University Synchrotron (USA) Electron Synchrotron, Institute for Nuclear Study, The University of Tokyo (Japan) NBS-SURF (USA)
2nd Generation (1970s-1980s)	An accelerator and experimental facilities dedicated to synchrotron radiation have been constructed, and stable synchrotron radiation can be supplied through the use of a storage ring. The shorter wavelength X-ray region is available from the wavelength region of vacuum ultraviolet radiation.	SOR-RING (Japan) Synchrotron Radiation Source SRS (UK) National Synchrotron Radiation Source NSLS (USA) Photon Factory (Japan) Siam Photon Source (SPS-I) (Thailand)
3rd generation (1990s-)	Facility designed to allow the installation of many undulator-based insertion devices in a dedicated accelerator in a high-performance low-emittance storage ring, making it possible to use higher brilliance synchrotron radiation. The hard X-ray region with shorter wavelengths than that of the second generation is available.	European Synchrotron Radiation Facility (France) Advanced Photon Source APS (USA) SPring-8 (Japan) NSLS-II (USA) TPS (Taiwan) Shanghai Synchrotron Radiation Facility (China)
4th generation (next generation)	It is an advanced SRF that has evolved from a conventional double-bend to a multi-bend lattice SRF. The brightness of the light is more than 100 times brighter than that of a conventional 3rd generation SRF, and the coherence of the light[6] is also improved. It is expected to produce research results in the fields of medicine and energy, which were not possible before.	MAX-IV (Sweden) SIRIUS (Brazil) NanoTerasu (Japan) *under construction: HEPS (China) * under planning: PAL (South Korea)
X-ray Free Electron Laser (next generation)	A free-electron laser (FEL) is a light source producing extremely brilliant and short pulses of radiation. A FEL functions and behaves in many ways like a laser, but instead of using stimulated emission from atomic or molecular excitations, it employs relativistic electrons as a gain medium	SACLA at the RIKEN Harima Institute (Japan) Pohang Accelerator Laboratory X-ray Free-Electron Laser (Korea) SwissFEL at the Paul Scherrer Institute (Switzerland)
Remarks	Multi-bend Achromat (MBA) lattice: A magnet array of the storage ring in which more bending magnets are installed to bend the electron beam in the basic structure of the magnet group (unit cell) that constitutes the storage ring than in the conventional two (double-bend Achromat (DBA)) to realize even lower emittance.	

Source: Prepared by JST based on SPring-8 web

[6] When the wavelength being observed is short compared to the bunch length, the radiation intensity is the sum of the number of electrons (incoherent radiation). Conversely, when the wavelength is long, the electromagnetic waves are superimposed in phase, and the radiation intensity is proportional to the square of the number of electrons. This is coherent light.



Source: JST

Figure 2-20 Characteristics of Synchrotron Radiation Facilities by Generation

As shown in Table 2-22, in recent years, due in part to the advances in short period undulator technology, hard X-rays can be used in facilities of about 3 GeV (for example: MAX-IV), and attempts to construct new high-energy storage rings are no longer being made.

Most of the newly built or planned SRFs around the world are of the 4th generation. “NanoTerasu”, which is operated by The National Institutes for Quantum Science and Technology (QST) is one of the typical SRFs of 4th generation. "NanoTerasu" is constructed in the campus of Tohoku University. It is expected to fundamentally strengthen Japan's R&D capabilities by integrating R&D in the age of AI and big data, using “visualization”[7] and “coherent light.” Many upgrades to 4th generation SRFs are being planned around the world.

2.3.2 Development of SRF in Thailand

(1) Siam Photon Project

In 1996, the National Synchrotron Research Center of Thailand (NSRC) was established to implement Thailand's synchrotron radiation program, named the “Siam Photon Project.” The plan was aimed at fostering HR to enhance education in basic sciences, especially physics and mathematics, in Thailand. In addition, the promotion of research in basic sciences such as physics and chemistry is indispensable for raising the national level of science and technology, and the Siam Photon Project is positioned to make an important contribution. The Siam Photon Project had two objectives: to foster HR and to promote basic research.

1) Construction of an electron storage ring dedicated to 1.0 GeV light sources. In the future, Siam Photon Project will consider increasing the electron energy to 1.2 GeV.
2) Construct beamlines for research on electronic states of solids and solid surfaces.

[7] Visualization of the functions of materials and life at the nano level

3) In the future, Siam Photon Project will consider applied research such as XAFS, microlithography, and ligatures.
4) In the future, Siam Photon Project will install a superconducting wiggler to produce X-rays and construct a beamline for X-rays.

(2) Donation of Light Source Accelerator System from Japan

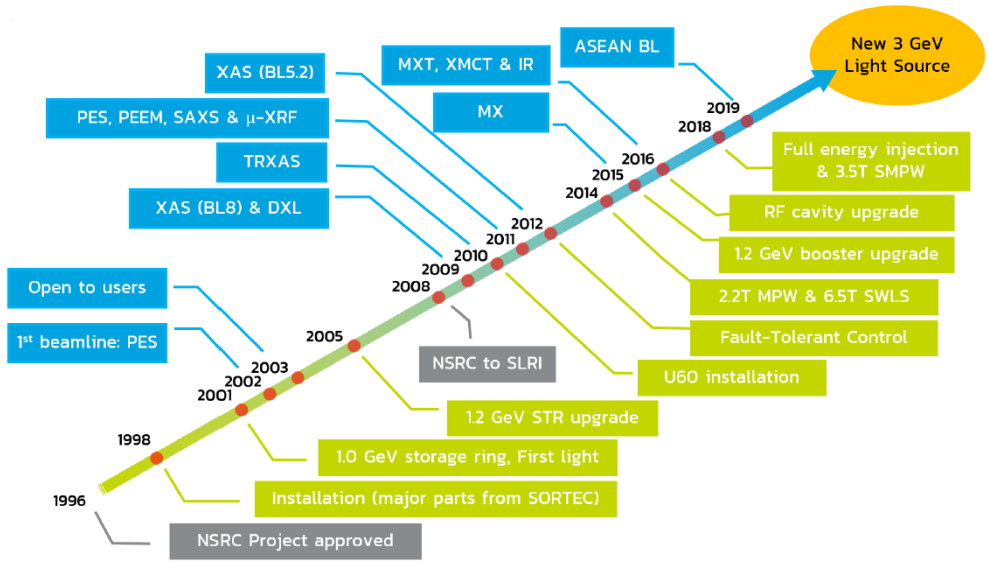
GOT received a donation of SORTEC light source accelerator system from Japan to construct and operate an SRF to promote S&T and to develop HR in Thailand. The storage ring for the light source of the accelerator complex (1 GeV electron storage ring, booster synchrotron, and injection linac) used at the SORTEC[8] laboratory was modified and used.

(3) Transition in the Development

The development's transition is shown in the figure below. The main parts of the accelerator were installed in 1998, the first light of the accelerator was confirmed in 2001, and it became available to users in 2003. In 2008, the Thai Cabinet issued the "Thai Synchrotron Radiation Research Institute Establishment Act of 2551," which is the basis for the establishment of the institute. The Thai Cabinet issued the "Thailand Synchrotron Radiation Institute Establishment Act of 2551 Buddhist Era (B.E.)" in 2008. The Thai Cabinet issued the Act on Establishment of the Thai Synchrotron Radiation Research Institute (SLRI) under the jurisdiction of the Ministry of Science, Technology, and Environment, and the research center was placed under its supervision.

In 2009, the Small Angle X-ray Scattering (SAXS) Beamline, Infrared Spectroscopy Microscope, and X-ray Absorption Spectroscopy Beamline (SUT-NANOTEC-SLRI) were designed. Operational testing of a Photoemission Electron Microscopy (PEEM).

[8] The company was established in 1986 by 13 private companies and the Center for Promotion of Basic Technology Research, an affiliated organization of the then Ministry of International Trade and Industry (MITI), to develop basic technology for manufacturing large-scale integrated circuits by microlithography using synchrotron radiation



* NSRC: National Synchrotron Research Center (previous name of SLRI), PES: Photoemission Spectroscopy, XAS: X-ray Absorption Spectroscopy, DXL: Deep X-ray Lithography, TRXAS: Time-Resolved X-ray Absorption Spectroscopy, PEEM: Photoemission Electron Microscopy, SAXS: Small Angle X-ray Scattering, XRF: X-Ray Fluorescence, MPW: Multi-Pole Wiggler, MX: Macromolecular Crystallography, MXT: Multiple X-ray Techniques, XMCT: X-ray Microtomography, IR: Infrared, SMPW: Superconducting Multi-Pole Wiggler

Source: SLRI

Figure 2-21 Development of SRF in Thailand

2.3.3 SRFs and their Technological Advantages in Japan and Other Countries

(1) SRFs in Japan's S&T Basic Plan

The Third Science and Technology Basic Plan (fiscal years 2006-2010) states that the national government should be responsible for the maintenance and sharing of SRF, and that no specific research organization should be responsible for the maintenance and sharing of these facilities, because the maintenance and operation of state-of-the-art large, shared research facilities require a large amount of money, and their wide sharing will lead to the creation of world-leading results. Therefore, the Japanese government was responsible for promoting the maintenance and sharing of the system, and the most appropriate organization was selected from various organizations in industry, academia, and government. In recent years, the "Science and Technology Research Institute" has also been emphasized as a tool for promoting research and development in science and technology that can be utilized across multiple fields or in fusion fields.

The Fifth Science and Technology Basic Plan (fiscal years 2016-2020) emphasizes the formation of a "place" that brings together human resources, knowledge, and funds from industry, academia, and government, and induces co-creation, in order to encourage stronger efforts to promote open innovation. For the rapid creation of innovations, in recent years, a research complex, i.e., a physical space within a certain scope, has been established to accelerate the formation of a world-class research infrastructure, organization, and it is considered effective to accelerate the formation of world-class research infrastructure, organizations, and other resource clusters to integrate world-class R&D, commercialization of results, and HRD.

(2) SRFs in Japan

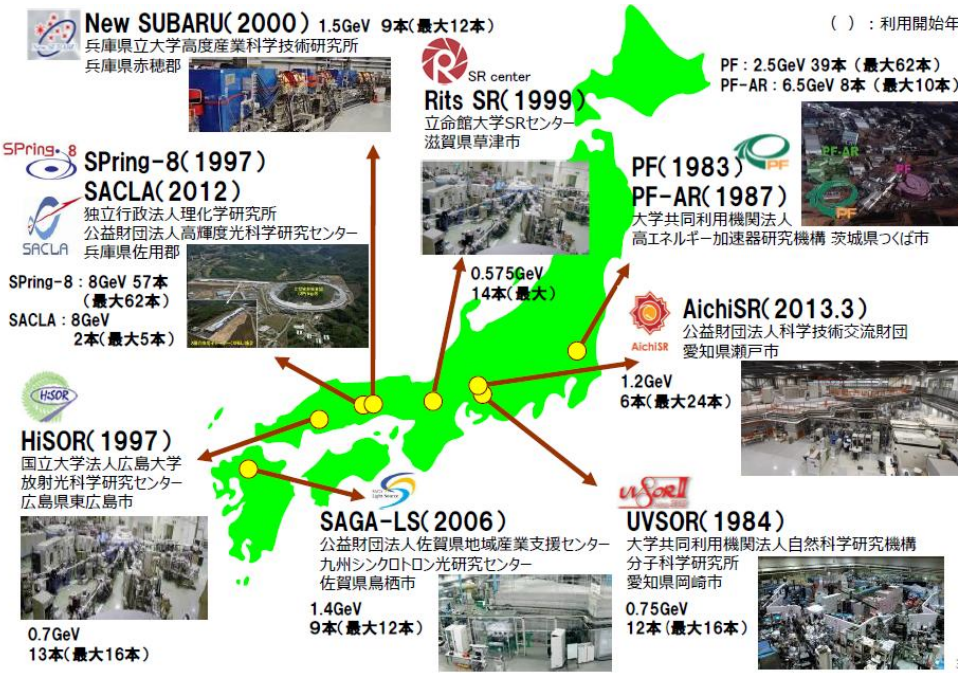
As shown in the figure below, 9 SRFs have been established in Japan by the national government, local governments, & universities and have produced numerous high-impact academic research results in a wide range of fields, including materials science, life science, and earth science. Industrial applications of synchrotron radiation are being promoted in fields such as drug discovery and new materials development, and SRF serves as a source of innovation that contributes to solving scientific, social, and economic issues.

Japan has played a leading role in the world's synchrotron radiation science in terms of technological development, including the development and advancement of in-vacuum undulators[9], which brought technological innovation to facilities around the world in the early days of synchrotron radiation science. Japan's technological superiority is reflected in the high international reputation and presence of SPring-8, one of the world's top three 3rd generation SRF, which has supported academic and industrial applications in Japan and abroad, as well as other distinctive advanced SRFs. NanoTerasu, the first 3GeV high-brilliance synchrotron radiation facility in Japan to use a fourth-generation light source, began user operation in April 2025. Other points of worldwide recognition are listed below.

- In 1990, an in-vacuum undulator was developed, and the PF-AR was adopted as the world's first insertion device for light sources.
- In 2004, SPring-8 started top-up operation[10]. The world's first "ideal top-up operation" that does not interfere with experiments at all was established. In the top-up operation, beam is injected with short intervals during user beamtime, and the current stored in the storage ring is kept constant. In the conventional operation, on the other hand, the stored current decayed with time and during beam injections, user experiments were interrupted due to beam orbit instabilities.
- In 2013, top-up operation was introduced at the same time as the AichiSR was put into service. The world's first generation of hard X-rays using superconducting bending magnets.

[9] The magnet array is placed inside a vacuum chamber. The gap can be adjusted to any value by moving the magnet array up and down inside the vacuum. While the minimum gap for a conventional undulator is about 10 mm, the vacuum-sealed type can be narrowed to about 3 mm, just before it touches the electron beam.

[10] This is an operation in which electrons are injected one after another to maintain the stored current at the upper limit of normal operation. In top-up operation, experiments can be performed during injection in the same way as when no electrons are injected.



Note: As of 2025, SACLA has 3 units of beamlines.
Source: Next Generation SRF Study Working Group (1st meeting) June 10, 2014

Figure 2-22 SRFs in Japan

(3) SRFs in ASEAN Countries

In ASEAN countries, there is another SRF in Singapore. The Singapore Synchrotron Light Source (SSLS) is part of the research facilities of the National University of Singapore and has been in operation since 1999. The SSLS is a second-generation compact superconducting storage ring with an electron energy of 700 MeV and a magnetic field of 4.5 T. The electron beam of the SSLS storage ring has a photon energy of 1.47 keV and a wavelength of 0.845 nm, allowing the effective X-ray spectrum to cover a range of about 10 keV and frequencies down to the far infrared below 10 cm-1. The flux is maximum in the soft X-ray region and the adjacent hard X-ray region, but the roll-off to hard X-ray is large and 10 keV is considered to be the practical limit, depending on experimental conditions. In the infrared, however, edge effects, i.e. the selection of the source point at about half of the maximum bending field in the entrance region of one of the two superconducting dipoles, allows high flux and brightness throughout the infrared spectral region. SSLS are mainly used for research applications in universities and research institutes.

Table 2-23 Main Parameters of Beamline of HELIOS in SSLS

Beamline	Name	Energy Range	Measurement technique
ISMI	Infrared Spectro / Microscopy	10^4-10 cm^{-1}	FTIR-1, FTIR-2
LiMiNT	Lithography for Micro- and Nanotechnology	>2 keV	
PCIT	Phase Contrast Imaging and Tomography	>2keV	
SINS	Surface, Interface and Nanostructure Science	0.05 – 1.2 keV	XPS, PES, XAS, XMCD, AFM/STM
SINS EUV	Surface, Interface and Nanostructure Science EUV		
SUV	Soft X-ray – Ultraviolet	3.5 -1500 eV	
XAFCA	X-ray Absorption Fine structure for catalysis	3.0-12.8 keV	XAFS
XDD	X-ray Development and Demonstration	2.4 – 10 keV	XRD, XRR, XRF, XRT

Source: JST

(4) Formation of a Research Complex Integrating the City, Universities, and SRF

A research complex is a complex innovation promotion infrastructure that integrates the activities of research institutes, companies, universities, and other organizations that are clustered in a region to develop cutting-edge R&D, commercialization of results, and HRD in a unified and integrated manner by integrating different fields that attract global attention (Source: Japan Science and Technology Agency website). As summarized in the table below, research complexes are rapidly growing around the world, with SRFs at the core.

Table 2-24 Research Complexes and SRFs around the World

Research Complexes	SRFs	Remarks
Saclay, France	SOLEIL	Declared maintenance in 2010 with a total budget of 350 billion yen.
Innovation Park, Switzerland	SLS	Park InnovAARE: Center for transferring PSI (Paul Scherrer Institut))'s advanced technology to the private sector Center for the transfer of PSI's advanced technology to the private sector • Beamtime: 5056 hours (99%: Utilization Rate) • Spin-offs are also encouraged, e.g. DECTRIS Ltd.
Hsinchu Science Park HSP, Taiwan	NSRRC (TPS)	Universities, research institutes, and the semiconductor industry have gathered to form the Hsinchu Science Park. universities, research institutes, and the semiconductor industry to form the Hsinchu Science Park: • Created UMC and TSMC as spin-out companies
Science Village (IDEON Science Park), Sweden	MAX-IV	Research complex formed by synchrotron radiation facilities, companies, and Lund University. Research Complex: • 350 companies, 2,700 jobs. In collaboration with Lund University • Open innovation and entrepreneurship support in cooperation with Lund University. ICT, telecom, life sciences ICT, telecom, life sciences • ESS (European Spallation Source): 5 MW spallation neutron source using 2 GeV superconducting proton linac (Completion: 2025)
Grenoble GIANT Campus/ EPN	ESRF	Academic use maintains high activity and produces excellent results in terms of both quality and quantity. Upgrade as a next-generation synchrotron radiation facility in 2020. • Beamtime: 5485 hours (99%: Utilization Rate) • Since 2009, organizational reforms and bold modifications to the beamlines was implemented with keywords: Extreme, Time resolved, Imaging, Nanobeams, Automated.

Source: JST

In order to make the most of the location of the next-generation SRF, the City of Sendai has formulated the following initiatives for the formation of a research complex in the Sendai City Economic Growth Strategy.

- Promote the location and concentration of R&D facilities and companies
- Promotion of research complex use by companies

Notably, Sendai City has acquired the right to use the facility for 2000 hours/year (for 10 years) and actively supports industrial use of the next generation SRF, NanoTerasu, by subsidizing part of the costs incurred when businesses conducting measurements at NanoTerasu receive support for analysis and measurements from universities, research institutes, etc. It is noteworthy that the next-generation SRF is positioned as an infrastructure for open innovation, where various fields i.e. electronic devices, batteries, magnetic devices, medicine, water and environment, food, livestock, agriculture, and fishery gather, and industry, government, and academia are working together to promote industrial use.

In addition to Tohoku University, Hokkaido University, the University of Tokyo, Nagoya University, Kyoto University, Osaka University, Kyushu University, and other research complex plans to organize a new center as a hub for building an international collaboration system with overseas universities.

2.3.4 O&M Mechanism of SRF

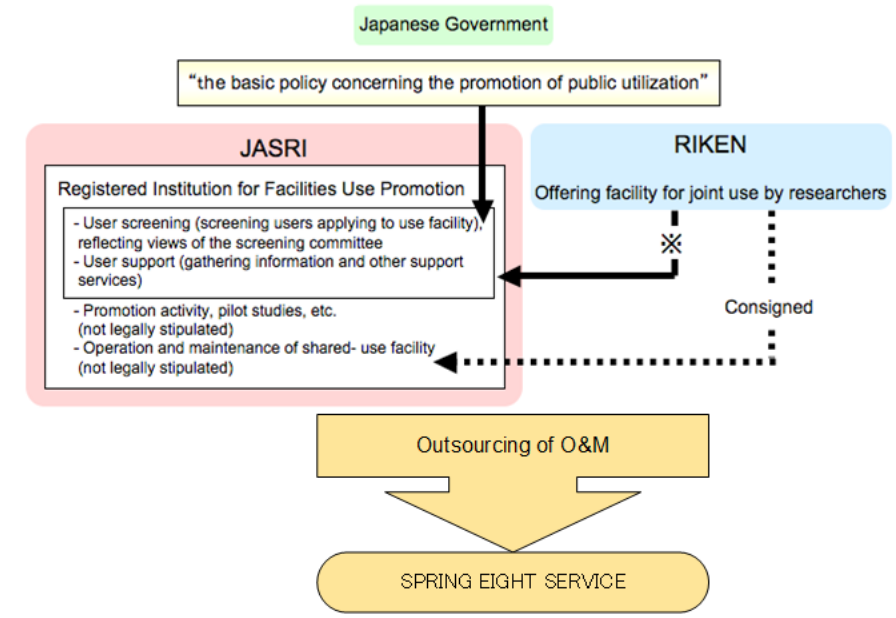
(1) Japan

In the case of synchrotron radiation facilities in Japan, many facilities outsource part of their operation and maintenance (O&M). A typical example is SPring-8. The outline of O&M system of SPring-8 is described below.

1) Management Structure of SPring-8

SPring-8 was originally planned to be constructed jointly by two organizations, RIKEN and the Japan Atomic Energy Research Institute (JAERI). Japan Atomic Energy Agency (JAEA), and then, Japan Synchrotron Radiation Research Institute (JASRI) was established for the purpose in order to promote research institutes other these two organizations, which was in charge of the operation of the public facilities and beamlines of SPring-8. JAEA withdrew from the operation of SPring-8 in 2005, and since then SPring-8 has been operated by two organizations, RIKEN and JASRI. The roles of each organization are as follows.

- RIKEN: Facility owner and operation contractor to JASRI
- JASRI: Commissioned by RIKEN to operate and maintain the facility and serves to promote SPring-8 usage and increase the number of institutions registered to use SPring-8



※ The Ministry of Education, Culture, Science and Technology may assign promotion work (user screening and user support) to the organization in charge of promoting user f the facility (JASRI)

Source: SPring-8

Figure 2-23 O&M Structure of SPring-8

2) Outsourcing of O&M of SPring-8

SPring-8 is operated by RIKEN and JASRI, and part of O&M works is outsourced to SPRING EIGHT SERVICE (SES)[11]. The main tasks outsourced to SES are described below.

- Accelerator operation and maintenance work: Routine operation work and daily maintenance work during the accelerator operation period, equipment inspection and maintenance assistance work such as maintenance during the shutdown period.
- Beamline maintenance and research and development support
- Research support for synchrotron radiation utilization, user support, industrial utilization support
- Operation monitoring, maintenance, and inspection of utility facilities
- Safety management work

In addition to SPring-8, SES is in charge of supporting O&M of Aichi SR and SAGA-LS.

One of the advantages of outsourcing O&M in Japan is that outsourcing allows researchers to concentrate more on their research activities. What makes O&M outsourcing possible in Japan is the depth of the Japanese engineers where the outsourcer has secured enough engineers familiar with synchrotron radiation technology for O&M of the synchrotron radiation facility.

[11] Spring Eight Services Co., Ltd. (SES) was established in 1996 and is primarily involved in accelerator operation, beamline management, radiation safety management, and software development at synchrotron radiation facilities such as SPring-8. They provide operation and support for research facilities that utilize synchrotron radiation technology, and do business with many research institutes and companies.

(2) Taiwan

The National Synchrotron Radiation Research Center (NSRRC) operates and maintains two synchrotron radiation facilities on its premises in Hsinchu, northern Taiwan: TLS (1.5 GeV, operational since 1993) and TPS (3 GeV, operational since 2016). NSRRC does not separate organizations for each facility but rather operates and maintains both synchrotron radiation facilities under the same organizational structure. For this reason, the timing of equipment inspections and maintenance at the two synchrotron radiation facilities is adjusted to avoid overlapping during shutdown periods.

(3) Thailand

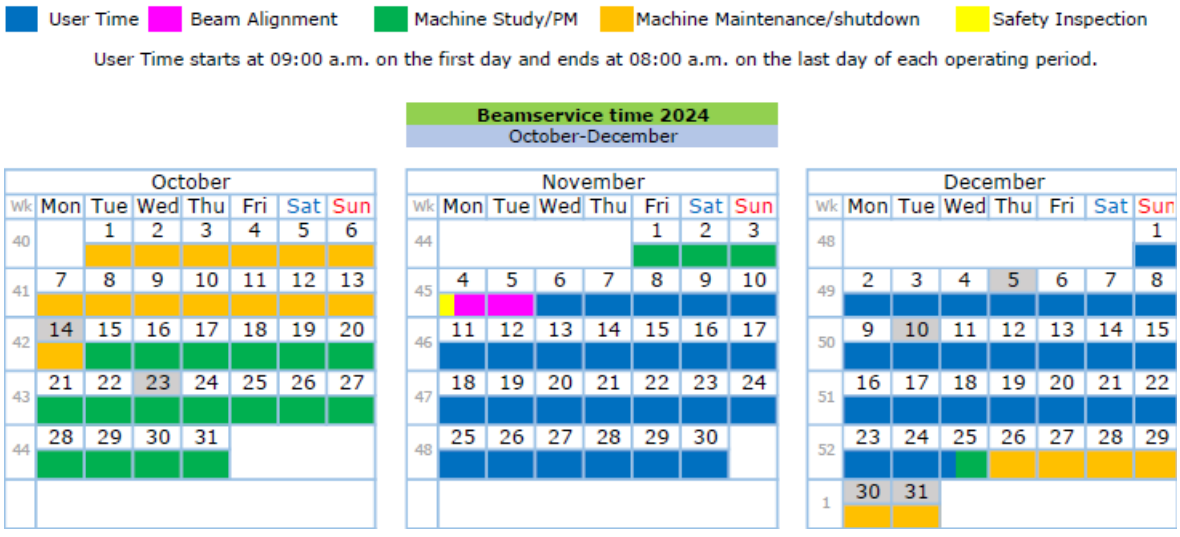
1) Organization Structure on O&M for SPS-I

In the case of SLRI, O&M of SPS-I is not outsourced, and O&M is carried out by the entire SLRI. As of February 2025, SLRI has a total of 231 staff that are working for the Project.

In the case of SLRI, business outsourcing method is not adopted for O&M of SPS-I where all departments are in charge of the O&M for SPS-I: daily operation & monitoring during operation time and periodical regular maintenance. SLRI plans to implement two organizational restructurings in February 2023 and 2033 in preparation for the SPS-II Project. Details of the organizational restructurings are described in Chapter 9.

2) Operation and Monitoring System During Operation Time

The operation schedule of SPS-I consists of 4 periods: 1) User Time (Beamline service), 2) Beam Alignment, 3) Machine Study, and 4) Machine Maintenance.

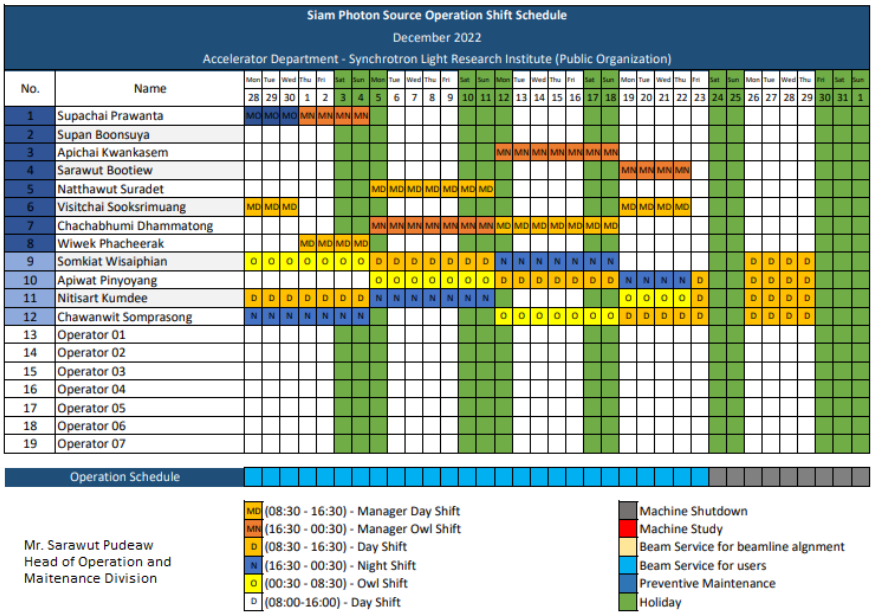


Source: SLRI

Figure 2-24 Sample of Operation Schedule of SPS-I

In User Time (Beamline service period), 24-hour operation and monitoring system is adopted by 3-time shifts (8 hour each) as follows:

- Day shift: 08:30 – 16:30
- Night shift: 16:30 – 00:30
- Owl shift: 00:30 – 08:30



Source: SLRI

Figure 2-25 Sample of Operation Shift Schedule

The main O&M works during User Time are described as follows:

- Monitoring of operation and assistance for an event of an abnormality
- Acquisition of operation data
- Routine maintenance-related work such as patrol inspection and data organization
- Pre-startup inspection or post-shutdown inspection work

Actual inspection works are implemented according to the check sheet prepared separately by detailed section. The followings are representative check sheets for O&M works.

- Weekly inspection sheet, which are designed to check separately by main equipment such as main compressor, oil removal system, dryer, recovery compressor, buffer tank, LN2 bulk, cold box, main dewar, valve box, LN2 phase separator, SMPW (superconducting multi-pole wiggler),
- Check sheet for chiller (including water pressure and pump reports)
- Check sheet for heat exchange
- Check sheet for generator and engine
- Check sheet for LINAC (Gun pulser LED status and Gun pulser parameter checking)
- Check sheet for LINAC (Klystron pulser modulator LED status, (Klystron pulser modulator parameter checking, and Klystron pulser modulator checking)
- Check Sheet for LINAC (Linac cooling unit)

- Check sheet for LINAC (Wave Guide Gas)
- Check sheet for STR Magnet Cooling Water
- Check sheet for Magnet and Magnet power supplies
- Check sheet for Storage Ring RF System (High Power Amplifier)
- Check sheet for Storage Ring RF System (Digital Low Level Radio Frequency)
- Check sheet for Storage Ring RF System (Cavity Cooling Unit)
- Check sheet for Synchrotron Ring RF System (Digital Low Level Radio Frequency)
- Check sheet for Synchrotron Ring RF System (Synchrotron RF System Cooling Unit)
- Check sheet for Synchrotron Ring RF System (Synchrotron RF Unit)
- Check sheet for Water Quality
- Check sheet for Vacuum System of Storage Ring

Guidelines for operation of injection procedures are summarized in the Standard Operation Procedures (SOP).

Siam Photon
RADIO FREQUENCY LABORATORY

Weekly Preventive Maintenance Check Sheet

Page: 1 / 1

Checked by:

Main System: Storage Ring RF System — Date:

Sub System: High Power Amplifier (HPA) — Week Ending:

ACDC Parameters Checking			
POWER	NORMINAL	ACTUAL	UNIT
DC VOLTAGE RF STATION 1			V
DC CURRENT RF STATION 1			A
DC VOLTAGE RF STATION 2			V
DC CURRENT RF STATION 2			A

HPA Flow Rate Checking			
Flow Meter	NORMINAL	ACTUAL	UNIT
HPA INLET			(l/min)
HPA OUTLET			(l/min)
HPA DUMMY LOAD			(l/min)
HPA CIRCULATOR			(l/min)

HPA Cooling Unit Parameters Checking				
ITEMS	SETTING	NORMINAL	ACTUAL	STATUS
Temperature Controller (C)	25	25.7		
Pressure (bar)		4.8		
Water in Reservoir Tanks				
Water Pump				
Compressor No.1				
Compressor No.2				

HPA Components Checking		
ITEMS	STATUS	Comments
Computer control		
Electric Cables		
Cable Connections		
Ventilation Fan		
Circuit Breakers		
Water Leakage		
Pump		

Source: SLRI

Figure 2-26 Sample of Check Sheet

Siam Photon	มาตรฐานขั้นตอนการปฏิบัติงาน (Standard Operation Procedures : SOPs) กระบวนงาน: ขั้นตอนการเติมอิเล็กตรอนแบบไม่ลดกระแสที่พลังงาน 1.2 กิกะอิเล็กตรอนโวลต์	รหัส: AcD-01-02 แก้ไขครั้งที่: 0 วันที่ประกาศใช้: 21 พ.ค. 64 หน้าที่ 3 จาก 9 หน้า
หน่วยงานที่รับผิดชอบ ส่วนเดินเครื่องและซ่อมบำรุง	ผู้จัดทำ: นายวิศิษฏ์ชัย สุขศรีเมือง ผู้ทบทวน: นายนาวิน จันทร์ทอง	ผู้อนุมัติ: นายสุพัฒน์ กลิ่นเขียว

5. กฎหมายที่เกี่ยวข้อง/เอกสารอ้างอิง

5.1 ไม่มี

6. ขั้นตอนการปฏิบัติงาน รายละเอียด และผู้รับผิดชอบ

ลำดับ	ผังกระบวนการ	ระยะเวลา	รายละเอียดงาน	กฎหมาย/เอกสารอ้างอิง	ผู้รับผิดชอบ
1	เริ่มต้น				
2	- ปิดการแจ้งเตือน Beam alarm message - ประกาศแจ้งเตือน Beam refill	5 นาที	- ปิดการแจ้งเตือนข้อความในโปรแกรม Beam alarm message  - เปิดการแจ้งเตือน Beam refill 5 นาที และ 1 นาที ตามลำดับ 		เจ้าหน้าที่เดินเครื่องฯ

Source: SLRI

Figure 2-27 Sample of Standard Operation Procedure (SOP)

The operational management during beamline operation at SPS-I is carried out based on the procedures described above. As for whether these methods are being operated properly, as shown in the figure below, the actual operating rate for the beamtime plan over the past 10 years has remained at a high level of approximately 97%. It is suggested that this be done properly.



Source: SLRI

Figure 2-28 Beamtime Pan and Actual (2014 – 2023)

3) Periodical Regular Maintenance System During Non-Operation Time

SPS-I conducts regular maintenance twice a year, in which the following are performed:

- Inspection and maintenance of electromagnet system and alignment
- Inspection and maintenance of power supply system
- Inspection and maintenance of acceleration system and aging of acceleration cavity
- Inspection and maintenance of high frequency generator
- Inspection and maintenance of klystron
- Inspection and maintenance of cooling system
- Inspection and maintenance of vacuum system
- Inspection and maintenance of beam diagnostic system

Actual maintenance works are implemented according to the maintenance schedule prepared each year as shown in Figure 2-29.

4) Radiation Safety Management System

The radiation safety management is performed under the guidance of Sub-committee and Chief executive officers. There are relevant regulations for radiation safety under Thai laws; Nuclear Energy

for Peace Act, B.E. 2559 (2016), and the amendment, B.E.2562 (2019), and Ministerial Regulation related to radiation safety, B.E.2561, (2018). Under these regulations, SLRI set up the radiation protection system to be the safety guideline for radiation operators, users, and authorized visitors. The protection plan was issued on September 5th, 2022, which objects to occupational exposure from Synchrotron and high-performance X-ray machines. 5 Radiation safety officers (RSOs) are assigned to supervise the safety operations. Radiation areas are categorized into controlled areas and supervised areas. All Area access permissions are strictly implemented. Individual dosimeters and area radiation detection meter are used to monitor radiation safety areas in terms of time-based maintenance.

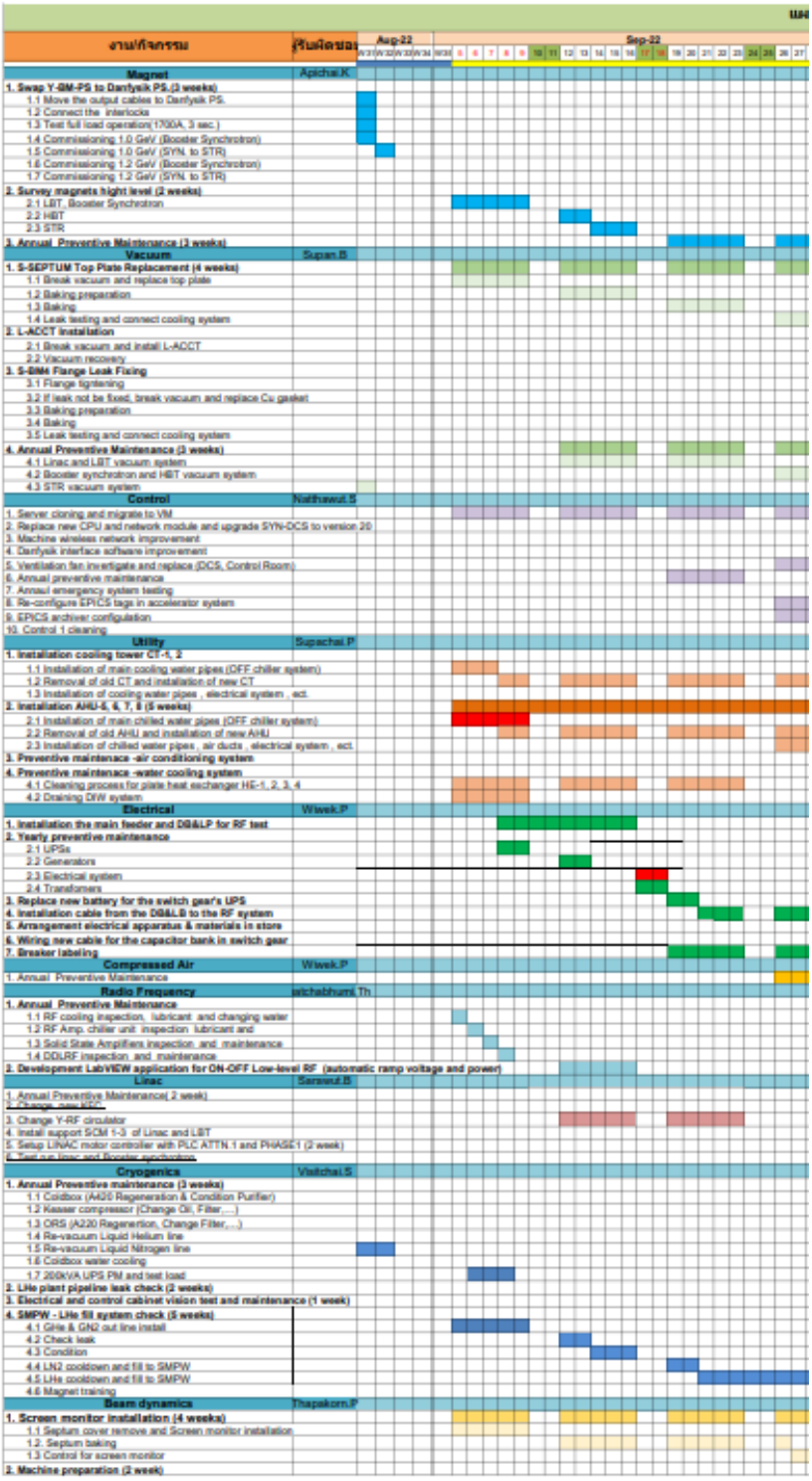
To raise awareness of safety management, SLRI organizes training at least once every two years to its staff to refresh their knowledge. The contents are:

- Rules and measures related to radiation protection and safety with emphasis on the use of radioactive materials or radiation generator safely.
- Internal regulations regarding safety-reporting the results of the radiation exposure of workers and practice in case of a radiation emergency content coverage internal regulations about radiation protection and safety radioactive material collection or radiation generator in safe place.

For overall management of safety management, SLRI prepares Operation Plan on Safety Management, which includes the following measures to prevent harmful radiation:

Designation of the control area surveillance area and measures to control access to the area:

- Area radiation surveillance
- Personal radiation surveillance
- Radiation Safety Regulations for Radiation Workers
- Tools and equipment for radiation protection
- Safety Measures for Synchrotron Light Generator Operation
- Safety measures for the use of the experimental station
- Working principles and components of the Personnel Safety Interlock system
- Procedure for requesting and authorizing the Personnel Safety Interlock



Source: SLRI

Figure 2-29 Sample of Maintenance Schedule

2.4 Overview, Utilization Status (Transition), and Issues of the Existing SPS-I

2.4.1 Outline of SPS-I

The existing 2nd generation SRF in Thailand is called Siam Photon Source (SPS-I) which was developed as the first synchrotron light source in the country Major parts of the source were transferred from the shutdown SORTEC laboratory, Japan.

The storage ring was redesigned for 1.2 GeV operation. The Siam Photon Project was managed by then the National Synchrotron Research Center (NSRC) which was established under the resolution of the Cabinet of the Thai Government met on 5 March 1996. At that time, the Cabinet agreed on the establishment of the NSRC Project under supervision of the Ministry of Science, Technology and Environment. The project aimed at promoting basic and applied scientific research in Thailand. The NSRC was located at the Technopolis of Suranaree University of Technology in Nakhon-Ratchasima. Later, the Synchrotron Light Research Institute (SLRI) was established to replace the NSRC.

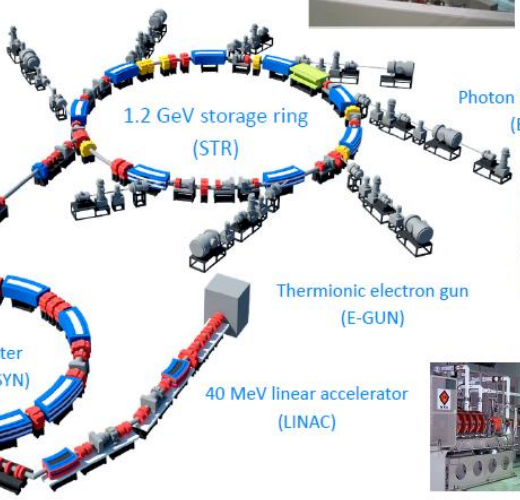
The Synchrotron Light Research Institute (SLRI) is a Public Organization under the supervision of the Ministry of Higher Education, Science, Research and Innovation of the Royal Thai Government. The institute operates the Siam Photon Laboratory (SPL) which is the first synchrotron facility of Thailand. The SPL services synchrotron light from SPS-I, a 1.2 GeV synchrotron light source. Many experimental techniques are available at the SPL for Thai and international users.

The existing SPS-I provides synchrotron light for users 23 hours/ day, 7 days a week. At present, beam lifetime is 11 hours at 100mA.









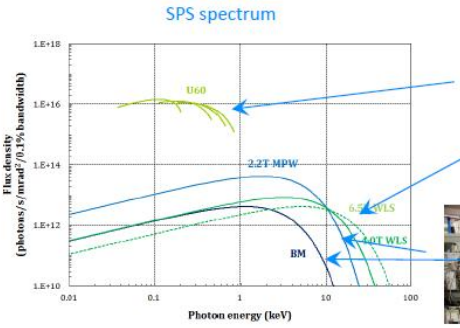






SPS machine parameters

Electron beam energy [GeV]	1.2
Beam current [mA]	150
Lattice	DBA
Number of superperiods	4
Natural emittance [nm-rad]	61
Mean Horizontal Emittance [nm-rad]	57.10
Mean Vertical Emittance [nm-rad]	4.45
Emittance Ratio	7.80 %
Circumference [m]	81.3
Revolution time/Orbital period [ns]	271
Betatron tunes ν_x, ν_y	4.78, 2.83
Synchrotron tune ν_s	2.86×10^{-3}
Natural chromaticities ξ_x, ξ_y	- 8.34, - 6.80
Momentum compaction factor α_c	0.01803
RF frequency [MHz]	118
Harmonic Number	32
RF voltage [kV]	300
RF power [kW]	80
Number of RF cavity	1
Damping times τ_x, τ_y, τ_s [ms]	10.87, 9.96, 4.78
Energy loss per turn [keV]	65.94
Natural energy spread [GeV]	0.0006
Synchronous phase [rad]	2.59
Linear energy acceptance	0.61%
Bunch length [ps]	163.62







U60 6.5T WLS





2.2T MPW 1.4 T BM



24H SPS operation



2006 – 2018 user beamtime statistics

Source: SLRI

Figure 2-30 Top to Bottom: SLRI Office in Korat, SPS-I Machine Lineup & Parameter

2.4.2 Overview of Beamline of SPS-I

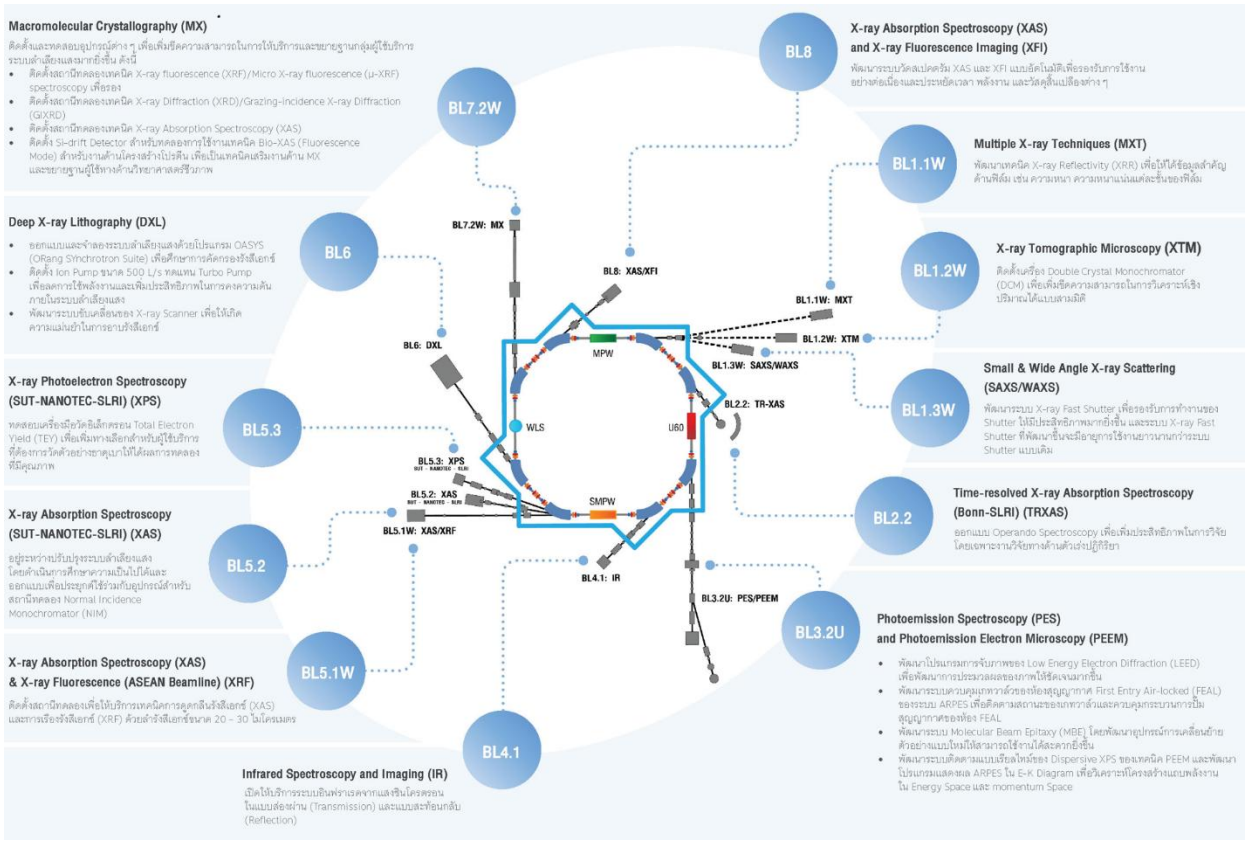
A beamline is a system of components, such as slits, monochromators, focusing mirrors and other optical elements used for shaping and delivering synchrotron light from the storage ring to the experimental stations. An experimental station, located at the end of a beamline, contains measurement systems for a specific measurement technique. In 2021 SPS-I operated 11 beamlines and 3 beamlines under commissioning. The following table summarizes the beamlines of SPS-I.

Table 2-25 Lineup of Beamline of SPS-I

Beamlines (Operating)		
1	BL1.1W MXT Multiple X-ray Techniques	The experimental techniques available are x-ray absorption spectroscopy (XAS) and x-ray fluorescence (XRF). The XAS can be used to determine oxidation states and atomic scale structure of materials. The XRF technique is used to qualitatively and quantitatively determine elemental compositions of materials. Experiments employing any of the techniques or coupling of the two techniques could be included in the proposal.
2	BL1.2W XTM X-ray Tomographic Microscopy	Beamline 1.2w is an X-ray beamline dedicated to X-ray imaging and computed microtomography. The 3D reconstructed images produced from BL1.2W will allow for non-destructive visualization and investigation of the matter inside a sample.
3	BL1.3W SAXS/WAXS Small & Wide Angle X-ray Scattering	Beamline 1.3W is dedicated for nano structural investigation of material such as analysis of particle size and size distribution, period of block copolymer, starch lamellar nano structure, percent crystallinity etc.
4	BL2.2 TRXAS Time-resolved X-ray Absorption Spectroscopy (Bonn-SLRI)	The short data collection time of TRXAS beamline opens a new opportunity for in situ x-ray absorption spectroscopy (XAS) experiments such as studies of changes of the electronic structures or the local coordination environments of an atom during a change in thermodynamic conditions.
5	BL3.2U/a PES Photoemission Spectroscopy	Soft-X ray spectroscopy beamline analyzes atomic elements and its chemical states of surface and interface of materials.
	BL3.2U/b PEEM Photoemission Electron Microscopy	The PEEM end station produces high resolution images from electrons that are emitted from the samples by the excitation with synchrotron soft X-ray. Additionally, information related to the surface chemistries and electronic structures of sub-micron domains in the images can be obtained via spatially-resolved near-edge X-ray absorption spectroscopy.
6	BL4.1 IR Infrared Spectroscopy and Imaging	Fourier Transform Infrared (FTIR) spectroscopy has been widely used for a routine analytical technique. Thanks to the high brightness of synchrotron radiation, synchrotron based Infrared microspectroscopy can provide high spatial resolution, good signal to noise ratio and short data acquisition time.
7	BL5.2 XAS X-ray Absorption Spectroscopy (SUT-NANOTEC-SLRI)	Beamline 5.2 is one of Synchrotron Radiation beamline at SLRI which dedicated to an X-ray Absorption Spectroscopy (XAS). This beamline is used to study an atomic arrangement and elemental specifications of materials. BL5 is a consortium beamline, jointly funded by Suranaree University of Technology, the National Nanotechnology Center and SLRI

Beamlines (Operating)		
8	BL5.3 XPS X-ray Photoelectron Spectroscopy (SUT-NANOTEC-SLRI)	Testing electron measuring equipment Total Electron Yield (TEY) to increase options for service users who wants to measure light element samples to obtain quality experimental results.
9	BL6 DXL Deep X-ray Lithography	Beamline 6a is a micromachining beamline using Deep X-ray Lithography (DXL) for fabrication of micro mechanical components.
10	BL7.2W MX Macromolecular Crystallography	Beamline 7.2W is a tunable energy beamline dedicated to macromolecular crystallography for determining the crystal structure of proteins, their complexes and other molecules at atomic resolution.
11	BL8 XAS/XFI X-ray Absorption Spectroscopy (XAS) and X-ray Fluorescence Imaging (XFI)	Beamline 8 is a X-ray Absorption Spectroscopy (XAS) beamline for studies of atomic arrangement in material
Beamlines (Not Operating)		
	BL5.1W X-ray Absorption Spectroscopy (XAS) X-ray Fluorescence (ASEAN Beamline) (XRF)	X-ray Absorption Spectroscopy (XAS) and X-ray Fluorescence Spectroscopy (XRF) are beamlines that evaluate the valence, local structure, trace components, and bonding state of elements in materials from the absorption of X-rays or the fluorescence that accompanies the absorption. Absorption spectroscopy has high sensitivity for light elements, while fluorescence spectroscopy has high sensitivity for heavy elements, making this beamline capable of evaluating a wide range of elements. As a result, it has a wide energy range and flexible measurement modes, making it suitable for a variety of research, including catalysts, battery materials, and environmental samples. XRF serves as a shared-use beamline in the ASEAN region, serving as a foundation to support research.
	BL3.1 (PES)	This beamline uses X-ray and ultraviolet (UV) photoelectron spectroscopy to investigate the electronic state of the surface of materials. By irradiating light and measuring the energy of the electrons emitted, it is possible to analyze the elemental composition, bonding state, and valence band structure of the surface. Furthermore, by drilling from the surface of the sample using an attached ion source, it is possible to obtain the bonding and distribution in the depth direction of the material. It is capable of XPS, UPS, angle-resolved measurements, etc., and is widely used for the surface analysis of catalysts, thin films, and functional materials.
	BL7.1 (XRF)	The measurement target is the same as the above (BL5.1W XRF), but the beam is narrowed, allowing for the determination of element distribution in a microscopic area.

Source: SLRI



Source: SLRI Annual Report 2021

Figure 2-31 Layout of Beamline of SPS-1

2.4.3 Situation of Facility Usage

(1) Outline of Beamlines and Experimental Stations

In fiscal year 2021, the institute operated synchrotron light with 11 beamlines and 12 experimental stations, and the following table shows commencement year of service of each beamline.

Table 2-26 SPS-I Beamline Commencement Year

Beamline	Technique	Open Year
BL1.1W MXT	Multiple X-ray Techniques	2016
BL1.2W XTM	X-ray Tomographic Microscopy	2016
BL1.3W SAXS/WAXS	Small & Wide Angle X-ray Scattering	2011
BL2.2 TRXAS	Time-resolved X-ray Absorption Spectroscopy (Bonn-SLRI)	2011
BL3.2U/a PES	Photoemission Spectroscopy	2011
BL3.2U/b PEEM	Photoemission Electron Microscopy	2011
BL4.1 IR	Infrared Spectroscopy and Imaging	2010
BL5.2 XAS	X-ray Absorption Spectroscopy (SUT-NANOTEC-SLRI)	2013
BL5.3 XPS	X-ray Photoelectron Spectroscopy (SUT-NANOTEC-SLRI)	2016
BL6 DXL	Deep X-ray Lithography	2006
BL7.2W MX	Macromolecular Crystallography	2009
BL8 XAS/XFI	X-ray Absorption Spectroscopy (XAS) and X-ray Fluorescence Imaging (XFI)	2005

Source: SLRI

(2) Overall Beamline Usage

The following figure shows hours of schooled and provided beamtime from 2014 to 2023 with the ratio of operation availability. Beamtime hours decreased in 2021 due to the COVID-19 pandemic, and in 2023 due to the increase in electricity bill.

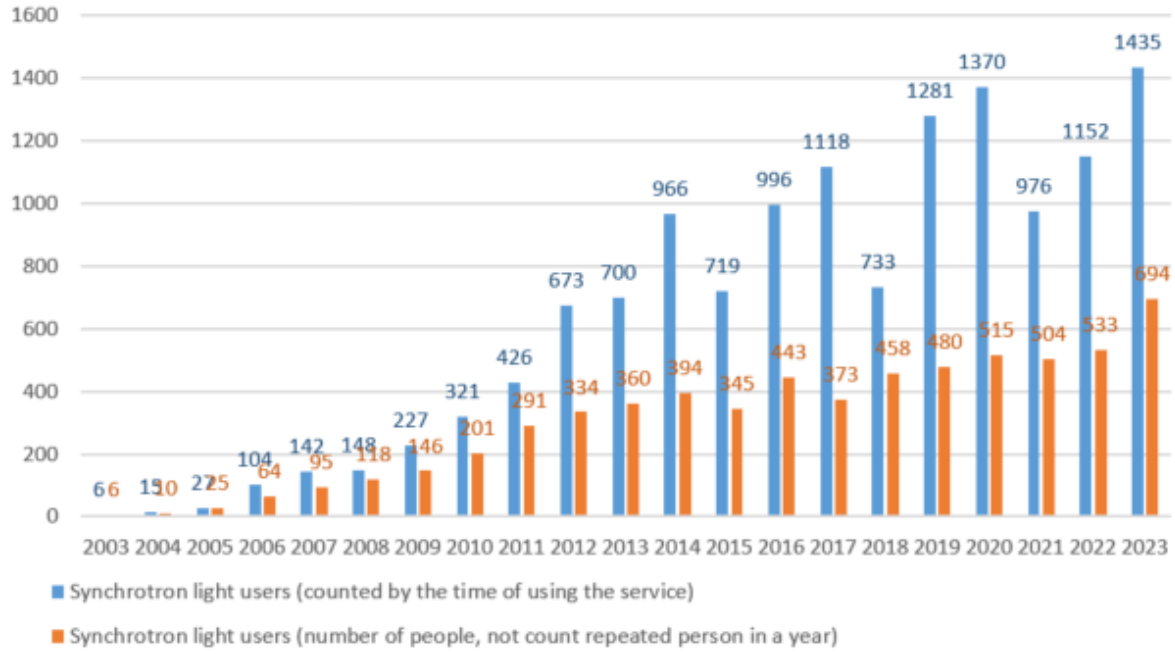


Source: SLRI

Figure 2-32 Schedule and Provided Beamtime (2014 to 2023)

The operation availability is generally marked at around 97% during the period.

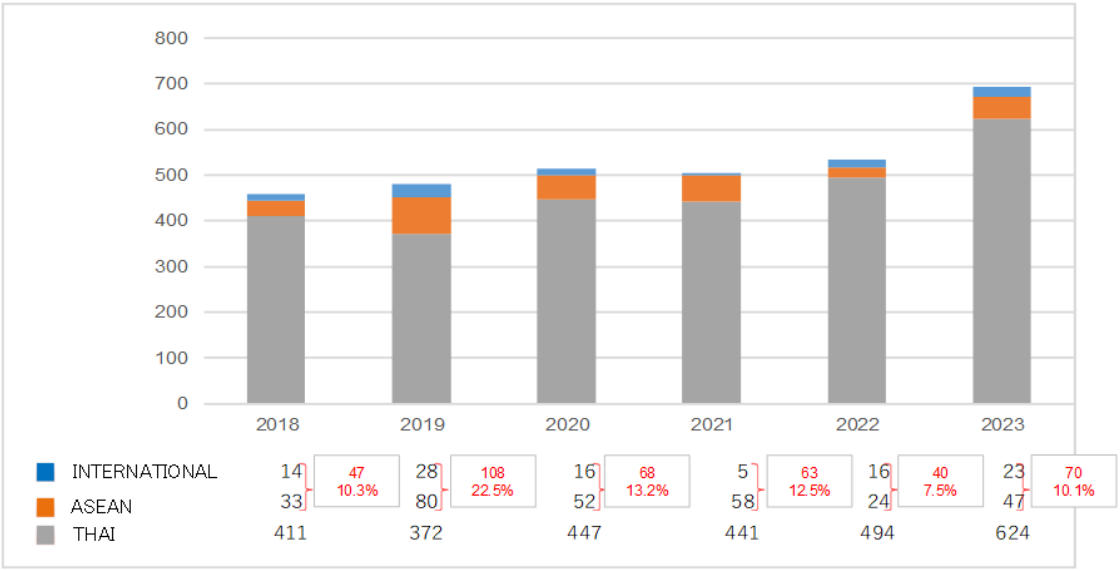
The following figure shows the users` number of SLRI by times of service users and users` number from 2003 to 2023 (not counting repeating user in a year).



Source: SLRI-Annual Report (translated by JST)

Figure 2-33 Number of Users (time and people) of SLRI (2003 -2023)

The number of times used has been increasing, although there were several years when it was lower than the previous year. The number of users has been also increasing, although the rate of increase is low compared to the number of times of use. In 2021, the number of users remains at same level, but the number of use times decreases by 29% from the previous year, which is presumed to be influenced by COVID-19. The Compound Annual Growth Rate (CAGR) of the number of use and users from 2003 to 2023 are as follows (number of use: 45.36%; number of users: 32.61%). The figure below shows users` type of SLRI by region from 2018 to 2023.



Source: SLRI-Annual Report

Figure 2-34 Type of Users (Project Participants) of SLRI by region (2018-2023)

The international users accounted for 22.5% in 2019, but it has decreased since then due to the impact of COVID-19.

Refer to **Attachment 1: SPS-I's Users Information** for the number of foreign users by beamline from 2018 to 2022 (The number of users does not exactly match Figure 2-34).The number of research projects that use synchrotron light at SLRI from 2003 to 2023 is 5,788 projects in total.



Source: SLRI-Annual Report (translated by JST)

Figure 2-35 Number of Research Project (2003 – 2023)

In 2023 the number of papers submitted to international journal by researchers of SLRI including co-author is 208 papers and 16 papers to international conference. The number of papers written by researchers from other institutes that referred SLRI in acknowledgement is 35 papers to international journal and 2 papers to international conference. The following table summarizes the number of papers from 2016 to 2023 (no data in 2020 and 2022).

Table 2-27 Summary of Papers (2016 - 2023)

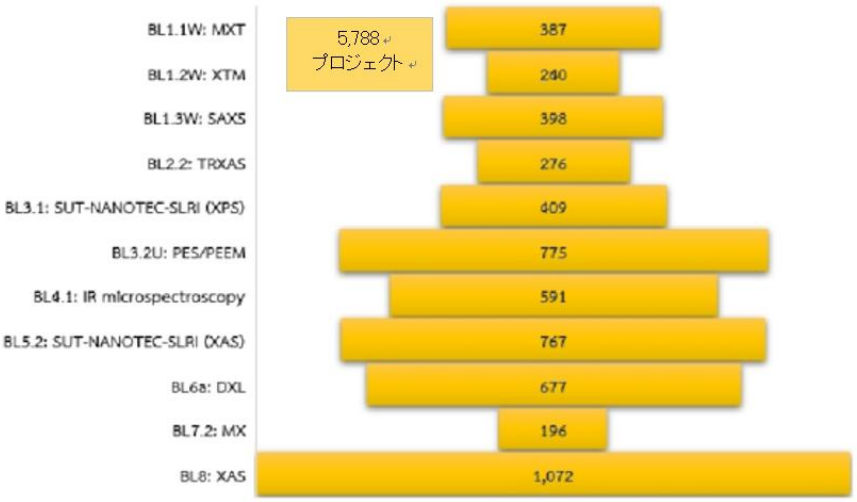
International Journal			
Year	Number of papers by SLRI researchers*	Number of papers SLRI in Acknowledgement	Total
2016	57	73	130
2017	106	61	167
2018	90	49	139
2019	111	48	157
2021	281	27	308
2023	208	35	243
Total	853	293	1,146
International Conference			
2016	7	-	7
2017	11	-	11
2018	10	-	10
2019	29	5	34
2021	8	3	11
2023	16	2	18
Total	81	10	91

*: including co-author papers

Source: SLRI- Annual Report, prepared by JST

(3) Usages of each beamline and experimental stations

The figure below shows the number of research projects by beamline from 2003 to 2023.

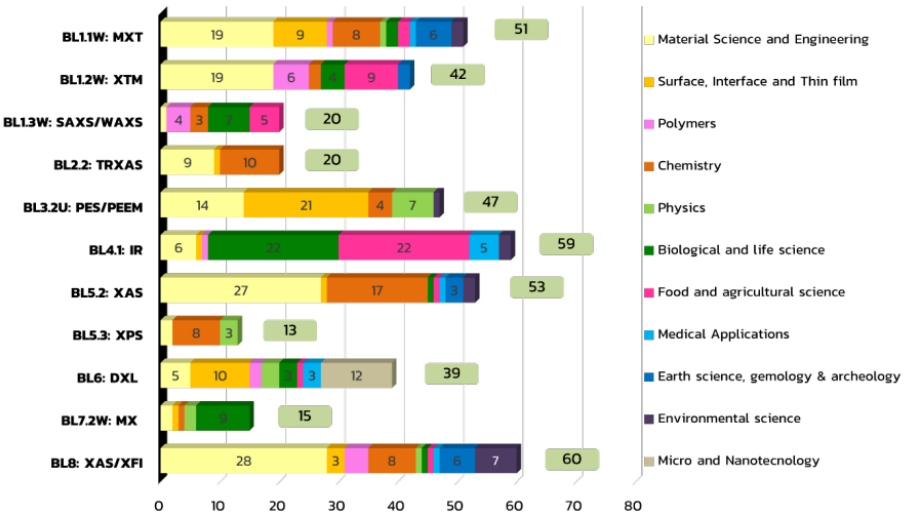


Source: SLRI-Annual Report

Figure 2-36 Number of Research Projects by Beamline from 2003 to 2023

The beamlines most frequently utilized are BL8: XAS/XFI (X-ray Absorption Spectroscopy and X-ray Fluorescence Imaging) and BL3.2U: PES & PEEM (Photoemission Spectroscopy and Photoemission Electron Microscopy), highlighting the essential role these techniques play in research across various fields. Additionally, BL5.2 (X-ray Absorption Spectroscopy), XBL6 (Deep X-ray Lithography), and BL4.1 (Infrared Spectroscopy and Imaging) are also widely used, particularly contributing significantly to studies in materials science and nanotechnology. In contrast, beamlines such as BL1.2 (tomography) and BL2.2(time-resolved X-ray absorption spectroscopy) appear to have more specialized applications in specific fields.

The figure below shows the sum number of beamline use classified by research field and type of beamline from 2010 to 2021.



Source: SLRI-Annual Report (translated by JST)

Figure 2-37 Number of Usage by Research Field and Beamline (2021)

The table below shows the potential of synchrotron service for research of each beamline based on beam use in 2017-2022. The data only extracted the use of the synchrotron light via beamline, as analyzed by 'Gap Analysis'. Beamtime is aligned with the institute policy: academic usage at the maximum of 80%, and industrial usage at least 20% of total usage. The data is recorded annually, then calculated back to average hour of service in each year, then to arithmetic average (6 years in total). Hence, the data represents the actual beamtime use with some remaining hours of beamtime. From the calculation, this shows that there is still room for both academic and industrial usage. The remaining potential for beam service - 63.92 % for BL1.3W: SAXS/WAXS is because the industrial beam usage is 116.20% (over 20% of total usage), showing the incredibly high demand for this technique.

Table 2-28 Potential of Synchrotron Service for Research of Each Beamline Based on Beam Usage in 2017-2022

Beamline	Beam Usage						Remaining Potential for Beam Service (Percent)
	Academic		Industrial		Overall		
	Average Number of Days	Percentage[1]	Average Number of Days	Percentage[2]	Average Number of Days[3]	Percentage[4]	
BL1.1W: MXT	131.83	77.67	0.97	2.29	132.80	79.96	20.04
BL1.2W: XTM	75.00	44.19	0.34	0.80	75.34	44.99	55.01
BL1.3W: SAXS/WAXS	81.00	47.72	49.31	116.20	130.31	163.92	-63.92*
BL2.2: TRXAS	96.58	56.90	-	-	96.58	56.90	43.10
BL3.2U: PES/ PEEM	121.00	71.29	0.75	1.77	121.75	73.06	26.94
BL4.1: IR	107.42	63.28	2.59	6.11	158.05	69.39	30.61
BL5.2: XAS	138.00	81.30	-	-	138.00	81.30	18.70
BL5.3: XPS	84.58	49.83	-	-	84.58	49.83	50.17
BL6: DXL	6.00	3.53	0.03	0.07	6.03	3.60	96.40
BL6: micro-XRF [5]	44.50	26.22	0.92	2.16	45.42	28.38	71.62
BL7.2W: MX	47.25	27.84	-	-	47.25	27.84	72.16
BL8: XAS/FXI	159.67	94.07	2.83	6.66	162.50	100.73	-0.73*
Total	**91.07**	**53.65**	**4.81**	**11.34**	**95.88**	**64.99**	**35.01 (Average)**

Remarks:

[1] "Percentage" of academic beam usage is the ratio of "Average Number of Days" to beam time for academic users, 169.74 days, which is 80 percent of average annual beamtime in 2017-2022 (212.17 days).

[2] "Percentage" of industrial beam usage is the ratio of "Average Number of Days" to beam time for industrial users, 42.43 days, which is 20 percent of average annual beamtime in 2017-2022 (212.17 days).

[3] "Average Number of Days" of overall beam usage is the total of "Average Number of Days" of academic and industrial beam usage.

[4] "Percentage" of overall beam usage is the total of "Percentage" of academic and industrial beam usage.

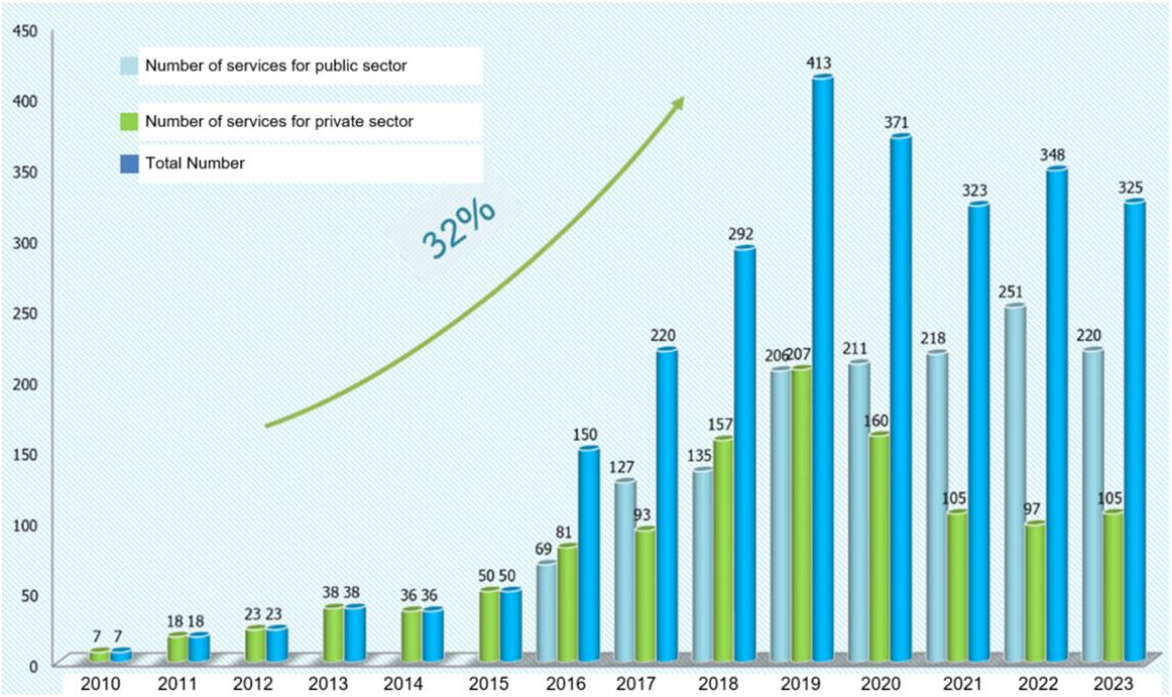
[5] Micro XRF was out of service from 2021

* Negative percentage of remaining potential of beam service represents beam usage over the full potential of the beamline according to different available annual beamtime and other factors.

Source: SLRI

(4) Services Provided by SLRI

SLRI provides not only Synchrotron radiation utilization service but also other type of services such as solution support service, consulting service, scientific equipment utilization service, engineering support services, and technology transfer, etc. for both private and public sectors. The figure below shows the Number of SLRI Other Services by Sector from 2010 to 2023.



Source: SLRI-Annual Report (translated by JST)

Figure 2-38 Number of SLRI Other Services by Sector (2010-2023)

In 2021 SLRI earned 19,882,144.48 THB in total from services. The table below shows the breakdown of income in 2021 classified by services including other services whose details are referred to in section 7.2.1 (1).

Table 2-29 Amount of Income in 2021 by Type of Services

No	Type of Services	Amount (THB)
1	Synchrotron radiation utilization service, solution support service, consulting service, and scientific equipment utilization service	10,524,733.24
2	Engineering support services	9,153,295.33
3	Technology transfer, seminar, training, retail service	204,115.91
	Total income from services provided by SLRI	19,882,144.48

Note:

Engineering support services include:

(1) Synchrotron radiation utilization service: SLRI researchers assist user to use beamline and/or to conduct analysis by using beamline instead of users. Solution support service: SLRI's researchers support users to solve problem by specialization of SLRI's researchers. Consulting service: SLRI's researchers provide business idea with users by specialization of SLRI's researchers. Scientific equipment utilization service: SLRI provide users with scientific equipment which SLRI own.

(2) Engineering service: SLRI's workshop manufacture prototype and mechanical parts by receiving user's order.

(3) Technology transfer: Technology developed by SLRI deliver to industry. Seminar and training: SLRI coordinate and conduct seminar and training program for users.

Source: SLRI-Annual Report, prepared by JST

Table 2-30 Summary of Economic Value Added from Services of SLRI in 2021

Services	Economic Value Added (MTHB)
Synchrotron light services and related technology for private sector	1,253,185
Synchrotron light services and related technology for public sector	108,105
Operations and provision of technical and engineering services	119,592
Support for scholarship (Master/PhD) and grant	8,600
Training / Seminar	11,800
Total	1,501,282

Source: SLRI-Annual Report, prepared by JST

2.4.4 Future Utilization/ Development Plans of SPS-I

After completion of SPS-II, the research utilizing synchrotron radiation will be carried out at SPS-II as the characteristics of the radiation is significantly superior to that of SPS-I. The SPS-I accelerator will be utilized for engineering development works, especially ones that utilize low and high energy electron beams. Examples of these development works include development of beam diagnostics and instrumentation, such as electron and x-ray beam position monitors, and development of solid-state detectors. SPS-I beamlines will be utilized mainly for educational purposes and training.

There is a plan to utilize the existing synchrotron radiation facility and workshop facility as an Engineering Development Facility in the future. The role of the planned Engineering Development Facility encompasses several engineering development aspects. Its functions consist of, but not limited to:

- Engineering design of accelerator and beamline components
- Mechanical, thermal, vibrational simulations
- Fabrication of accelerator and beamline components
- Verification and testing of fabricated components
- Beam testing of beam diagnostic systems
- Engineering service to SLRI collaborators
- Testing of accelerator and beamline components before installation at SPS-II
- SPS-II equipment repair and refurbishment

2.5 Trends (Distribution) in the Construction of SRF Around the World: Outlines, Utilization Status, Issues, and Future Construction Plans

Compared to existing facilities for soft X-ray in Japan, the next-generation SRFs have low emittance electron beam and can produce synchrotron radiation 100 to 1,000 times brighter than existing facilities, enabling clearer observation of local areas using various measurement methods. In addition, when the same sample is measured, clear data can be obtained even in 1/100 of the time (100 times time resolution) compared to existing facilities, enabling measurement of high-speed changes such as chemical reactions of materials.

In other countries, high-brilliance 3GeV-class SRFs with emittance performance of several nanometer radians [nm-rad] were constructed successively in the 2000s, and NSLS-II (USA) and TPS (Taiwan) were

constructed in the 2010s to achieve even lower emittance. In June 2016, MAX-IV (Sweden), which targets an emittance of around 0.3 nm/rad by employing a multi-bend achromat (MBA) lattice, started operation. Furthermore, Diamond (UK) and SOLEIL (France) are planning to upgrade to a low-emittance ring by adopting MBA lattices, and it can be said that other countries are also developing 4th generation SRFs with lower emittance than the 3rd generation facilities.

The table below summarizes the next-generation SRF of the same scale as planned for Thailand's SPS-II.

Table 2-31 Next-Generation SRF in the World Similar to SPS-II

Next Generation Synchrotron Radiation Facility Name	Facility Overview	Project cost and operating expenses	Maintenance status/others
NanoTerasu (Japan)	Accelerator energy: 3 GeV Storage current: 400 mA Ring circumference: 349 m Emittance: 1.14 nmrad Maximum number of beamlines: 28	Total project cost: 37 billion yen Government share: 20 billion yen Private sector's share: 17 billion yen Total operation cost: 2.9 billion yen/year Including 1.9 billion yen/year for accelerator operation (For detailed breakdown, see note below)	Construction completed and in operation since April 2025. Ten beamlines has been be installed in Phase 1.
NSLS-II (USA)	Accelerator energy: 3 GeV Stored current: 400 mA Ring circumference: 792 m Emittance: 0.55 nmrad Maximum number of beam lines: 60	912 million USD to build the facility	Construction completed and in operation. Effective emittance performance is 1.0 nmrad.
TPS (Taiwan)	Accelerator energy: 3 GeV Storage current: 500 mA Ring circumference: 518 m Emittance: 1.6 nmrad Maximum number of beamlines: 25	Approximately 7 billion NT$ (224 million USD)	Construction completed in 2014 and in operation from 2016. Effective emittance performance is 1.5 nmrad.
MAX-IV (Sweden)	Accelerator energy: 3 GeV Stored current: 300 mA (to be upgraded to 500mA) Ring circumference: 528 m Emittance: 0.33 nmrad Maximum number of beamlines: 19	Approximately 6 billion SEK (580 million USD)	Construction started from 2011 and completed and in operation from 2016.
SIRIUS (Brazil)	Accelerator energy: 3 GeV Stored current: 100 mA (as of July 2022) Ring circumference: 518 m Emittance: 0.25 nmrad Maximum number of beamlines: 40	Total investment: 1.8 billion Reais	Construction started from 2015 and completed and in operation from 2020.

Next Generation Synchrotron Radiation Facility Name	Facility Overview	Project cost and operating expenses	Maintenance status/others
High Energy Photon Source (HEPS) (China)	Accelerator energy: 6 GeV Stored current: 200 mA Ring circumference: 1360m Emittance: 0.06 nmrad Maximum number of beamlines: 90 (Phase 1: 14)	Total investment: Unknown	Booster installation was completed. (Feb 2023) Estimated completion : 2025

Note:
Accelerator operation management cost: 1.9 billion yen
- Operating expenses (including personnel expenses) 1.4 billion yen
- Utility costs 500 million yen

Maintenance and management of 10 beamlines: 800 million yen
- Labor costs: 100 million years
- Maintenance cost: 400 million yen
- Usage support: 300 million yen

Others (office management expenses): 200 million yen

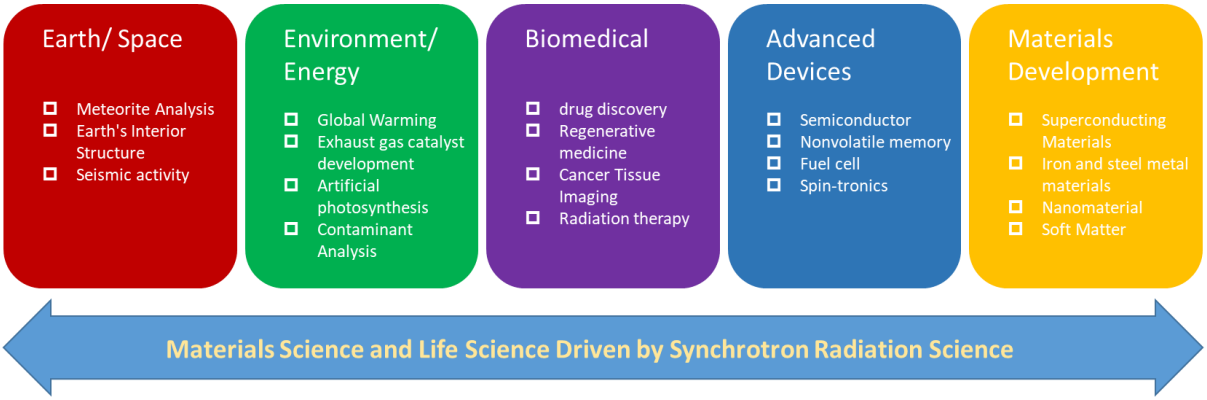
Source: JST

The reason the next generation SRFs are being developed in other countries is possibly due to the growing academic and industrial needs for relatively low photon energy regions, such as tender X-rays (2 to 5 keV) and soft X-rays (2 keV or lower), as well as the development of accelerator technology that can cover the hard X-ray region (5 to 20 keV) even in 3 GeV-class SRFs.

2.6 Target Business and Related Demand Survey

2.6.1 Trends in the Creation of New Fields in Industry and Potential Use of Synchrotron Radiation Research

The potential use needs and expectations for the next generation of synchrotron radiation are spread across environment/energy, health/medicine, materials, information/communication, fundamental science and industrial applications as shown in the figure below. The beamline created by synchrotron radiation could provide various measurement techniques, so that R&D in various industrial fields will be able to be carried out by using the beamline, as mentioned above in section 2.4 (3).



Source: Next Generation SRF Study Working Group Report (April 2015), prepared by JST

Figure 2-39 Spread of advanced R&D using synchrotron radiation

(1) Academic and Industrial Use of Soft X-Rays (Analysis of Material Surfaces)

Cutting-edge science and technology is increasingly required to analyze the electronic structure of material surfaces in detail in order to accurately understand the functions of materials and chemical reaction processes in the development of new materials, catalysts, medicine, drug discovery, etc.

In the development of new materials, catalysts, medicine, and drug discovery, there is a growing need for detailed analysis of the electronic structure of material surfaces to accurately understand the functions of materials and the chemical reaction processes. The world's research trend is to focus on the "structure" of materials. The global research trend is toward "understanding the function" of materials in addition to "structural analysis" of materials. It is important to establish a high-brilliance soft X-ray environment that can track changes in the electronic state of material surfaces over time.

The development of accelerator technology has made it technically possible to generate high-brilliance synchrotron radiation even at relatively low electron energies, which has led to the development of soft X-ray technology in various foreign countries. In the 2000s, the development of a soft X-ray environment with high-brilliance has become an important issue. In the 2010s, the U.S., Taiwan, and Sweden began operating even more advanced high-brilliance synchrotron radiation sources for soft X-rays, and recently it is under development in Brazil and Japan.

(2) Academic and Industrial Use of Hard X-Rays (Analysis of the Interior of Materials)

It is necessary to investigate hard X-ray applications at similar facilities to see what kind of hard X-ray applications are possible at the medium-scale next-generation synchrotron radiation facility planned by Thailand. At NanoTerasu, it is conducting a total of four X-ray spectroscopic studies: X-ray operando spectroscopy (HX: 2-20KeV, Beam Size: 100nm), X-ray structure (HX: 2-20KeV, Beam Size: 50μm), X-ray hierarchical structure analysis (HX: 4.4-30KeV, Beam Size: 50μm), and X-ray coherent imaging), and X-ray coherent imaging.

2.7 Responses of Other Aid Agencies/ States to Thailand's Science and Technology Research Sector

2.7.1 Country Assistance in the Field of Advanced Science and Technology

Table 2-32 Other Aid Agencies/ States to Thailand

Country	Main Assistance
USA	The U.S. Trade and Development Agency (USTDA) is implementing a project to develop a solar energy storage system for a solar power generation company in Thailand.
German	International exchange between Thailand and Germany has a long history, with more than 600 German companies in Thailand. Both countries have over 200 cooperative partnerships with institutions of higher education. There is a track record of technology transfer in the fields of telecommunications, electric power, medicine, metrology, and fully automated driverless vehicle systems.
France	The French Center for International Cooperation in Agricultural Technology (CIRAD) is actively engaged in joint research and other exchanges with researchers affiliated with Kasetsart University, AIT, and KMUTT. CIRAD has established close relationships mainly in the field of agriculture, but also in epidemiological research, environmental conservation and natural resource management, and aeronautics and space. Furthermore, in 2023, Thailand's MHESI signed a Declaration of Intent with the Ministry of Higher Education and Research of France on Cooperation for Higher Education, Science, Research and Innovation.
ASEAN	In the ASEAN Commission on Science, Technology, and Innovation (ASEAN COSTI), the ASEAN COSTI is deepening academic exchanges in biotechnology, food science and technology, infrastructure and resource development, metrology and geophysics, microelectronics and IT, marine science and technology, materials science and technology, space technology applications, and sustainable energy research.
EU	Under Horizon 2020, researchers from ASEAN and the EU will collaborate on 27 joint research projects in the fields of health, food, ICT, environment, and nanotechnology. EURAXESS ASEAN was established in Singapore and Thailand to promote collaboration between ASEAN and EU researchers and to provide a forum for information exchange through workshops, seminars, internships, etc.
China	Between 2024 and 2025, Thailand's MHESI strengthened ties with China through several key agreements: a 2024 MOU with the China National Space Administration (CNSA) for lunar exploration (MATCH instrument on Chang'e-7), followed by 2025 MOUs and Letters of Intent (LOI) focusing on joint AI laboratories, peaceful nuclear technology cooperation, and initiatives in traditional Chinese medicine and general S&T innovation.

Source: JST

2.7.2 Responses to S&T Research Sector by Thai Administrative Agencies/ State

As mentioned in Section 2.1, the 20-Year National Strategy (2017–2036) shows 6 long-term national strategies and 23 master plans has been formulated according to these 6 strategies.

1) Well-being of Thai people and society
2) National competitiveness, economic growth and income distribution
3) Development of human capital
4) Social equality and equity
5) Sustainability of national biodiversity, environmental quality and natural resources
6) Government efficiency and better access to public services

Although science and technology policy is related to any strategy, it is particularly close to 2) National competitiveness, 3) Development of human capital, and 5) Sustainability of national biodiversity, environmental quality and natural resources.

The 12th Development Plan (2017 – 2021), which was formulated and implemented in parallel with the 20-Year National Strategy, stated that Thailand's were insufficient and advocated the necessity to strengthen R&D capabilities (refer to Section 2.1.1).

In such flow, the Higher Education, Science, Research and Innovation Policy and Strategy (2020-2027) has been formulated taking into account government reform and the domestic and international current situations. The 2020-2027 Policy and Strategy consists of four platforms, each incorporating programs to drive forward the implementation process. These four platforms are: 1) manpower and knowledge development; 2) research, development and innovation for grand challenges; 3) research, development and innovation for competitiveness; and 4) research and development for area-based development and inclusiveness.

Table 2-33 Four Platforms and Programs

Platform 1 Manpower and Knowledge Development	Platform 2 Research, Development and Innovation for Grand Challenges	Platform 3 Research, Development and Innovation for Competitiveness	Platform 4 Research and Development for Area-based Development and Inclusiveness
1) National Brain Power Ecosystem 2) Highly Skilled Workforce for Eastern Economic Corridor (EEC) and New Growth Engines 3) Lifelong Learning and Future Skills Set 4) AI for All 5) Frontier Research 6) Big Science	7) Resources, Environment and Agriculture 8) Aging Society 9) Quality of Life and Security	10) RDI for New Economy 11) Startup, IDEs and Innovation Ecosystem 12) National Quality Infrastructure and Services	13) Local Economy and Innovative Community 14) Poverty Eradication 15) Smart/Livable City
16) Reinventing Universities & Research Institutes			

Source: NXPO, prepared by JST

As priority research areas in accordance with the above measures, environment/energy, digital information and communication technology, agriculture, robot/AI, advanced manufacturing, and medical care are listed. As a cross-cutting program over the 4 platforms, the reorganization and revitalization of universities and research institutes was set up to enable efficient management of limited R&D funds.

2.7.3 Collaborations between SLRI and Other Countries/Organizations

In recent years, SLRI has made collaborations with other countries or organizations. Below is the list of countries/ organizations which SLRI has collaborated with.

Table 2-34 Collaborations between SLRI and Other Countries/Organizations

No.	Year	Country/ Group of Collaboration	Name of Organization
1	Since 2016	Australia	Australian Synchrotron (ANSTO)
2	Since 2012	Asia Ocenia Forum for Synchrotron Radiation Research (AOFSRR)	Asia Ocenia Forum for Synchrotron Radiation (AOFSRR)
3	Since 2016	A Large Ion Colider Experitment (ALICE)	A Large Ion Colider Experitment (ALICE)
4	Since 2019	China	Shanghai Advanced Research Institute (SARI), Chinese Academy of Science (CAS)
5	Since 2024	The Arab Republic of Egypt	National Research Centre, the Arab Republic of Egypt
6	Since 2015	European Organization for Nuclear Research (CERN)	European Organization for Nuclear Research (CERN)
7	Since 2013	Germany	Deutshces Elektronen Synchrotron (DESY)
8	Sicne 2014	Indonesia	National Research and Innovation Agency (BRIN)
9	Since 2019	Indonesia	University of Bengkulu
10	Since 2018	Japan	The School of Engineering, Tokyo Institute of Technology
11	Since 2006	Japan	RIKEN SPring-8 Center
12	Since 2006	Japan	Japan Synchrotron Radiation Research Institute
13	Since 2017	Japan	Tokyo Denki University
14	Since 2020	Japan	Institute of Materials Innovation, Institute of Innovation for Future Society, Nagoya University
15	Since 2021	Japan	Department of Materials Science and Technology, Nagaoka University of Technology
16	Since 2010	Japan	The Institute of Materials Structure Science, High Energy Accelerator Research Innovation (KEK)
17	Since 2018	Malaysia	Universiti Putra Malaysia
18	Since 2022	Philippines	University of the Philippines
19	Since 2019	South Korea	Pohang Accelerator Laboratory
20	Since 2019	South Korea	Korea Association for Fusion Energy and Accelerator Technology (KAFAT)
21	Since 2025	South Korea	Research Institute of Advanced Materials, Seoul National University
22	Since 2025	South Korea	Graduate School for Molecular Materials Chemistry (BK21 FOUR), Gyeongsang National University
23	Since 2022	SYNAPSE	Synchrotrons for Neuroscience - an Asia-Pacific Enterprise
24	Since 2006	Taiwan	National Synchrotron Radiation Research Center (NSRRC)
25	Since 2012	United Kingdom	Diamond Light Source Limited
26	Since 2012	Vietnam	Institute of Materials Science, Vietnam Academy of Science and Technology
27	Since 2012	Vietnam	Institute of Physics, Vietnam Academy of Science and Technology
28	Since 2016	United States of America	UChicago Argonne, LLC

Source: SLRI

Since 2006, the partnership between Japan's RIKEN SPring-8 Center and Thailand's SLRI has centered on technology transfer, capacity building, and joint research to advance synchrotron science in the Asia-Pacific. SPring-8 supports the continuous upgrade of Thailand's 1.2 GeV SPS-I and grants Thai scientists access to its advanced 8 GeV facility for complex hard X-ray experiments.

SLRI and KEK of Japan originally established a collaborative partnership in 2000 and renewed it in 2010. The partnership focuses on fostering academic exchange and research cooperation regarding synchrotron radiation light sources. During the discussions in 2010, leaders from both institutions explored how KEK could share its technical expertise to support SLRI's plans to expand its SPS-I facility.

Since 2006, the partnership between Thailand's SLRI and Taiwan's National Synchrotron Radiation Research Center (NSRRC) has evolved into a highly practical engineering and technical collaboration. A major milestone was NSRRC's custom design and installation of a 3.5 Tesla superconducting wiggler for Thailand's SPS-I in 2016. NSRRC is also currently conducting technical training in specialized fields like ultra-high vacuum systems and radiation safety.

Below is a list of recent research collaborations between SLRI and Japanese academic institutions.

Table 2-35 Research Collaborations between SLRI and Japanese Academic Institutions

No.	Year	Name of Organization/ Project	Research Topic
1	2025	Aichi Knowledge Hub Priority Research Project Phase 5	Development of Supercritical Plasma Production System for Nanopore Material Catalysts
2	2023	Institute of Material Structure Science of High Energy Accelerator Research Organization	Development of advanced X-ray beamlines for the use of a fourth generation synchrotron light source
3	2018	School of Engineering, Tokyo Institute of Technology	Study on dependence of sp2/sp3 carbon bonding ratio of diamond-like carbon films on resistivity of their substrates
4	2019	School of Engineering, Tokyo Institute of Technology	Local Structure Evaluation of Diamond-like Carbon Film for Gas Barrier Coating
5	2019-2020	Tokyo Denki University	Investigation of Biocompatible DLC Films Structures for Cell Adhesion
6	2021	Department of Materials Science, Nagaoka University	Amorphous Carbon Nano-Interface-Modified Aluminum Anodes for High-Performance Dual-Ion Batteries

Source: SLRI

2.8 Economic and Social Conditions In and Around the Project Area

2.8.1 EECi

The National Science and Technology Development Agency (NSTDA), an independent administrative agency under the Ministry of Higher Education, Science, Research and Innovation of Thailand, is responsible for the development of EECi. NSTDA is working with PTT Public Company Limited, Thailand's state-owned energy company, to make Wangchan Valley as the first major site for EECi. In this partnership, PTT is primarily responsible for basic infrastructure and smart city development, while NSTDA will focus on developing EECi's innovation ecosystem.

EECi is an innovation hub positioned as a translational research and technology localization platform for Southeast Asia region and mainly promotes 6 focused industries:

1) Modern Agriculture

2) Bio refinery
3) Battery and Modern Transports
4) Automation, Robotics and Intelligent Systems
5) Aviation
6) Medical Devices

EECi had its grand opening in November 2022. On November 15, SLRI signed a Memorandum of Cooperation (MOC) with VISTEC and PTT for a land lease and has a 30-year right to use the land for the purpose of developing a next-generation synchrotron radiation facility. The MOC clearly states that the three parties will conclude an agreement after the cabinet approval on the revised project proposal.

2.8.2 Companies in EECi

EECi is one of the four EEC special zones promoted in the EEC (Eastern Economic Corridor) concept, which is the core of the new national strategy "Thailand 4.0" formulated by the Thai government in 2016. The other three EEC special zones than EECi are EECd (Digital Park), EECa (Eastern Airport City) and EECmd (Medical Hub). Investment projects promoted in these four EEC special zones or 21 designated industrial zones will be granted additional tax incentives as determined by the Board of Investment of Thailand (BOI).



Source: BOI

Figure 2-40 Promoted Zones of EEC

(1) BOI Promotion Scheme

The following table summarizes the additional tax incentives in the investment promotion measures in EEC announced by the Board of Investment (BOI) and effectuated from December 2019 under BOI investment promotion Act.

Table 2-36 Summary of Incentives for EEC under BOI Promotion Scheme

Key Features	Investment Incentives	Targeted Activities			
		Section 8	A1	A2	As
Standard tax package	Tax holidays	10 years (no cap)	8 years (no cap)	8 years	5 years
Investment projects which are engaged in human resource development programs	Tax holidays	2 years (no cap)	-	-	-
	50% reduction of CIT	-	3 years	3 years	3 years
Investments located in EECi, EECd, EECa and EECmd	Tax holidays	1 year (no cap)	-	-	-
	50% reduction of CIT	-	2 years	2 years	2 years
Investments located in industrial estates and promoted industrial parks	Tax holidays	1 year (no cap)	-	-	1 year
	50% reduction of CIT	-	-	-	-

A1: Knowledge-based activities focusing on R&D and design to enhance the country's competitiveness.
A2: Infrastructure activities for the country's development activities using advanced technology to create value-added, with no or very few existing investment in Thailand.
A3: High technology activities which are important to the development of the country, with a few investments already existing in Thailand.
Section 8: Technology and innovation development includes targeted core technology development such as development of biotechnology, nanotechnology, advanced materials technology and digital technology.

Source: BOI

According to BOI's announcement, investment projects in 12 target industries in the EEC region in 2020 were 231 projects (down 2.1% from previous year) and 104.204 billion baht (down 9.0%) on an application basis and there were 235 projects (up 7.8%) and 96.358 billion baht (down 51.1%) on a permit basis. According to BOI statistics for the same year, investment in target industries across Thailand totaled 821 projects worth 230.74 billion baht on an application basis and 806 projects worth 216.83 billion baht on an approval basis. As a result, in terms of both applications and approvals, investment in target industries within the EEC region accounts for about 30% of the total number of projects and nearly 50% of the total investment amount in Thailand[12].

As of February 2023, the following two companies had applied for EECi and been approved to enter EECi and applications from several companies were under review.

- PTT Exploration and Production Public Company Limited
- Sumitomo Heavy Industries (Thailand) Ltd.

(2) EEC Promotion Scheme

There are investment incentives in the promoted zones for specific industries under EEC Act in aiming to attract potential targeted investment, to transform Thailand to be the Center of Investment in Technology and Advanced Innovation. For specially designed technology and cluster industries EEC is willing to

[12] (https://www.jetro.go.jp/biznews/2021/09/c62c2ebfe90343a7.html).

"negotiate and mutually design the customized inventive package" within the scope of the maximum incentive package approved by the EEC policy Committee.



Source: EEC

Figure 2-41 Summary of Incentives and Enablers under EEC Promotion Scheme

(3) Investment by Japanese Company in EECi

On 16 June 2022, Sumitomo Heavy Industries (Thailand), a subsidiary of Japanese Sumitomo Heavy Industries, signed an agreement to rent a space at the EECi for its new office. Sumitomo Heavy Industries is the first Japanese company to sign on as a tenant to EECi.

In addition, EECi Visit Program for Embassy of Japan in Thailand and Japanese Chamber of Commerce has been conducted in August 2022. More than 50 members have participated in this program.

2.8.3 Research Institutions in EECi

In the Education Zone (178 Rai or 28.48 ha) of EECi, currently there are Kamnoetvidya Science Academy (KVIS), Vidyasirimedhi Institute of Science and Technology (VISTEC) (refer 2.1.5 (2)), and Wangchan Forest Project. It is planned that the National Science and Technology Development Agency (NSTDA) will launch 3 innovation clusters in EECi; BIOPOLIS, ARIPOLIS, and SPACE INNOPOLIS.

BIOPOLIS	✓ Innovative Agriculture ✓ Chemical & Bioprocess Technology ✓ Functional Ingredient
ARIPOLIS	✓ Sensing Innovation ✓ Computing Innovation ✓ Manufacturing & Service Innovation ✓ Cyber-Physical System Integration
SPACE INNPOLIS	✓ High Altitude Pseudo-Satellite Unmanned Aerial Vehicle (HAPS UAV) & Global Navigation Satellite System (GNSS) ✓ NQI Aerospace

These 3 innovation clusters work closely with major research institutes and universities, local and international firms, and government agencies as well as local communities with the objective to develop frontier industries in EEC and other regions in Thailand. Currently several universities and research institutes in Thailand are registered as partners of EECi.

Partner Universities

VISTEC, Suranaree Institute of Technology, Chulalongkorn University, Mahidol Univerisuty, Kasetsart University, Chaing Mai University, Thammasart University, Walailak University, Prince Songkla Universitym Konkhaen University, King Mongkht's Universiity of Technology North Bangkok, Asian Institute of Technology, Burapha University, Rajamangala University of Technology Isan, Rajamangala University of Technology Phranakorn, Rajamangala University of Technology Rattanakosin, Rajamangala University of Technology Thanyaburi, Rajamangala University of Technology Krungthep, Rajamangala University of Technology Srivijaya, etc.

Research Agencies / Institutes

NSTDA, Geo-Informatics and Space Technology Development Agency (GISTDA), National Institute of Metrology (NIMT), Industrial Technology Research Institute, Thailand Automotive Institute, Thailand Institute of Scientific and Technology Research (TISTR), Thai-German Institute, Thailand Center of Excellence for Life Science (TCELS), etc.

2.9 Project Rationale and Alignment with National Goals and Higher-Level Plans

In the 12th Development Plan (2017-2021), GOT has identified investment in national R&D infrastructure and human resource development as priority issues necessary to improve the country's international competitiveness to become a developed country, which is consistent with the objectives of this Project.

EECi, the target site of this Project, aims to promote the development of a center for R&D by industry, government, and academia for the advancement of industry under the "Thailand 4.0" concept based on the 20-year national strategy, which is also consistent with the higher-level plan.

In Japan, which is a pioneer in synchrotron radiation technology, the NanoTerasu facility (soft X-ray), which excels in refined analysis of surface chemical reactions and light element analysis, began shared use in April of last year. Additionally, budget approval has been granted for the advanced upgrade (SPring-8-II) of the existing SPring-8 facility (hard X-ray), which excels in non-destructive analysis of internal nanostructures and heavy element analysis, and construction has commenced. Both investments are government initiatives aimed at promoting industry and strengthening international competitiveness. As next-generation synchrotron facilities are being developed worldwide, the upgrade of SPring-8, which has been in shared use for over 25 years since 1997, was deemed essential for leading future industries.

Similarly to Japan, the GOT has put forth Thailand 4.0 as a national development strategy aiming for a "transition to an industry structure based on knowledge, technology, and innovation." Key priorities include promoting S-Curve industries, strengthening R&D capabilities and human resource development, and accelerating digitalization and industrial cluster formation. Furthermore, Thailand is focusing on promoting

the BCG Economy Model[13] as a policy framework for sustainable economic development. The establishment of advanced R&D infrastructure is becoming increasingly important for realizing these policy goals.

In contrast, the existing SPS-I (SPS 1.2 GeV), which has supported scientific and industrial technology development in Thailand, has been in operation for over 20 years since 2001. Due to both aging and limitations in light source performance, the current facility is increasingly unable to meet the advanced analytical needs essential for cutting-edge scientific research and technological innovation. This constraint poses a significant challenge to driving the technological innovation required by the priority industries outlined in Thailand 4.0 and the BCG Economy Model.

The Next Generation Synchrotron Radiation Facility (SPS-II) is designed to supply high-luminosity, stable, and coherent light across a broad energy range, from soft X-rays to hard X-rays. This will enable precise measurements and advanced analysis that have previously been difficult in Thailand. For example, in the accelerating EV (Electric Vehicle) industry, SPS-II can precisely determine structural changes in battery materials during operation, contributing to higher performance and longer design life. In the semiconductor sector, nano-analysis of interface states and impurity distribution can form the necessary technological foundation for next-generation device development. Moreover, in the medical and bio fields, high-resolution analysis of protein structures will accelerate new drug discovery, and in agriculture, the visualization of trace element distribution in crops will contribute to quality improvement and the evaluation of nutritional properties. These advanced measurement and analysis technologies provided by the next-generation synchrotron facility are expected to significantly contribute to enhancing the competitiveness of Thailand's key industries.

Thus, the introduction of the next-generation synchrotron facility is extremely important as a foundation for supporting a wide range of research activities, promoting the advancement of industrial technology, and facilitating the development of advanced research personnel and engineers. The societal need for the development of this facility is exceptionally high, particularly in terms of its ability to contribute to the Thailand 4.0 policy goals of fostering innovation, strengthening R&D capabilities, and developing highly skilled human capital.

[13] Bio-Circular-Green (BCG) Economy Model aims for sustainable economic growth through innovation by integrating three elements: Bio (sustainable use of biological resources), Circular (reducing waste and recycling resources), and Green (aiming for high-quality living and economic growth while reducing environmental impact).

3 Consideration of Project Plans and Alternative Proposals from GOT

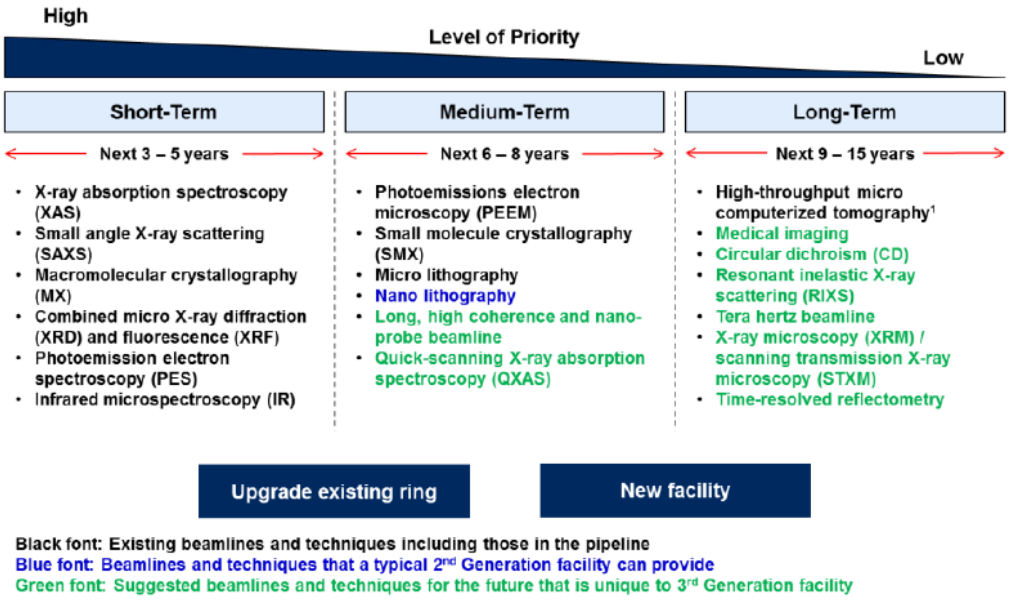
3.1 Project Planning from GOT

3.1.1 Background and the Latest Status Confirmation and Arrangement of Project Plan

(1) Feasibility Study (F/S)

Conducted in 2016 by Thai side, the outline of the F/S are as follows.

Table 3-1 Summary Table of F/S

Accelerator	■ Injector/ Booster: Linear full-energy injector linac with potential for future expansion to free-electron lasers (FEL) ■ Storage Ring MBA Lattice.
Beamline	
Site location	In Nakhon Ratchasima, Thailand

Source: SLRI

(2) Detailed Design Study (D/D)

Conducted in 2021 by Thai side, with the following key points differing from F/S.

Table 3-2 Summary Table of D/D

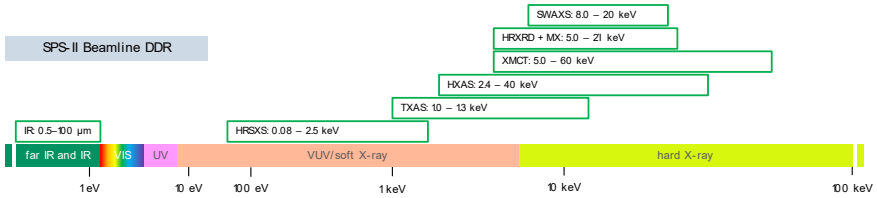
Accelerator	■ Injector/ Booster: A design that combines a linear injector linac and a ring-shaped booster synchrotron that can be manufactured to a certain extent by domestic companies in Thailand (common configuration for general-purpose SRF) ■ Storage Ring: DTBA Lattice
Beamline	7 photon beamlines in Planning (HRSXS, TXAS, HXAS, XMCT, MX, SWAXS, HRXRD)
Site location	Plot K in EECi in Rayong Province, Thailand

Source: SLRI

(3) Current Design

As of May 2025, there have been some changes from D/D, as follows.

Table 3-3 Design Changes Made from D/D

<table>
<tr><td>Accelerator</td><td>■ Injector/ Booster:
No change
■ Storage Ring:
No change</td></tr>
<tr><td>Beamline</td><td>7 photon beamlines in Planning (HRSXS, TXAS, HXAS, XMCT, SWAXS, HRXRD+ MX))


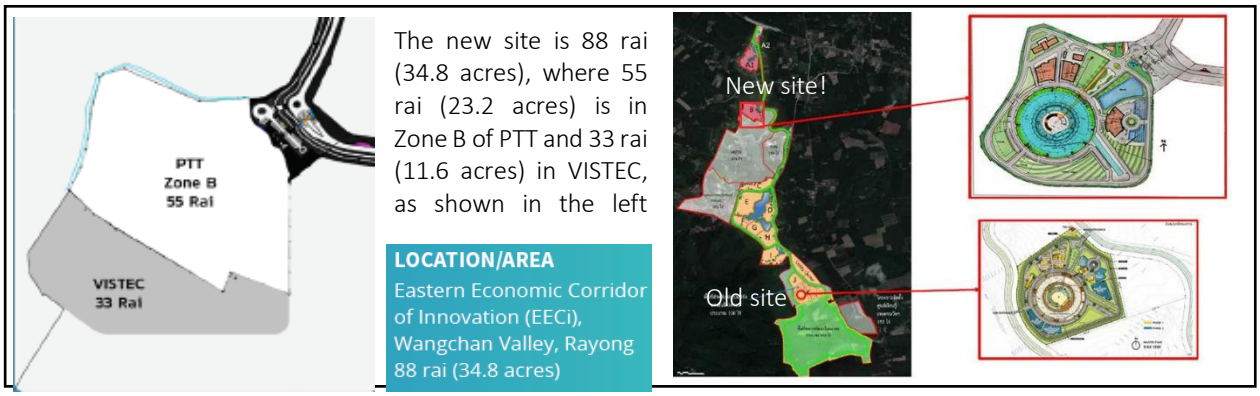
<table>
<tr><th>Beamline</th><th>Name</th><th>Photon Range</th><th>Beam size (H x V)</th><th>Scientific Technique</th></tr>
<tr><td>HRSXS</td><td>High Resolution
Soft X-ray Spectroscopy</td><td>0.08 – 2.5 keV</td><td>• Station A: 0.04 x 0.04 mm²
• Station B: 0.07 x 0.01 mm²</td><td>ARPES, XPS, NEXAFS, XMCD
PEEM, XMCD-PEEM</td></tr>
<tr><td>TXAS</td><td>Tender X-ray
Absorption Spectroscopy</td><td>10 – 13 keV</td><td>• Focused beam: 0.10 x 0.06 mm²
• Large beam: 13 x 2 mm²</td><td>XANES, EXAFS, XRF
Full-field Imaging: XRF</td></tr>
<tr><td>HXAS</td><td>Hard X-ray Absorption Spectroscopy</td><td>2.4 – 40 keV</td><td>• 0.12 x 0.11 mm²</td><td>XANES, QEXAFS, XRF</td></tr>
<tr><td>XMCT</td><td>X-ray Microtomography</td><td>5.0 – 60 keV</td><td>• 40 x 10 mm²</td><td>Micro-Tomography</td></tr>
<tr><td>SWAXS</td><td>Small and Wide-Angle X-ray
Scattering</td><td>8.0 – 20 keV</td><td>• 0.33 x 0.18 mm²</td><td>SAXS, WAXS, USAXS, GISAXS</td></tr>
<tr><td>HRXRD + MX</td><td>High Resolution X-ray Diffraction and
Macromolecular Crystallography</td><td>5.0 – 25 keV</td><td>• Station A: 1.4 x 0.9 mm²
• Station B: 0.02 x 0.01 mm²</td><td>High Resolution XRD
XRD imaging
Micro-focused MX, MAD, SAD</td></tr>
</table></td></tr>
<tr><td>Site location</td><td>Zone B of PTT and a part of VISTEC area in EECi in Rayong Province, Thailand</td></tr>
</table>

Source: SLRI

SLRI considered lineup of beamline in SPS-II by conducting needs survey of the existing SPS-I users and prospective future users. Therefore, 7 beamline lineup was proposed by SLRI in consideration of both results of needs survey and budget.

One of the main industries in Thailand is agriculture. According to the utilization record of beamline in SPS-I, research on protein analysis in agricultural product is very active in Thailand. There are XMD and MX beamlines in SPS-I, with which the research on analyzing protein content has been conducted. On the other hand, these beamline in SPS-I have specific issues: limited spatial resolution and spot beam diameter. Therefore, if the HRXRD+MX beamline will be installed in SPS-II, precise measurement can be achieved. Consequently, the installation of HRXRD+MX beamline in SPS-II is reasonable.

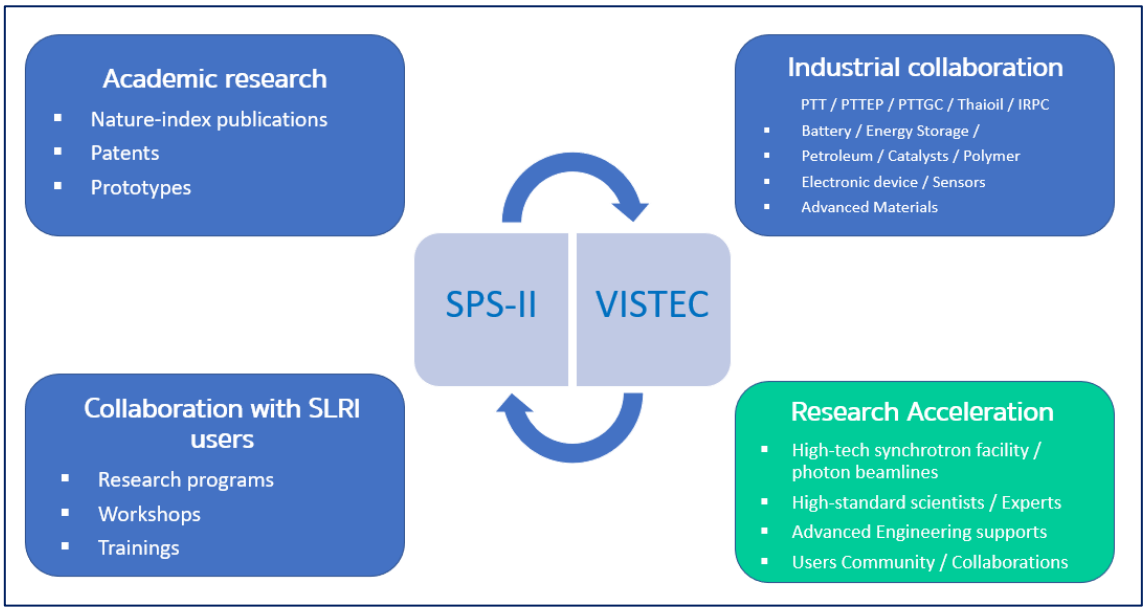
Table 3-4 New Site Location



Source: SLRI

The reasons behind the site change have been confirmed as follows:

- Geological stability: the previous site is surrounded by undeveloped area, next to the vehicle testing field of the Department of Science Service, and close to a 250-meter runway (flight-strip) – all of which cause vibration and not conducive for SRF. On the other hand, the new site is surrounded by farmlands, VISTEC and EECi, and SLRI confirmed that there is no risk of any large-scale construction or site development of the farmlands in the future. In addition, based on boring surveys, geotechnical experts in Thailand have confirmed that the ground at the new site is sufficient to support the load of the synchrotron facility.
- Transportation accessibility: the new site is closer to EECi's entrance and VISTEC, one of the main user and research collaborators. The microtremor survey's result will be used to confirm that there is no effect of traffic vibrations to the campus road
- Prospective user/ collaborators nearby: industrial estate, neighboring scientific research institutes and universities in Eastern Economic Corridor (EEC) area



Source: SLRI

Figure 3-1 SPS-II – VISTEC - PTT Collaboration

The necessity and appropriateness of the site change have been confirmed. In relation to the site change, the following adjustments are planned:

- MOC of the new site has been signed on November 15th, 2022
- Geotechnical survey (boring) at the new site has been conducted at the end of November 2022 under SLRI Budget
- Ground vibration survey (micro tremor measurement) at the new site has been conducted at the end of November 2022 (together with the above geotechnical survey) under this preparatory survey budget (see **Attachment 2: Vibration Survey Report**).
- EIA is not necessary for the new site, according to information from SLRI. Has been reconfirmed by JST (Refer to Section 12).
- Final design adjustment to the new site is necessary, and the additional cost is to be borne by SLRI

(4) Project Phase Separation

The tentative schedule for the SPS-II Project is planned in 3 phases, as follows.

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Project Formulation Phase														
Project Implementation Phase														
Operation & Maintenance Phase														

Note: Schedule is subject to the timing of Cabinet Approval and Loan agreement signing

1. Project Formulation Phase (Sep 2022 – April 2026)

The following were confirmed as part of the Project Formulation phase.

- Submit revised Project Proposal (PP) by SLRI to Office of the National Economics and Social Development Council (NESDC) via MHESI
- SLRI will receive review comments from NESDC via MHESI (October 2024)
- Revised PP approval from the Cabinet of Thailand (October 2024)[14]
- Project cost approval from Parliament (December 2025)
- JICA Fact Finding Mission & JICA Appraisal (January 2026)
- Pledge, L/A Negotiation, L/A Signing, and E/N Signing (April 2026)

2. Project Implementation Phase (April 2026 – August 2034)

- Basic Design (B/D) and Detailed Design (D/D) for Facility, Accelerator and Beamline
- Selection of Consultant
- Bidding
- Construction of Facility
- Procurement of Equipment for Accelerator and Beamline
- Hand-Over

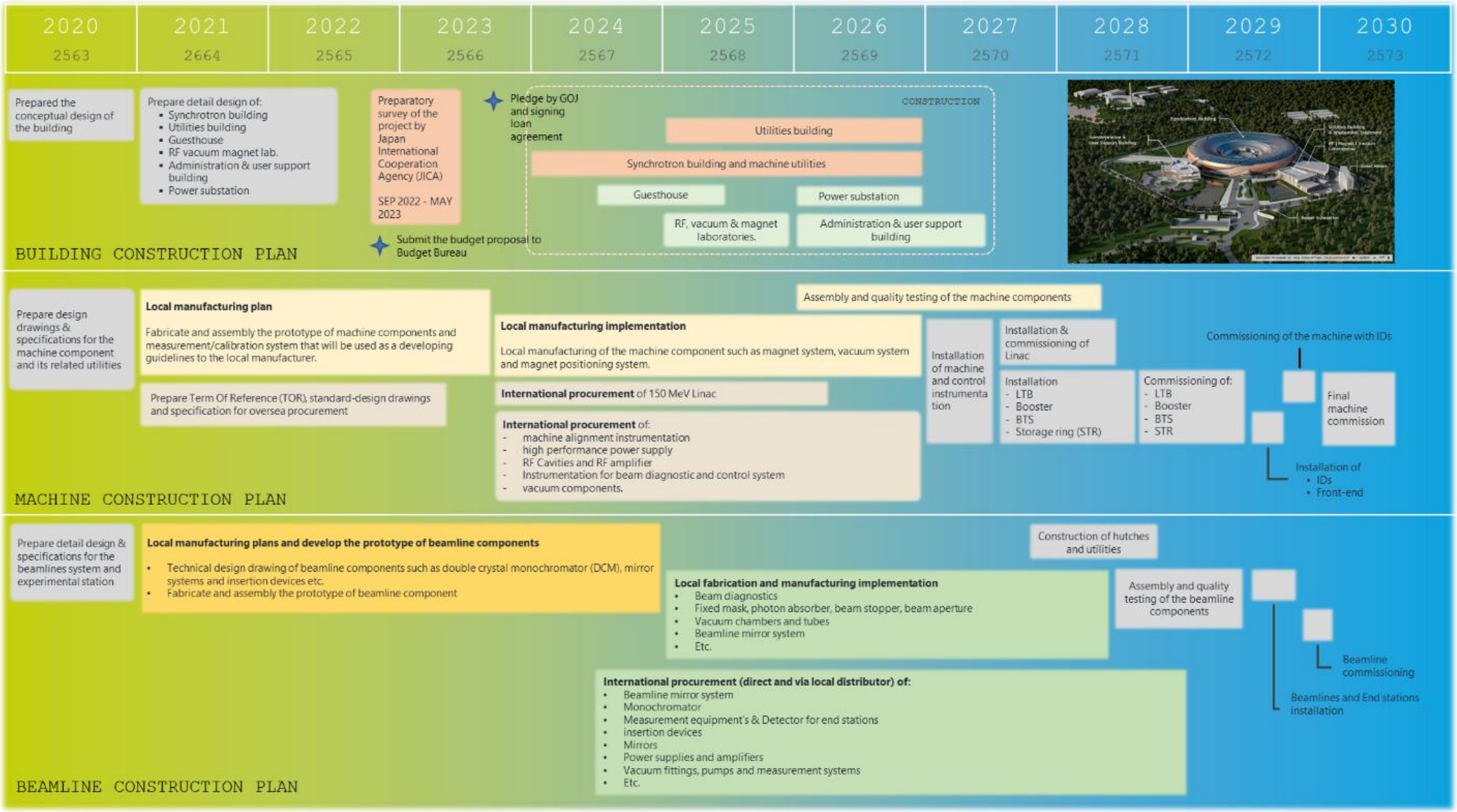
[14] The revised PP approval from the Cabinet schedule was planned by SLRI.

- Defects Notification Period for Facility
- Warranty Period for Equipment of Accelerator and Beamline

In addition, similar to NanoTerasu, it was confirmed that the maintenance and commissioning of the front-end and insertion device (ID) will be implemented as part of the accelerator/ machine.

3. Operation & Maintenance Phase (September 2034 –)

The operation and maintenance phase including additional beamline development (Phase 2 and more) is not covered by this Yen Loan. Therefore, the Yen loan will cover until beamline commissioning and Warranty Period for Equipment of Accelerator and Beamline (Phase 1).



Source: SLRI

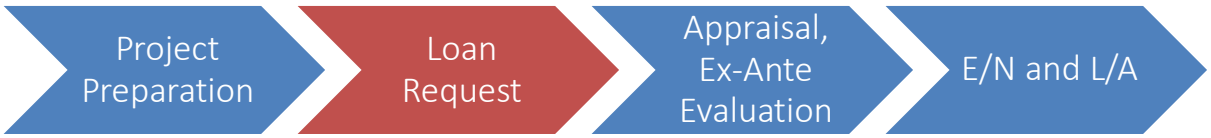
Figure 3-2 Overall Project Schedule from SLRI

(5) Project Plan Finalization Process

Since the Project plan finalization process differs depending on the country, the process are explained by country.

Japan Side

Prior to Project implementation, the steps to be done by Japan side starts with Project Preparation. After that, the borrowing country, in this case Thailand, needs to submit a Loan Request to Japan. Upon receiving the request, Japan will follow up with Appraisal & Ex-ante Evaluation, Exchange of Notes (E/N) and Loan Agreement (L/A).

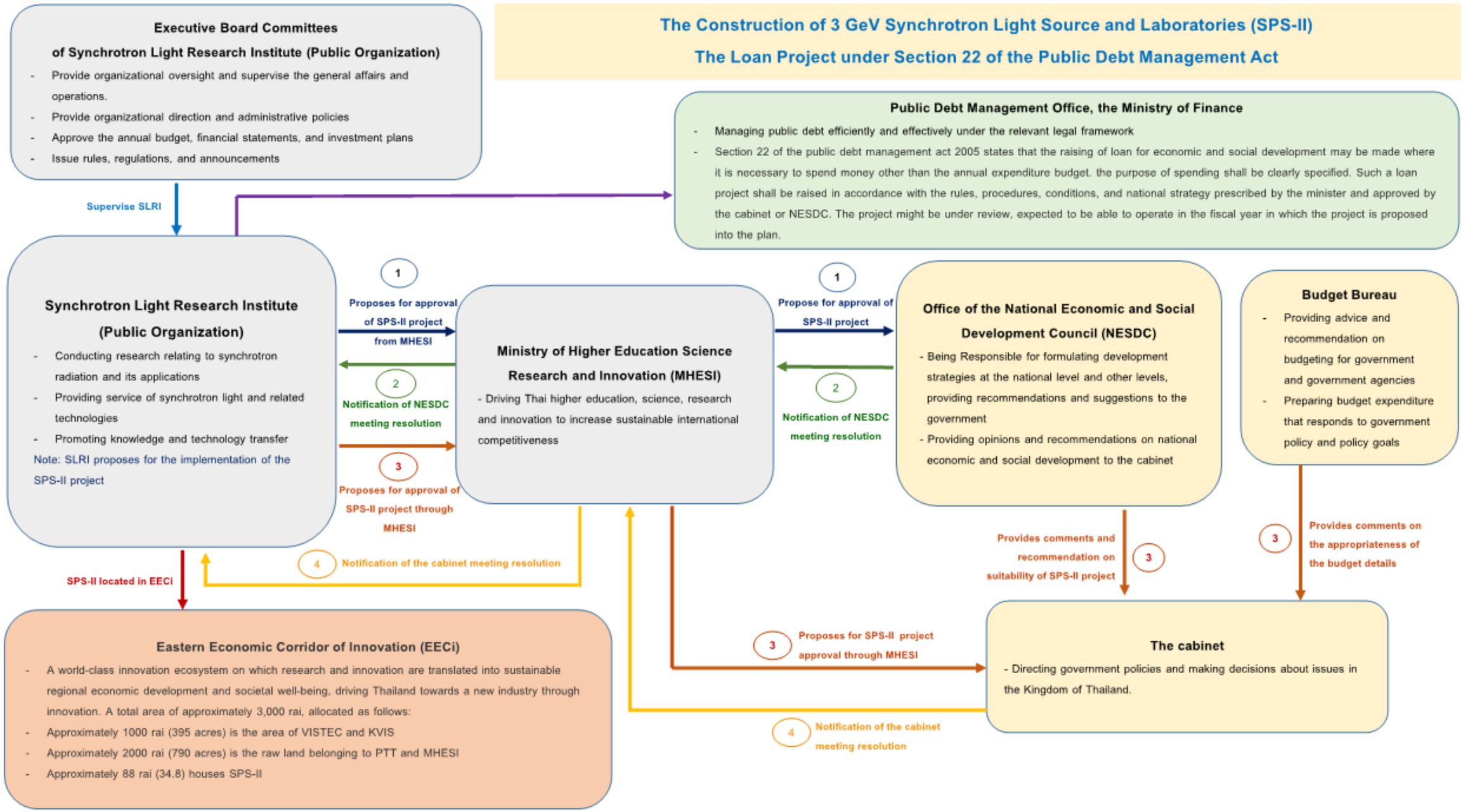


Source: JST

Figure 3-3 Steps to L/A of ODA Loans

Thailand Side

After the Cabinet approval (shown as no.4 in Figure 3-4 below), Public Debt Management Office (PDMO), the Ministry of Finance (MOF) shall submit a Yen Loan request application to the Government of Japan (shown in red in Figure 3-3 above).



Source: SLRI

Figure 3-4 Functions & Workflows of Related Organizations of GOT

3.2 Study of Alternative Proposals

3.2.1 Budget Allocation Policy in Design and Implementation

It is desirable to allocate a budget from the viewpoint of promoting the use of SRF in order to ensure its sustainable and stable operation and to contribute to the sustainable economic development and improvement of international competitiveness, which are the Project goals. In the case of establishing a new SRF in Thailand, sufficient budget should be allocated for the Storage Ring and beamline, and the budget for the construction of the injector system (Linac + Booster Synchrotron) should be sufficient to meet the required specifications.

(1) Upgrade of the Existing 2nd Generation SRF

According to the operation plan of the SRF in Thailand, the existing synchrotron light facility (SPS-I) will provide a soft-X-ray beamline, which is in high demand from industry. Moreover, the new synchrotron light facility (SPS-II) will provide a higher-energy, high-intensity, low-emittance hard X-ray beamline for industry and academia.

At present, SLRI has developed two operational scenarios for SPS-I and SPS-II. The first plan involves operating both synchrotron facilities simultaneously, while the second focuses on using only SPS-II. Although a final decision between these plans is expected within a few years of SPS-II's completion, the current intention is to operate both facilities. However, maintaining two facilities requires substantial maintenance costs and personnel. Consequently, given the limited budget and resources, it is considered difficult to upgrade the existing SPS-I to a next-generation synchrotron facility.

In addition, there is a big difference in the circumference of the Storage Ring (and Booster Ring) between SPS-I and SPS-II, which are 81.3m (SPS-I) and 327.5m (SPS-II). The challenge is whether it is possible to secure a place where synchrotron radiation exceeding 300m can be installed in the existing SPS-I and the surrounding area. Moreover, regarding the technical specifications of the newly constructed SPS-II, there are few equipment components that can be diverted from SPS-I to SPS-II whereas for the old parts, new equipment will be necessary. However, the cost of constructing the accelerator and beamline is not significantly different from the cost of building a new SRF.

Due to the situation described above, it is presumed that upgrading SPS-I to a next generation SRF will be difficult from both technical and cost aspects.

(2) Possibility of Utilizing SRF in Other Countries

If the use of synchrotron radiation beamlines is only for measurement results, it is less costly for Thai researchers to use SRFs in other countries than to build a new one in Thailand.

On the other hand, the effects of having advanced research facilities in Thailand include (i) fostering of students/researchers/engineers in Thailand, (ii) derivative effects on industry in Thailand, and (iii) serving as a research symbol in Thailand. These should be taken into consideration to improve the scientific and

technological capabilities of Thailand, and it is meaningful for the Thai people to design and manufacture their own research facilities that they can be proud of.

It will contribute to improving Thailand's scientific and technological capacity, if opportunities are provided for young researchers and engineers who have gained experience at overseas universities and research institutes to continue their research in their home country after returning to Thailand. It is also important to note the potential of the country as a research base in ASEAN.

(3) Lineup of the Beamlines

The beamline's lineup and priority are determined by the purpose of use and budget of the beamlines. SLRI determined the lineup of beamlines to be installed at SPS-II by conducting a needs assessment survey of SPS-I beamline users as well as the future beamline users and organizations. The decision to start with 7 beamlines as the first phase of the beamline installation plan is considered appropriate in view of the fact that the Taiwan Photon Source (TPS), an SRF of the same scale, started with 7 beamlines.

3.2.2 Concept of Linac (Linear Accelerator)

The injectors used in SRF around the world can be broadly classified into two types: the combination of linac and booster synchrotrons, and the full-energy linac. Representative facilities using the combination of linac and booster are National Synchrotron Light Source II (NSLS-II) in the USA, TPS in Taiwan and Sirius in Brazil, while facilities using full-energy linacs[15] are MAX IV in Sweden, SPring-8-II and NanoTerasu in Japan, and Pohang Light Source II (PLS II) in South Korea.

In the F/S report published by the Thai government in 2016, a Full-Energy Linac with Top-up operation was planned in anticipation of the upgrade to the Free Electron Laser (FEL) in the future. As the top-up operation increases the operating time of the synchrotron, the Full Energy Linac was expected to reduce operating costs such as electricity charges in comparison with the linac and booster combination, but the FEL increased the construction cost because the FEL requires the high-precision control system.

JST confirmed that SLRI has no plans to upgrade to FEL in the future due to limited budget and construction space, and that the combination of linac and booster synchrotron will be adopted as the injector system for SPS-II. JST considered the injector system in terms of construction cost, operating cost and technical challenges. As a result, JST considered the concept of the injector system, which is the combination of linac and booster synchrotron, to be feasible.

3.2.3 Injector Linac Frequency Band Concept

As mentioned in 3.2.2., JST confirmed that SLRI has planned to use the combination of linac and booster synchrotron as the injector system for SPS-II. JST confirmed that the frequency band of the linac is changed from C-band to S-band accordingly. JST considered the frequency band of the linac in terms of construction cost and technical stability. As a result, JST considered the frequency band proposed by SLRI to be reasonable.

[15] Full-energy linac: A device in an accelerator system that injects and accelerates electrons. It consists of an S-band photocathode RF gun, a C-band accelerating structure, a magnetic channel, and a hot cathode gun.

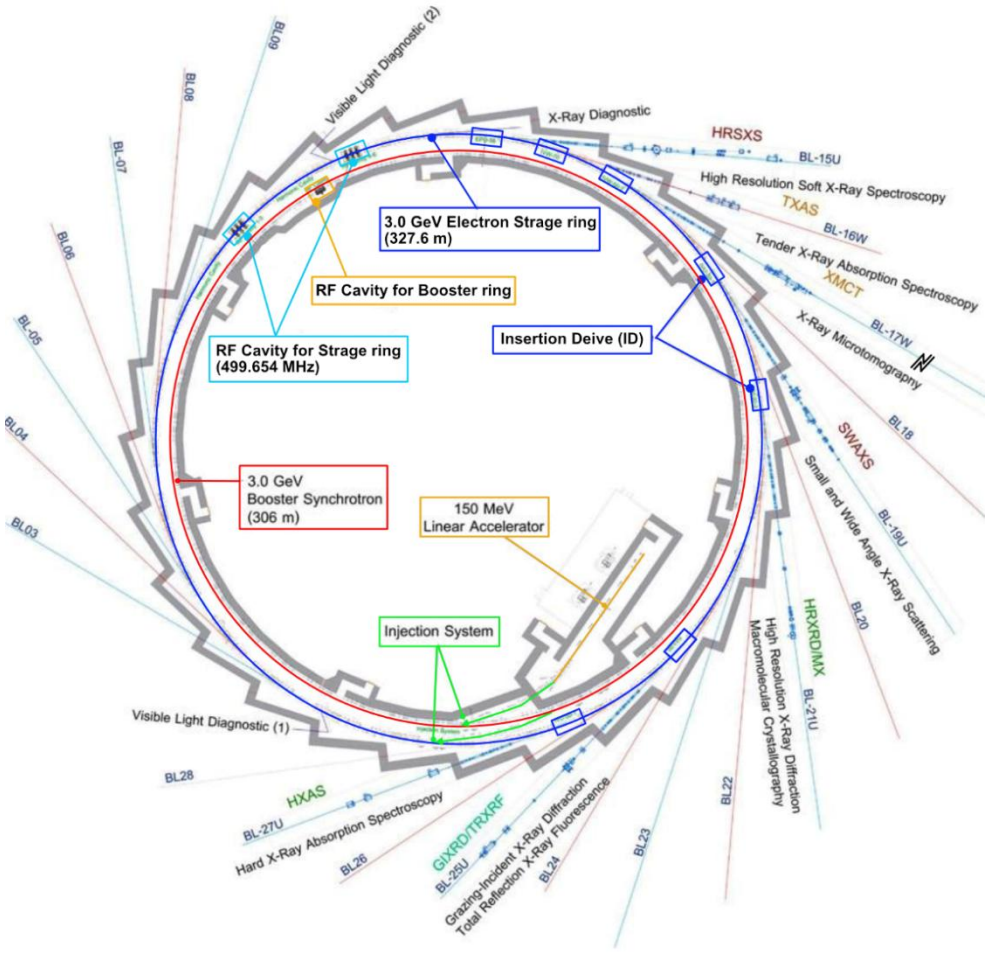
4 Preliminary Design Results for Accelerator and Beamline

4.1 Preliminary Design of Accelerator (Injector Linac, Booster Synchrotron, Storage Ring)

The SPS-II accelerator consists of three main components: a 150 MeV injector linac, a 3.0 GeV booster synchrotron and a 3.0 GeV storage ring.

The injector accelerator consists of a 150 MeV injector linac and a 3.0 GeV booster synchrotron. Electrons accelerated to 150 MeV in the injector linac are transported to the 306.0 m booster synchrotron, which achieves an electron energy of 3.0 GeV and a low-emission electron beam of less than 10 nm-rad for stable injection in top-up operation.

The storage ring will have a circumference of 327.6 m and will be designed to achieve a low emittance beam of 0.97 nm-rad. The frequency of the (RF) system in the storage ring is planned to be 499.65 MHz, and a Double Triple Bend Achromat (DTBA) lattice is adopted as the grating design. The DTBA lattice will allow 14 standard straight sections and 14 central straight sections to be formed in the SPS-II storage ring and is designed to accommodate up to 21 light sources in the future.



Source: SLRI

Figure 4-1 Schematic Diagram of the SPS-II Accelerator

4.1.1 150 MeV Injector Linac

(1) Technical Requirements

A 150 MeV injector linac is chosen for SPS-II. The most important reason why a 150 MeV injector linac was selected for SPS-II is that the beam emittance of the electron beam generated by the high-energy linac is extremely small. Beam emittance is a quantity that indicates the distribution of momentum and position of particles in the beam, and the smaller it is, the higher the beam convergence. Since the relative energy spread is small (because energy dispersion is suppressed), a high-quality electron beam is formed, and as a result, a compact beam size suitable for injection into the booster synchrotron is generated. By suppressing the beam emittance from the 150 MeV injector linac within an appropriate range, the injection efficiency into the booster synchrotron can be improved and high beam transmission efficiency can be ensured.

The required technical specifications for the 150 MeV injector linac are shown below.

- Triode gun with a 500 MHz modulation at the gun grid and high-voltage deck
- 500 MHz standing-wave subharmonic prebuncher (SHB)
- S-band traveling-wave buncher (BCH)
- four S-band traveling-wave accelerating structure in $2\pi/3$ mode
- solenoids between the gun and the first S-band structure
- four sets of triple quadrupolr, placing after each individual accelerating structure section
- 500 MHz solid-state amplifier for the SHB
- two S-band RF stations, each consisting of a 45-MW klystron and a modulator
- low-level RF controls
- dipole magnet with adjustable magnetic field for beam energy measurement (45°) and for beam transfer to the booster (18°)
- two beam dumps for beam energy measurement (45°) and for safety (forward direction).

Top-up mode will be the main operation mode of SPS-II. A bunch train[16] with charge 3 nC or more is required for each top-up injection to the SPS-II storage ring for the stored beam current of 300 mA. The storage ring and booster ring are designed based on the RF system[17] described later. Each bunch of electrons (particles) in the bunch train transported from the injection linac to the booster synchrotron ring and the storage ring must be precisely injected into an RF bucket (an electron trapping region formed by a radio frequency electric field) formed by the accelerator's RF system. In order to achieve a highly efficient beam injection[18], the injector linac must produce the beam with a bunch structure corresponding to the RF buckets. Main Parameters related to beam injections to the SPS-II storage ring are summarized in Table 4-1.

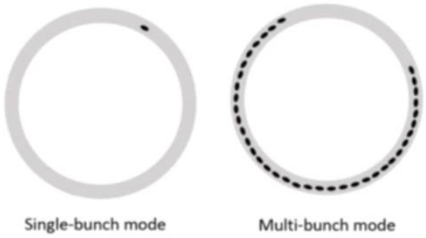
[16] Bunch train: A small bundle of electrons moving together in time and space is called a "bunch." A state in which bunches are connected in a row with a single point interval between them is called a bunch train.
[17] RF system: A radio frequency linear acceleration system consisting of an electron injector and a linear acceleration tube.
[18] Highly efficient beam injection: The bunch formed in the injection linac is injected with "high efficiency" into the RF bucket formed in the accelerator (booster ring, storage ring).

Table 4-1 Design Parameters of SPS-II Injector Linac

Parameter	Specification
Accelerating particle	Electron
Beam Energy at linac exit	≥ 150 MeV
RF frequency (S-band) of accelerating structure	2997.924 MHz
Normalized beam (1σ) emittance at linac exit	≤ 50 π mm mrad
Energy spread (rms) at linac exit	≤ 0.5%
Pulse-to-pulse energy variation (rms)	≤ 0.25%
Beam position error at linac exit	Within ±0.5 mm (for horizontal and vertical planes)
Pulse-to-pulse beam position variation (rms)	≤ 0.2mm (for horizontal and vertical planes)
Pulse-to-pulse jitter	≤ 100ps
Bunch charge	≥ 6.0 nC (MBM) / 1.5 nC (SBM)
Bunch duration (SBM)	< 1.0 ns (SBM)
Repetition rate range (Hz)	1.0-5.0 Hz (Adjustable)
Operation mode	Single bunch mode (SBM), Multi-bunch mode (MBM)

Source: SLRI

The 150 MeV injection linac for SPS-II is planned to be a linac that can be changed to multi-bunch mode and single-bunch mode to accommodate various experiments in the future. Schematic diagrams of multi-bunch mode and single-bunch mode are shown in the figure below.



Source: JST

Figure 4-2 Single-Bunch Mode and Multi-Bunch Mode

1) Multi-Bunch Mode (MBM)

For Multi-bunch mode (MBM) operation, the linac will generate a long-pulsed beam with a maximum macro-pulse length of 600 ns. The MBM will chop the beam at 500 MHz (at the gun level). For top-up injections, the linac must consistently deliver single MB trains at a few mHz (every 10 to 300 seconds) or sequences of MB trains (at 1 to 5 Hz for 1 to 10 seconds) at intervals of a few mHz (every 1 to 5 minutes).

Table 4-2 Beam Parameters at Linac Exit of Multi-Bunch Mode (MBM) Operation

Parameter	Specification
Bunch train length	150 to 600 ns
Charge in bunch train	≥6nC with equal charge for all bunch
Bunch train uniformity	< 10%
Energy	≥ 150 MeV
Pulse-to-pulse energy variation (rms)	≤ 0.25%
Relative Energy spread (rms)	≤ 0.5%
Normalized emittance (1σ)	≤ 50 π mm·mrad (for horizontal and vertical planes)
Repetition rate	1 to 5 Hz (adjustable)
Pulse to pulse time jitter	≤ 100 ps

Source: SLRI

2) Single-Bunch Mode (SBM)

For Single Bunch mode (SBM) operation, the linac will deliver short pulses of less than 1 ns at an adjustable repetition rate of 1 to 5 Hz. Each pulse is split into several S-band micro-bunches, which are injected into a single 500 MHz RF bucket in the booster. A 500 MHz sub-harmonic pre-buncher should be considered to ensure good single-bunch purity. The total charge per bunch is at least 1.5 nC. For top-up injection, the linac must reliably deliver single bunches at intervals of a few mHz (every 10 to 300 seconds) or sequences of single bunches (at 1 to 5 Hz for 1 to 10 seconds) at a rate of a few mHz (every 1 to 5 minutes). The beam parameters for SBM operation are listed in Table 4-3.

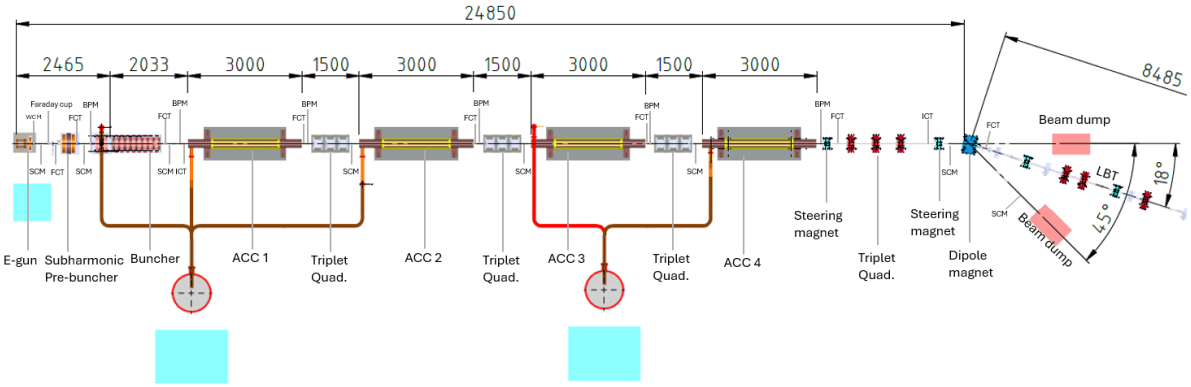
Table 4-3 Beam Parameters at Linac Exit of Single Bunch Mode (MBM) Operation

Parameter	Specification
Macro-puls length	< 1ns
Charge in single bunch	≥ 1.5nC
Energy	≥ 150 MeV
Pulse-to-pulse energy variation (rms)	≤ 0.25%
Relative Energy spread (rms)	≤ 0.5%
Normalized emittance (1σ)	≤ 50 π mm·mrad (for horizontal and vertical planes)
Single bunch purity	Better than 1%
Repetition rate	1 to 5 Hz (adjustable)
Pulse to pulse time jitter	≤ 100 ps

Source: SLRI

(2) Configuration of Injector Linac for SPS-II

Many synchrotron facilities around the world use turnkey linac systems[19] as the injector linac. We plan to use a turnkey linac system as the injector linac for SPS-II, referring to other facilities, because of the similarity of design and ease of manufacture. The SPS-II 150 MeV injector linac consists of a hot-cathode triode-type electron gun with beam chopping by a RF system to be designed, a bunching system combining a subharmonic pre-buncher and an S-band buncher, and a main S-band accelerator. The SPS-II injector linac is planned to be composed of four SLAC 3m-type accelerating tubes with a constant gradient of 15 MeV/m or less, and the total length of the injector linac is about 25 m to appropriately accelerate the 150 MeV beam. A schematic diagram of the 150 MeV injector linac for SPS-II is shown in the figure below.



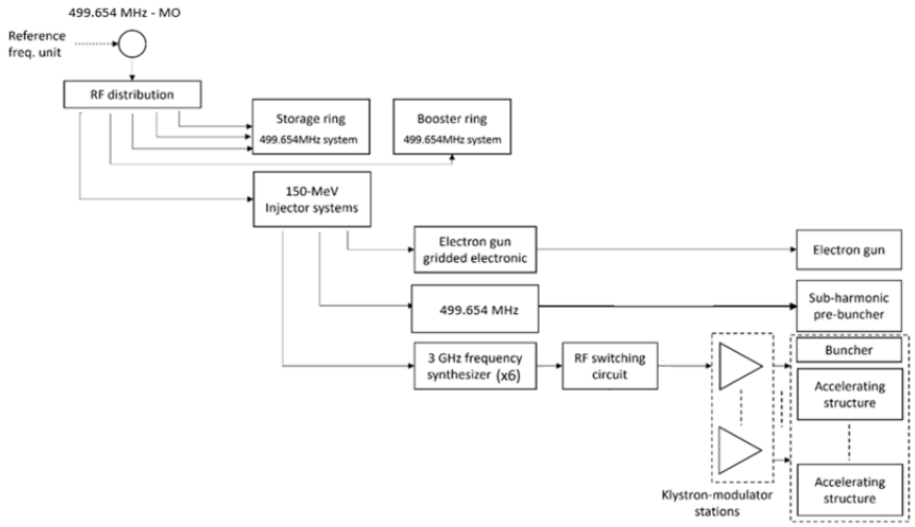
Source: SLRI

Figure 4-3 Layout of 150 MeV Injector Linac for SPS-II

(3) RF System of Injection Linac

The RF system of the injection linac is divided into separate systems for each system. As shown in the figure below, the master frequency is obtained from the same master oscillator as the storage ring. The injection system is based on the S-band and to synchronize it with the RF frequency of the storage ring (499.654 MHz), its frequency is set to 2,997.924 MHz. The subharmonic cavity is set to 499.654 MHz. The subharmonic buncher cavity is used to generate short bunches. The injection linac for SPS-II consists of four accelerating tubes (SLAC 3m) and the total electron energy is accelerated to a nominal 150 MeV. The average energy obtained from each accelerating tube is estimated to be 37.5 MeV, and the input power is 9 MW. This allows for stable acceleration and efficient injection beam generation.

[19] A lump-sum order contract in the sense that the equipment will be delivered in a state where it can be operated simply by turning the key.



Source: SLRI

Figure 4-4 RF System Configuration for Injection Linac

4.1.2 Booster Synchrotron

The SPS-II injector accelerator consists of a 150 MeV linac and a 3.0 GeV booster synchrotron. The 3.0 GeV booster synchrotron is designed to accelerate the 150 MeV beam supplied from the linac up to 3 GeV, and to deliver a low-emittance electron beam into the storage ring. The design objective is to provide an electron beam with an emittance of 10 nm-rad or less, thereby ensuring stable beam injection during top-up operation.

The SPS-II booster synchrotron is planned to be installed within the same tunnel that houses the storage ring. As shown in Table 4-4, synchrotrons equipped with in-tunnel boosters have been developed and are being operated at many synchrotron radiation facilities, including SIRIUS (Brazil), TPS (Taiwan), SLS (Switzerland) and ALBA (Spain).

Table 4-4 Parameters of Booster Synchrotron at Other Synchrotron Radiation Facilities

Parameter	SIRIUS	TPS	SLS	ALBA	SPS-II
Injection energy (GeV)	0.15	0.15	0.1	0.1	0.15
Maximum energy (GeV)	3.0	3.0	2.4	3.0	3.0
Circumference (m)	496.8	496.8	270	249.6	306.0
Repetition rate (Hz)	2	3	3	3.125	2
Beam current (mA)	2		12	1	2
Emittance from liniac (mm. Mrad)	< 50	< 50		< 50	
Emittance at injection (mm.mrad)	170	150			
Emittance in booster (mm-rad)	3.47	10.3	9	9	5.89
Distance bw BS and STR (m)	3.44	3.44	2.9	2.8	3.43

Source: SLRI

(1) Technical Requirements

The technical requirements for the SPS-II booster synchrotron are as follows:

- To avoid the stay fields disturbing an electron beam in storage ring, the distance between Storage ring (STR) and Booster synchrotron (BS) should be more than 3.40 m.
- To minimize stray field, an H-type dipole is selected for the booster bending magnet.
- The space between STR and BS should be comfortable and enough for equipment installation and transportation.
- RF frequency in booster must be different by less than 5 kHz from RF frequency in STR.
- Booster will be operated with a repetition rate of 2 Hz and a beam current of 2 mA.

Based on these specifications, the circumference of the booster synchrotron was first examined. In determining the circumference of the booster ring, the RF frequency is regarded as a key design parameter. The RF frequency is closely related to the timing and acceleration efficiency of the electron bunches, and it must be set as an integer multiple of the revolution frequency so that the electron bunches pass through the cavity in phase with the accelerating RF field on each turn. By properly matching the RF frequency to the revolution frequency and maintaining the resonance condition, energy can be efficiently transferred to the electrons. Furthermore, the adoption of a higher RF frequency allows shorter bunch structures, which in turn improves injection synchronization accuracy and enhances beam stability.

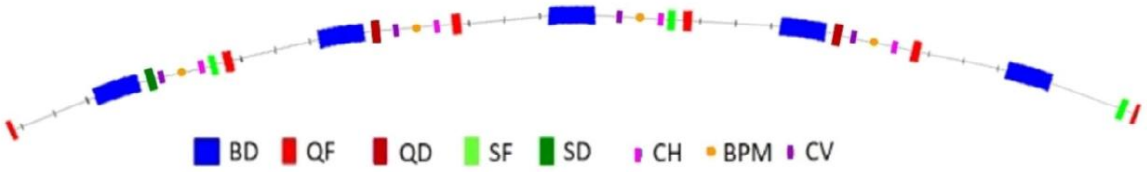
For SPS-II, the RF frequency of both the storage ring and the booster synchrotron has been set at 499.654 MHz, with reference to other synchrotron radiation facilities. With an RF frequency of 499.654 MHz and a harmonic number[20] of 510, the calculated circumference of the booster synchrotron is 306.0 m. The booster synchrotron has been designed with a circumference of 306.0 m, resulting in an average radial separation of 3.43 m from the storage ring (circumference 327.6 m), thereby satisfying the technical specification requirements. This separation is considered sufficient to mitigate stray magnetic fields from the magnets installed in the booster, as confirmed by comparison with facilities such as SIRIUS and TPS.

(2) Lattice Design of 3.0 GeV Booster Synchrotron

The lattice of the SPS-II booster synchrotron is composed of 40 FODO cells with combined-function magnets (BD) in order to achieve the low-emittance electron beam and the high injection efficiency into the RF buckets required for top-up operation. The booster synchrotron, with a circumference of 306.0 m, is divided into eight lattices, each consisting of five FODO cells with a length of 38.25 m. No dispersion-free straight sections are included in the lattice.

Each lattice contains five BDs, and a focusing quadrupole magnet (QF) is installed between each pair of BDs. In addition, a defocusing quadrupole magnet (QD) is placed downstream of the second and fourth BDs from the upstream side. Furthermore, sextupole magnets (SF/SD) are located downstream of the BDs. The magnet arrangement within a unit FODO lattice is illustrated in Figure 4-5.

[20] The harmonic number is the ratio between the RF frequency and the particle rotation frequency in the accelerator, and is an important parameter that determines the number of bunches (particle groups) that can be accommodated in one rotation.



Source: SLRI

Figure 4-5 Layout of 1/8 of SPS-II Booster Synchrotron

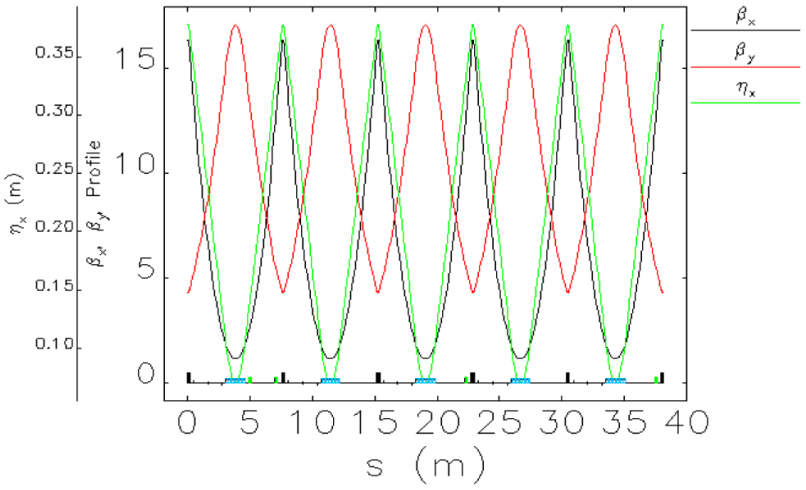
Adjustment of the electron beam operating point (tune) is carried out using the focusing quadrupole magnets (QF) and the defocusing quadrupole field components of the combined-function magnets (BD). By utilizing the quadrupole components of the BDs, both tune adjustment and chromaticity correction can be performed simultaneously. However, since the quadrupole field components of the BDs may introduce field errors, fine adjustment is carried out by 16 dedicated defocusing quadrupole magnets (QD) installed in the lattice. In addition, eddy currents induced in the BD vacuum chambers during energy ramping can generate sextupole fields, which are compensated by sextupole magnets (SF/SD). The non-dispersion-free straight sections are used for the installation of injection and extraction components, RF cavities, and diagnostic devices to monitor the status of the beamline.

The lattice of the SPS-II booster synchrotron has been designed on the basis of the parameters listed in Table 4-5, and optical functions representing the beam orbit and focusing characteristics were calculated to verify the validity of the design. The results are shown in Figure 4-6. The maximum values of the betatron functions, which indicate the amplitude of transverse oscillations of the particles, were 16.3 m in the horizontal plane and 17.1 m in the vertical plane. These values are relatively low, demonstrating that the beam size is well controlled. The optical functions confirm that stable low-emittance operation can be achieved.

Table 4-5 Main Parameters for Magnet in Booster Synchrotron SPS-II

Parameter	Specification
Circumference	306.0 (m)
Beam energy	3.0 (GeV)
Relativistic factor (γ)	5870.85
Emittance	5.89 nm-rad
Nat. energy spread	0.091 (%)
Nat. Chromaticity (ξ_x/ξ_y)	-23.63/-10.31
Tune (Q_x/Q_y)	14.71/5.61
Momentum compaction (α_c)	1.671e-3
Energy loss per turn (U_0)	0.75 (MeV)
RF frequency	499.654 (MHz)
Harmonic number	510
Beam current	2 (mA)
Repetition rate	2 (Hz)

Source: SLRI



Source: SLRI

Figure 4-6 Optical function for one symmetric lattice, (Maximum horizontal betatron functions=16.3m, maximum vertical betatron function=17.1m, and maximum dispersion function=0.377m)

(3) Magnet System for the Booster Synchrotron

Design parameters of magnets in booster are summarized in Table 4-6, Table 4-7 and Table 4-8.

The booster magnets for SPS-II consist of combined-function dipole magnets (BD), quadrupole magnets (QF/QD), and sextupole magnets (SF/SD). A combined-function magnet can generate multiple magnetic field components within a single magnet, thereby reducing the total number of magnets required and enabling both cost reduction and efficient use of the limited space.

The effective magnetic length of the BD for the electron beam is 1.5 m, with a maximum field strength of 1.048 T, a quadrupole field gradient of −2.084 T/m, and a sextupole field gradient of 29.995 T/m². The individual field components included in the BD cannot be controlled independently. The focusing quadrupole magnets (QF) and defocusing quadrupole magnets (QD) are designed to the following specifications: The QF has a field gradient of 19.395 T/m and an effective length of 0.25 m, while the QD, intended for correcting magnetic field errors has a field gradient of less than 2.0 T/m and an effective length of 0.15 m.

Two types of sextupole magnets are installed to correct chromaticity. The focusing sextupole magnets (SF) are designed with a field gradient of 221.355 T/m², and the defocusing sextupole magnets (SD) are designed with a field gradient of −66.579 T/m². Both types of sextupole magnets are designed with an effective length of 0.2 m.

Table 4-6 Magnet Specification of SPS-II Booster Magnets

Magnet	Field / Gradient
Combined function dipole (BD)	1.048 (T), -2.084 (T/m), -29.995 (T/m^2)
Combined function quadrupole (QF)	19.395T/m)
Quadrupole (QD)	-1.189 (T/m)
Sextupole (SF/SD)	221.355 (T/m^2) / -66.579 (T/m^2)

Source: SLRI

Table 4-7 Design Parameter of Combined Function Magnets for SPS-II Booster

Parameter	Combination fn. Dipole (BD)
Effective length	1.5 (m)
Deflection angle (degree)	9 (degree)
Bending radius	9.55 (mm)
Dipole field	1.048 (T)
Quadrupole field	-2.084 (T/m)
Sextupole field	-29.995 (T/m2)
GFR	±10 (mm)
Field homogeneity	1.0 x 10-4

Source: SLRI

Table 4-8 Design Parameter of Defocusing Quadrupoles and Sextupoles for SPS-II Booster

Parameter	Focusing Quad. (QF)	Defocusing Quad. (QD)	Sextupoles (SF / SD)
Effective length	0.25 (m)	0.15 (m)	0.2 (m)
Quadrupole field	19.395 (T/m)	1.189 (T/m)	-
Sextupole field	-	-	221 (T/m^2) / -66.579 (T/m^2)
GFR	±19 (mm)	±15 (mm)	±18 (mm)
Field homogeneity	5.0×10^{-4}	5.0×10^{-4}	1.0×10^{-4}

Source: SLRI

The specifications of the power supplies (PS) for the booster synchrotron magnets are shown in the Table 4-9. In order to achieve a beam energy of 3.0 GeV, the power supply for the dipole magnets (BD) is required to reach the maximum current within 0.25 seconds. As high currents and voltages are required, the supply is configured with two units, with the upper and lower coil groups independently powered in series. Both supplies deliver sinusoidal currents with an identical waveform and phase (2 Hz) and are synchronized by current detectors. The rated output of the BD power supply is 1050 A / 850 V. The power supplies for the quadrupole (QF) and sextupole (SF) magnets are operated in a series connection. In particular, the 40 focusing quadrupole magnets (QF) require a power supply capable of providing up to 700 V. The correction magnet power supplies adopt an independent configuration to enhance flexibility in orbit correction.

Table 4-9 Design Parameter of Power Supplies for Booster Magnets

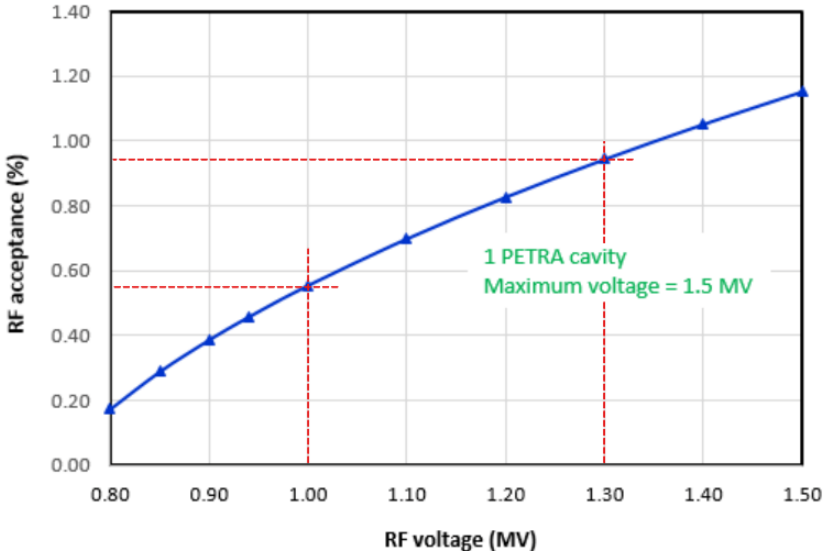
Magnet type	BD	QF	QD	SF	SD
Number of magnets	40	40	16	16	16
Number of power supplies	2	1	1	1	1
Magnet's max current (A)	958	421	61	250	250
PS. Max output current (A)	1050	460	65	250	250
PS. Max output voltage (V)	850	700	60	110	110
Short-term stability, < 1 min (ppm)	10	10	10	10	10
Long-term stability, < 8 hrs (ppm)	10	10	10	10	10
Current setting resolution (bits)	16	16	16	16	16
Current reading resolution (bits)	16	16	16	16	16
Output current ripple (ppm)	10	10	10	10	10

Source: SLRI

(4) RF System for Booster Ring

The RF system of the booster synchrotron provides the accelerating voltage required to increase the energy of the electron beam from 150 MeV to 3.0 GeV. The booster synchrotron has a circumference of 306.0 m, determined by a harmonic number of 510 and an RF frequency of 499.654 MHz. To maintain synchronous operation, the booster synchrotron and the storage ring operate at the same frequency. An electron beam circulating in the 306.0 m booster synchrotron loses approximately 0.75 MeV of energy per turn due to synchrotron radiation. Therefore, sufficient RF voltage must be supplied to compensate for this loss and ensure stable acceleration.

Figure 4-7 shows the calculated RF acceptance (the allowable relative energy deviation) for various RF voltages. With the RF voltage set to 1.0 MV, the RF acceptance exceeds ±0.5%. Increasing the RF voltage to 1.5 MV raises the acceptance to greater than 1%, thereby improving beam stability and injection efficiency and enhancing the overall performance of the RF system.



Source: SLRI

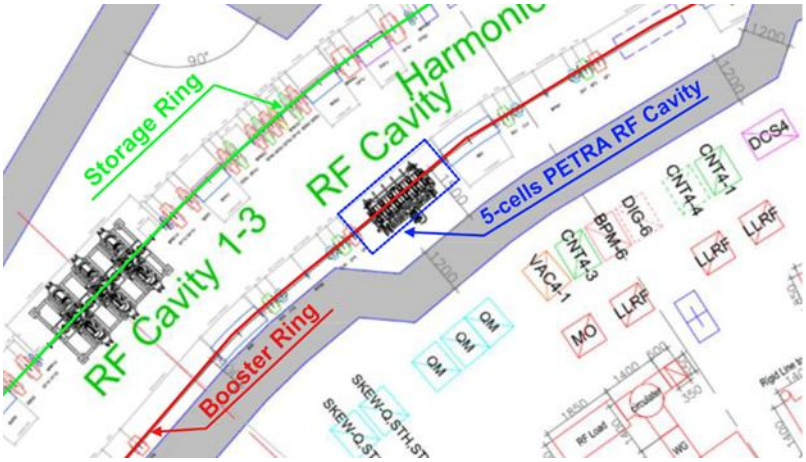
Figure 4-7 RF Acceptance Calculation for the Booster Ring

As shown in Table 4-5, the nominal tune values[21] of the SPS-II booster synchrotron are set to 14.71/5.61. Under these conditions, the dynamic aperture[22] is sufficient for long-term stable circulation of low-emittance electron beams, and the design ensures a momentum acceptance[23] greater than 1%.

During the process in which the electron beam energy gradually increases due to the RF voltage, the reduction of beam oscillations and emittance is referred to as adiabatic damping. However, if the energy ramping rate is excessively fast, adiabatic damping does not function sufficiently, resulting in beam instability and a shortened beam lifetime. To address this, the SPS-II booster synchrotron is equipped with

[21] Tune value: Theoretical tune value set to allow electrons to rotate and accelerate stably within the accelerator (number of horizontal and vertical oscillations an electron undergoes during one revolution around the accelerator).
[22] Dynamic aperture: Spatial range within the accelerator within which the electron beam can rotate stably.
[23] Momentum acceptance: Permissible range of momentum of the electron beam that can be stably maintained within the accelerator.

a 5-cell PETRA- RF cavity installed downstream of the focusing quadrupole magnets as shown in Figure 4-9. This cavity is designed to supply the appropriate RF voltage to ensure the stability of the circulating electron beam.

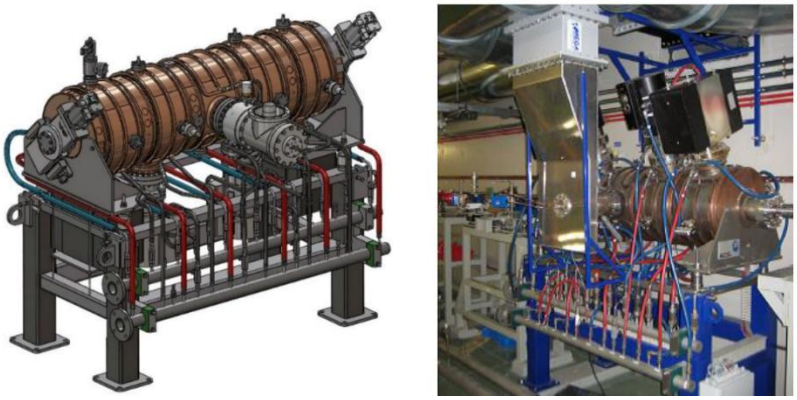


Source: SLRI

Figure 4-8 RF Cavity Location in Booster Synchrotron

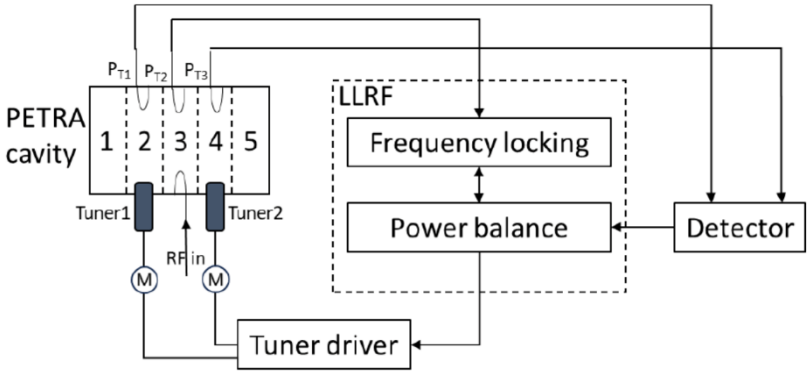
Figure 4-9 and Figure 4-10 below show the schematic layout and circuit diagram of the five-cell PETRA-type RF cavity. The cavity consists of five cells. A high-power coaxial coupler installed in the central cell efficiently delivers RF power to the cavity. Independent motor-driven mechanical plunger tuners are installed in the cells adjacent to the central cell, allowing precise adjustment of the resonant frequency.

The RF cavity is designed to generate a strong electric field through resonance and to efficiently supply accelerating voltage to the electron beam. To maintain the vacuum inside the cavity, two ion pumps are installed near the outer cells. Consequently, the PETRA-type RF cavity can generate an accelerating voltage of up to 1.3 MV and is powered by a single 60 kW RF transmitter.



Source: SLRI

Figure 4-9 Schematic Diagram and Photo of 5-Cell PETRA RF Cavity



Source: SLRI

Figure 4-10 Configuration of RF System for Booster Ring (and Storage Ring)

4.1.3 3.0 GeV Storage Ring

The SPS-II storage ring has been designed to achieve improved performance and expanded functionality compared to the SPS-I. To improve performance, electron beam emittance is reduced to provide a photon beam with higher brightness and an improved coherence fraction. To enhance functionality, a Double Triple Bend Achromat (DTBA) lattice has been adopted to double the number of straight sections available for installing insertion devices (IDs). Figure 4-1 shows a schematic layout of the SPS-II storage ring.

(1) Requirements

The SPS-II storage ring has been designed to achieve an electron beam with much lower emittance than the SPS-I. This reduced emittance will provide a synchrotron radiation beam with higher brightness and improved spatial coherence. The lattice structure incorporates a Double Triple Bend Achromat (DTBA), which increases the number of straight sections per cell, allowing more insertion devices (IDs) to be installed and thereby expanding the number of synchrotron radiation beamlines.

One possible method to suppress the natural emittance of the electron beam to below 1 nm·rad is to increase the ring circumference. However, due to site constraints, the SPS-II circumference must be limited to less than 400 m. Therefore, the design combines the DTBA lattice with this circumference to achieve the target low emittance.

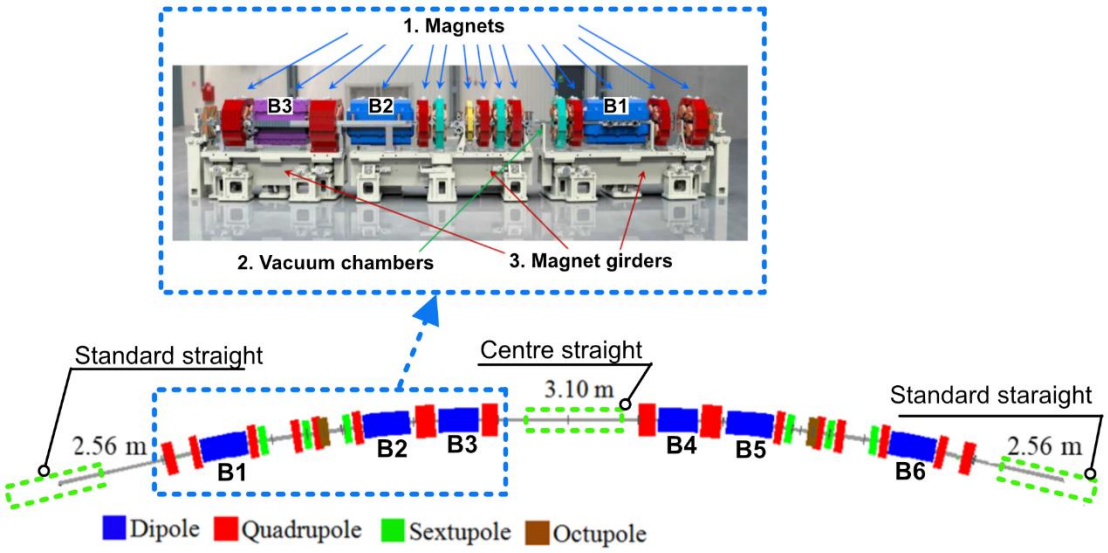
The design requirements for SPS-II storage ring are summarized as follows:

- Ring circumference below 400 m,
- 3.0 GeV electron beam energy,
- 300 mA maximum beam current,
- Beam emittance below 1.0 nm rad,

(2) Lattice for SPS-II Storage Ring

The SPS-II storage ring has been designed to achieve a 3.0 GeV electron beam, a natural emittance below 1 nm·rad, and to accommodate a large number of synchrotron radiation beamlines. However, due to site constraints, the ring circumference must be limited to below 400 m.

Lattice design studies for the SPS-II storage ring were therefore conducted under these conditions, and as a result the Double Triple Bend Achromat (DTBA) lattice was adopted. The DTBA lattice[24] was originally developed for upgrading the Diamond Light Source storage ring. It combines the features of the Double-Double Bend Achromat (DDBA) lattice, characterized by the addition of a central straight section, with the low emittance and excellent dynamic properties of the Hybrid Multi-Bend Achromat (HMBA) lattice developed for ESRF-II[25].



Source: SLRI

Figure 4-11 Schematic Diagram of SPS-II DTBA Cell and Photo of Prototype of Half-Cell of DTBA Lattice

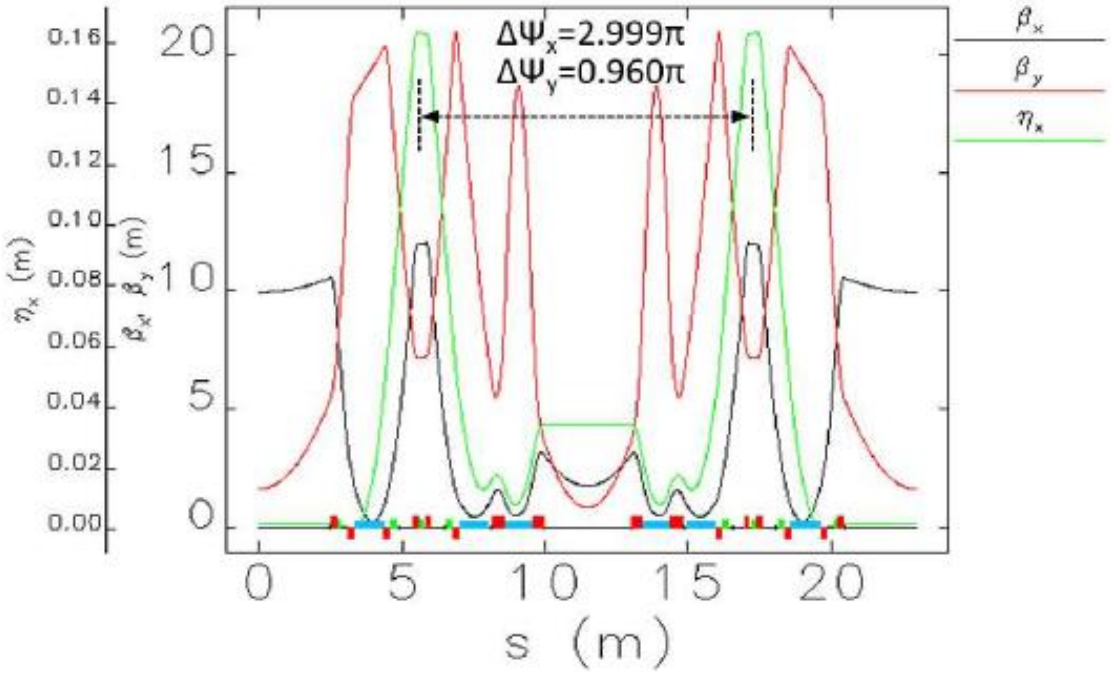
Figure 4-11 shows the Schematic diagram of SPS-II DTBA cell and a photo of prototype of half-cell of DTBA lattice. Each DTBA cell consists of six dipole magnets and incorporates two types of straight sections: a standard straight section of 5.12 m and a centre straight section of 3.10 m. The centre straight section can accommodate insertion devices, such as a 2.0 m long undulator. By providing both the standard and centre straight sections within a single cell, the total number of available straight sections is increased.

The linear optics design of the SPS-II DTBA lattice was conducted with the objective of reducing beam emittance and adjusting the betatron function in the center straight sections. Figure 4-11 shows the two innermost dipoles (B3 and B4), which are combined-function dipoles (DQs). These magnets provide the transverse magnetic field gradient required to control the optical functions at the center of each cell. By increasing the damping partition number[26] (Jx), the DQs contribute to reducing the horizontal beam emittance. The four outer dipoles (B1, B2, B5, and B6) are normal dipoles with identical magnetic fields. Under non-dispersive straight-section conditions, the adjacent dipoles B1 and B6 exert a significant influence on beam emittance. To minimize emittance, the magnetic fields of B1 and B6 must be reduced, while those of B3 and B4 must be increased, thereby maintaining the total bending angle per cell at 25.71°

[24] Diamond-II Project (UK, started in September 2023)
[25] ESRF upgrade II Project
[26] The damping partition number is a value that indicates how much the energy attenuation (damping) of the electron beam is distributed in the horizontal, vertical, and longitudinal directions in the accelerator.

(360°/14). An increase in the dipole field of DQs reduces the achievable transverse gradient due to magnetic saturation in the iron core. Accordingly, in the SPS-II design the dipole fields of B3 and B4 are set to 0.6 T, while the remaining dipoles are set to 0.87 T. This configuration suppresses the natural emittance to below 1 nm·rad. Although strong dipole fields are generally required for compact storage rings, the dipole fields in the SPS-II DTBA lattice are not necessarily stronger than those in conventional Double Bend Achromat (DBA) or Triple Bend Achromat (TBA) lattices. Nevertheless, they are sufficient to function as a high-performance synchrotron radiation source. The compactness of the storage ring, however, introduces challenges in photon extraction from the dipoles, as the reduced space complicates beamline alignment.

Figure 4-12 illustrates the optical functions of the DTBA lattice. The lattice exhibits a phase advance of 2.999π in the horizontal plane and 0.96π in the vertical plane, measured between the peaks of the dispersion bumps. A dispersion bump is an optical structure in which the dispersion function is locally varied to create suitable conditions for nonlinear correction or for the installation of insertion devices. In general, an odd multiple of π phase advance is considered preferable for optimizing the performance of dispersion bumps. Although the phase advances in this lattice deviate from the ideal odd-π condition, the lattice nevertheless demonstrates adequate performance. The essential feature of this lattice design is its symmetry, which enables nonlinear terms to be correctly cancelled at the designed positions. While breaking the symmetry is undesirable in terms of overall machine performance, adopting flexible lattice configurations can still be effective when tuning for operational or beamline requirements.



Source: SLRI

Figure 4-12 Schematic Diagram of SPS-II DTBA Cell

The SPS-II storage ring, with a circumference of 326.7 m, consists of a total of 14 DTBA cells. To maintain symmetry, all 14 cells are designed identically. The ring includes 28 straight sections in total: 14 standard straight sections of 5.02 m in length and 14 centre straight sections of 3.10 m in length. The centre straight

sections are designed to accommodate undulators up to 2.0 m in length. The main design parameters of the SPS-I and SPS-II storage rings are summarized in Table 4-10.

Table 4-10 Parameters for SPS-II Storage Ring

Parameter	SPS-I	SPS-II
Circumference (m)	81.3	327.6
Beam energy (GeV)	1.2	3.0
Relativistic factor (γ)	2348.34	5870.85
Emittance (nm-rad)	41.0	0.96
Beam current (mA)		300
Nat. energy spread (%)	0.066	0.077
Nat. Chromaticity (ξx/ξy)	-8.7/6.4	-69.1/-69.7
Tune (Qx/Qy)	4.75/2.82	34.21 / 12.37
Momentum compaction (αc)	1.70e-2	3.24e-4
Damping times hor. / ver. / long (ms)	10.7/9.8/4.7	9.8 / 11.3 /6.1
Damping partition number Jx/Jy / Jδ	0.92/1.0/2.08	1.15/1.0/1.84
Straight /Circumference	0.33	0.35
Energy loss per turn (U0) (MeV)	0.066	0.578
RF frequency (MHz)	118	499.654
RF voltage (MV)	0.3	2.2
Harmonic number	32	546
Over voltage (V/ U0)	4.5	3.8
Synchronous phase (degree)	167.29	164.77
Synchronous tune	0.00460	0.00446
Nat. bunch length (mm)	29.03	2.903
Nat bunch duration (ps)	96.8	9.68

Source: SLRI

(3) Magnet System for Storage Ring

Table 4-11 to Table 4-16 present the design parameters of the magnets that constitute the DTBA lattice of the storage ring. The DTBA lattice consists of five types of magnets: dipole magnets, combined-function dipole magnets, quadrupole magnets, sextupole magnets, and octupole magnets.

Table 4-11 Magnetic Specification for SPS-II Storage Ring

Magnet type	Field / Gradient
Dipole	0.87 (T)
Combined fn. Dipole	0.6 (T) / 25.4 (T/m)
Quadrupole	60 (T/m)
Sextupole	2,030 (T/m^2)
Octupole	72,000 (T/m^3)

Source: SLRI

Table 4-12 Dipole Magnetic Specification for SPS-II Storage Ring

	Combined fn. Dipole (DQ1)	Dipole (D0)
Length	0.850 (m)	1.0 (m)
Integrated field	0.51 (T*m)	0.87 (T*m)
Field	0.60 (T)	0.87 (T)
Integrated gradient	23 (T)	-
Gradient	25.4 (T/m)	-

Source: SLRI

Table 4-13 Quadrupole Magnetic Specification for SPS-II Storage Ring

	QF1	QD2, QD3, QD5	QF4	QF6	QF8
Length	0.215 (m)	0.162 (m)	0.162 (m)	0.412 (m)	0.328 (m)
Integrated gradient	9.9 (T)	7.8 (T)-Max.	7.1 (T)	22.7 (T)	16.4 (T)
Gradient	46.0 (T/m)	48.0 (T/m)-Max.	44.0 (T/m)	55.0 (T/m)	50.0 (T/m)

Source: SLRI

Table 4-14 Sextupole Magnetic Specification for SPS-II Storage Ring

	SD1	SD2	SF3
Length	0.14 (m)	0.14 (m)	0.14 (m)
Integrated field	238 (T/m)	172.2 (T/m)	203.0 (T/m)
Gradient	1,700 (T/m^2)	1,230 (T/m^2)	1,450(T/m^2)
Integrated skew gradient	8.0×10^{-3} (m^{-1})	8.0×10^{-3} (m^{-1})	8.0×10^{-3} (m^{-1})
Corrector strength	8.0 (mT*m)	8.0 (mT*m)	8.0 (mT*m)

Source: SLRI

Table 4-15 Dedicated Octupole Magnetic Specification for SPS-II Storage Ring

	OF1
Length	0.1049 (m)
Integrated gradient	7,550 (T/m^2)
Gradient	72,000 (T/m^3)

Source: SLRI

Table 4-16 Dedicated Corrector Magnetic Specification for SPS-II Storage Ring

	COR
Length	0.10 (m)
Corrector strength	8.0 (mT*m)
Field	0.08 (T)

Source: SLRI

(4) RF System for SPS-II Storage Ring

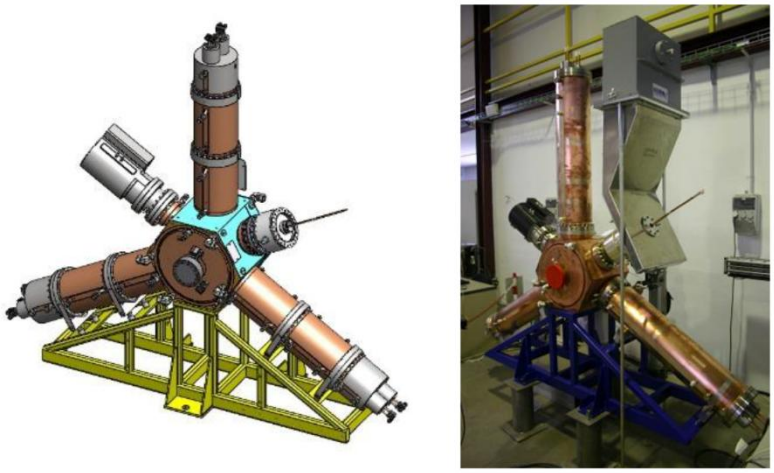
The RF system of the storage ring plays a critical role in providing accelerating voltage to the circulating electrons and compensating for the energy loss caused by synchrotron radiation. Synchrotron radiation is the phenomenon in which charged electrons emit radiation energy when deflected by magnetic fields. This energy loss must be compensated by the RF system in order to maintain the energy and stability of the beam.

Two frequency options were compared in the SPS-II RF system: a low-frequency band (119 MHz), which had been used in operation at SPS-I, and a high-frequency band (500 MHz), which is widely adopted in 3.0 GeV storage rings. Based on this evaluation, the high-frequency band was selected, as it ensures electron beam stability while delivering high-quality synchrotron radiation. This frequency band optimizes beam dynamics and provides superior performance in synchrotron radiation generation, making it the optimal choice for the SPS-II storage ring.

The RF system provides accelerating voltage to the electron beam by installing RF cavities in the storage ring and generating high-frequency electromagnetic fields within these cavities. In the SPS-II design, the RF frequency is set to 500 MHz. This shortens the RF bunch length and reduces the energy spread, thereby improving the stability of the electron beam. Consequently, the installation of a Landau cavity is unnecessary, and tolerance to beam losses caused by the Touschek effect is improved, making beam maintenance easier. Furthermore, the 500 MHz RF frequency has been widely adopted at many other synchrotron facilities, enabling the sharing of operational knowledge and maintenance experience. For these reasons, a 500 MHz RF system has been adopted as the optimal choice for the SPS-II storage ring.

However, when the electron beam passes through the RF cavity, higher-order modes (HOMs) may be excited. The excitation of HOMs can degrade the stability of the electron beam and adversely affect the overall performance of the accelerator. Therefore, HOM damping mechanisms are required to suppress such instabilities. A representative example of an HOM-damped cavity for 500 MHz storage rings is the EU-HOM damped cavity, which has been demonstrated to be effective in stabilizing the electron beam.

The RF cavity to be introduced into the SPS-II storage ring is being designed with reference to RF cavities that have demonstrated operational reliability at other synchrotron facilities operating in the 500 MHz band. Figure 4-13 shows a schematic diagram and a photograph of the RF cavity under design, based on the EU-HOM RF cavity.



Source: SLRI

Figure 4-13 Conceptual Design of RF Cavity for the SPS-II Storage Ring (Based On the Design of EU-HOM Damped Cavity)

The RF system of the storage ring compensates for the energy loss caused by synchrotron radiation generated by dipole magnets and insertion devices by providing sufficient accelerating voltage. For the SPS-II storage ring, the design specifications specify an RF frequency of 499.654 MHz and a maximum stored beam current of 300 mA. Under these conditions, the radiation loss from the dipole magnets is estimated to be 0.578 MeV per turn.

In Phase 1, insertion devices consisting of undulators and multipole wigglers will be installed. Among these, the multipole wiggler (MPW50) will contribute to the largest radiation loss, estimated at 50 keV/turn. The total radiation loss from all seven insertion devices is approximately 230 keV/turn, resulting in a combined radiation loss of about 0.81 MeV/turn when added to the dipole losses. If the number of insertion devices is expanded to a maximum of 21 in the future, the total radiation loss is expected to reach approximately 1.27 MeV/turn.

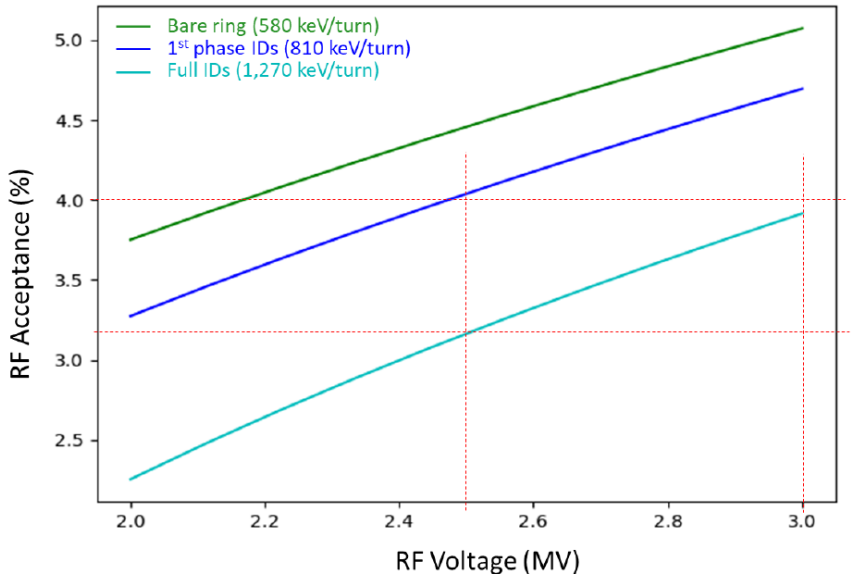
Table 4-17 Dedicated Corrector Magnetic Specification for SPS-II Storage Ring

Property	Bar Lattice	1st Phase IDs	Full IDs
Energy loss (keV/turn)	580	810 (580+230)	1,270 (580+690)
Beam current (mA)	300	300	300
Beam power (kW)	174	243	381
Cavity voltage (MV)	3.0	3.0	3.0
Number of cavities	6	6	6
Voltage per cavity (kV)	500	500	500
Cavity shunt impedance (MΩ/cav.)	3.4	3.4	3.4
Total Copper power loss (kW)	220.6	220.6	220.6
Total power required/cavity (kW)	65.8	77.2	100.3

Source: SLRI

The RF system is designed based on the lattice configuration and the momentum acceptance of the storage ring. In particular, the RF acceptance must be greater than the momentum acceptance, which is limited by the transverse dynamic aperture. This ensures that the RF voltage does not restrict the beam lifetime. Momentum acceptance refers to the allowable momentum range within which the beam can remain stable in the accelerator.

Figure 4-14 エラー! 参照元が見つかりません。 shows the relationship between RF acceptance and RF voltage. As shown, when seven insertion devices are installed, the required momentum acceptance is approximately 3.5%, whereas SPS-II is designed with an RF acceptance of 3.6%, which exceeds this requirement. Furthermore, in anticipation of expanding to 21 insertion devices, the installation of six RF cavities is planned. Additionally, space has been secured to accommodate a seventh RF cavity to provide redundancy in RF voltage and ensure sufficient beam lifetime if necessary.



Source: SLRI

Figure 4-14 RF Acceptance Calculation for the Storage Ring

(5) Vacuum System for the Storage Ring

Proper design of the vacuum system is essential for ensuring adequate beam lifetime and stable operation of the storage ring, as well as for realizing high-brilliance synchrotron radiation. The SPS-II storage ring adopts a Double Triple Bend Achromat (DTBA) lattice, a type of Multi-Bend Achromat (MBA). Arranging multiple bending magnets in series enhances beam confinement and enables high-brilliance photon generation.

The introduction of the MBA structure requires vacuum chambers with high precision and mechanical stability. In regions containing focusing magnets, such as quadrupoles, the chamber diameter becomes extremely small. This substantially reduces vacuum conductance, which limits pumping efficiency. Therefore, high-performance vacuum pumps are required to compensate for this limitation. In addition, since high thermal loads are anticipated in certain areas, efficient photon absorbers must also be incorporated.

Based on the above, the following technical requirements are necessary for the design of the SPS-II vacuum system.

- Maintaining Ultra High Vacuum (UHV) level
- Stable vacuum system
- Reliable vacuum system
- Efficient thermal absorbers
- Less influence on beam instabilities

To achieve these design concepts, the material, the design, and the fabrication process of vacuum chambers are of great importance.

1) Material for Vacuum Chamber

Candidate materials for the vacuum chamber of the SPS-II storage ring include stainless steel, aluminium, and oxygen-free copper. For SPS-II, aluminium has been selected, considering its mechanical strength, workability, and cost-effectiveness.

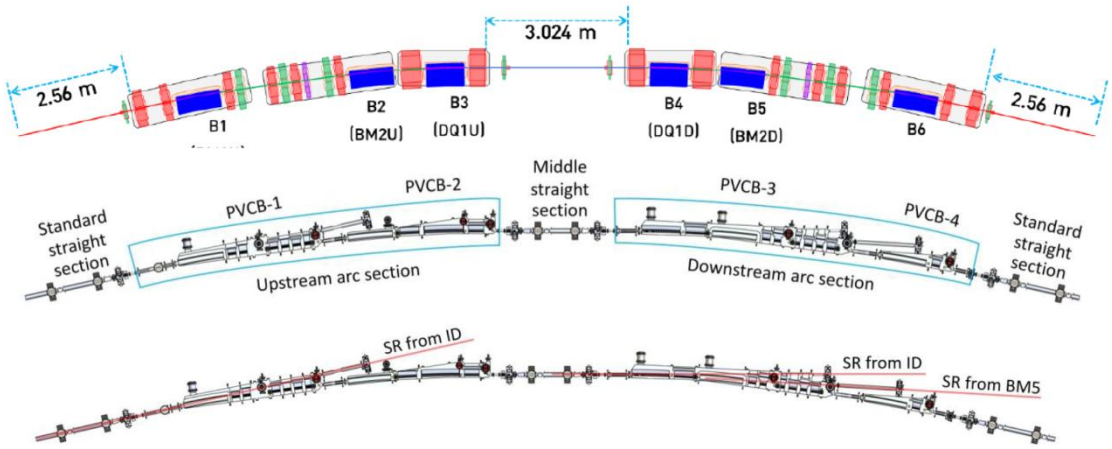
The vacuum chamber must be installed in the limited space between the magnetic poles, requiring thin walls while maintaining sufficient mechanical strength. Aluminium, being lightweight while offering the required strength, also provides excellent weldability and machinability, making it suitable for the fabrication of high-precision vacuum chambers. The vacuum chambers will be manufactured by a company in Thailand.

2) Structural Design of Vacuum Chamber

The storage ring lattice is the Double Triple Bend Achromat (DTBA), which consists of 4 normal dipole magnets (BM), 2 combined-function dipole magnets (DQ), 16 quadrupole magnets (QD, QF), 8 sextupole magnets, and 2 octupole magnets per cell, as shown in Figure 4-15. The storage ring comprises 14 DTBA cells (23.4 m per cell), giving a total circumference of 327.6 m. This lattice design provides 14 standard straight sections of 5.12 m and 14 centre straight sections of 3.10 m, making a total of 28 straight sections. The vacuum chambers are classified into three types corresponding to this lattice configuration.

- Straight section (standard straight sections, middle straight sections),
- Upstream arc section (including bending chambers PVCB-1 and PVCB-2),
- Downstream arc section (including bending chambers PVCB-3 and PVCB-4)

The vacuum chambers are designed to accommodate synchrotron radiation from 3 types of sources: insertion devices (IDs) installed in the standard straight sections, insertion devices (IDs) installed in the centre straight sections, and radiation from the fifth bending magnet located downstream in the DTBA cell, as shown in Figure 4-15.

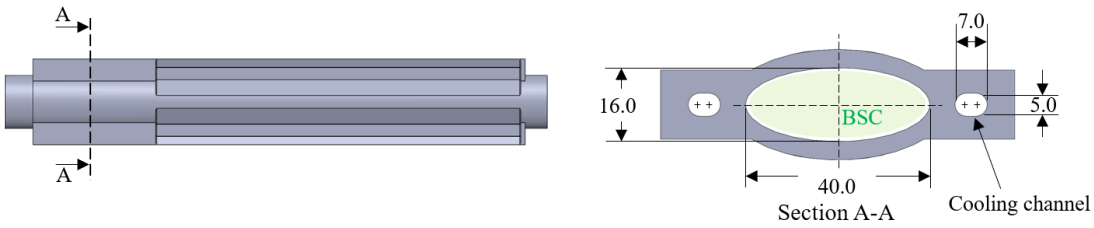


Source: SLRI

Figure 4-15 Schematic Diagram of DTBA Unit Cell (Upper), Schematic Diagram of Sectioned-Vacuum Chamber of DTBA Unit Cell (Middle), and Schematic Diagram of Vacuum Chamber with Synchrotron Radiation Path (Lower)

3) Design of Vacuum Chamber of Straight Section

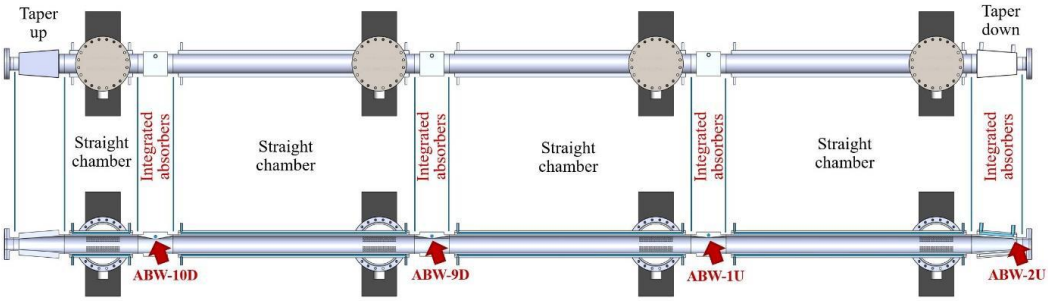
Figure 4-16 shows the cross-section of the beam duct installed in the straight sections. The cross-section is elliptical, with a short axis of 16 mm and a long axis of 40 mm. Since the horizontal emittance of the electron beam is larger than the vertical emittance, a wider horizontal cross-section has been adopted to secure sufficient beam clearance. The elliptical cross-section provides the required mechanical strength as a vacuum structure and is capable of maintaining a stable shape against external pressure. Before insertion devices are installed, circular dummy chambers made of aluminium will be placed in the straight sections. These dummy chambers are designed with an inner diameter of approximately 62.7 mm and a wall thickness of 4 mm.



Source: SLRI

Figure 4-16 Standard Cross-Section of Straight Beam Duct in Bending Sections

Figure 4-17 shows a schematic diagram of the dummy chamber installed in the standard straight section. The dummy chamber consists of a straight chamber with a pump port, an integral absorber, and a tapered section. At the upstream and downstream ends, there are bimetal flanges made of aluminium and stainless steel. The integral absorber captures radiant light and locally processes its energy, thereby reducing gas loads generated by photon-stimulated desorption and enabling efficient exhaust. This maintains the entire vacuum chamber in a clean and stable condition.

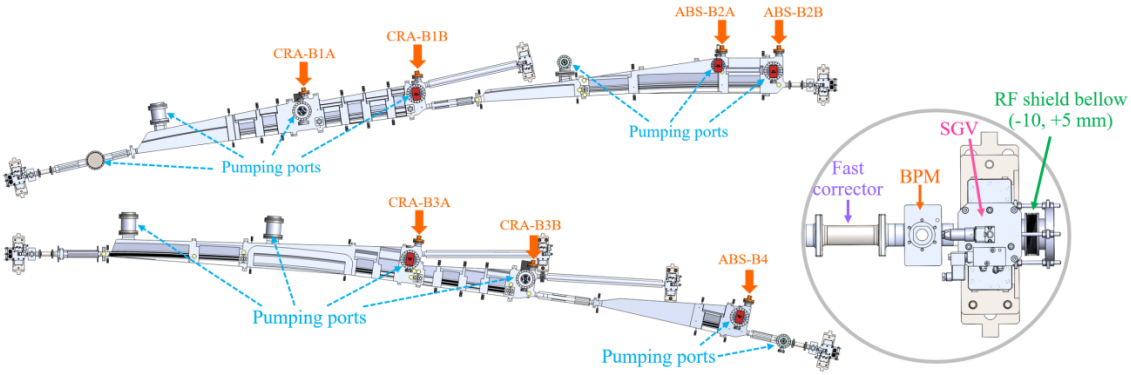


Source: SLRI

Figure 4-17 Standard Cross-Section of Straight Beam Duct in Bending Sections

4) Design of the Vacuum Chamber in Arc Section

Figure 4-18 shows an overview of the vacuum chambers installed upstream and downstream of the arc section. The limited spaces between the magnets of the DTBA cell are equipped with photon absorbers and vacuum pumps. The photon absorbers in the arc section are designed to absorb synchrotron radiation entering the vacuum chamber, localize gas generation caused by photon-stimulated desorption, and enable efficient evacuation by the vacuum pumps.



Source: SLRI

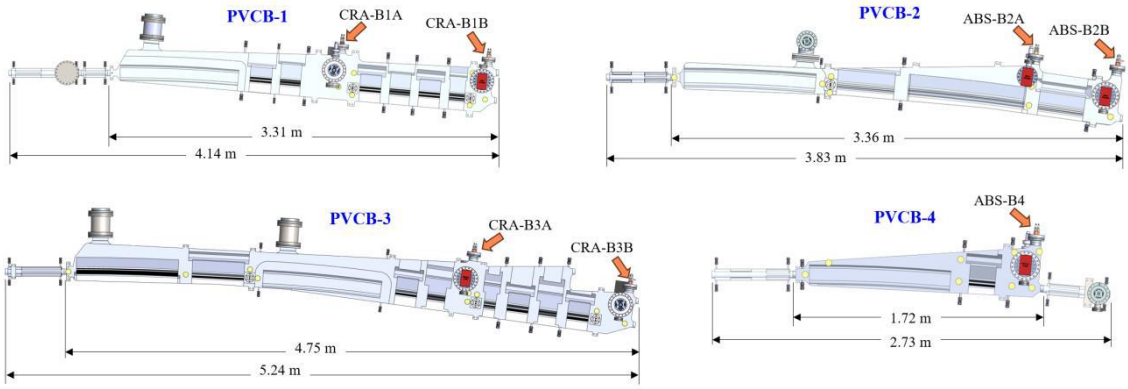
Figure 4-18 Layout of Upstream and Downstream Arc Sections

At the upstream end of the arc section, a 1 mm-thick Inconel 625 chamber for the fast orbit correction kicker, a Beam Position Monitors (BPM)[27] and a sector gate valve equipped with an RF contact shield are installed. Inconel 625 is a special alloy with excellent heat resistance and corrosion resistance, and it has been adopted as the material for the fast orbit correction kicker chamber because it can maintain stable vacuum performance even under high thermal load conditions. The sector gate valve with an RF contact shield enables seamless transmission of the beam's high-frequency electromagnetic fields, suppresses impedance mismatches and high-frequency noise, and thereby prevents interference with the electron beam and diagnostic devices while ensuring overall system stability.

The dimensions (lengths) of all arc chambers are shown in Figure 4-19. The vacuum chambers for SPS-II are scheduled to be manufactured by a domestic company in Thailand. Considering the machining

[27] The Beam Position Monitor (BPM) measures the beam position in real time and helps to stabilize the beam operation.

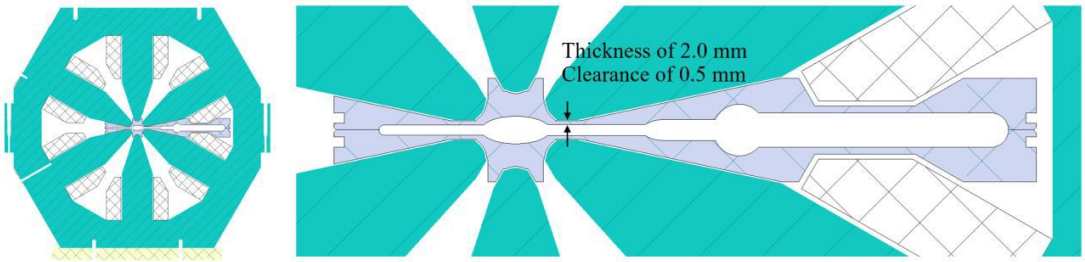
capabilities of locally available CNC milling machines, the length of each chamber has been limited to within 5 m.



Source: SLRI

Figure 4-19 The Total Length of Bending Chambers and Their CNC Machining Parts

Figure 4-20 shows the cross-section of the vacuum chamber integrated into the multipole magnet. Because the space between the magnet poles is extremely limited, the minimum wall thickness of the chamber is specified as 2.0 mm. To ensure sufficient structural strength, the wall thickness is increased in regions less affected by the magnetic field. With this approach, the balance between strength and weight is maintained, and the maximum external vertical dimension of the chamber is designed to be 96.0 mm



Source: SLRI

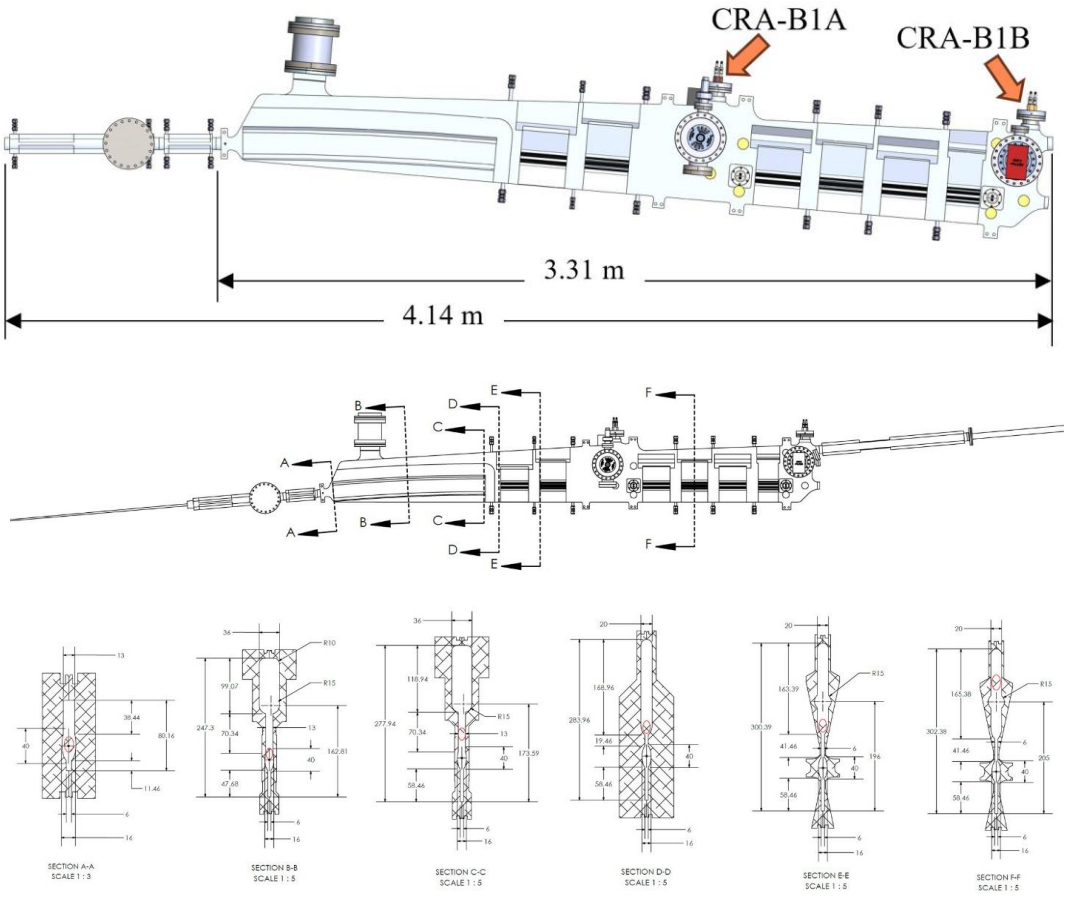
Figure 4-20 Cross-Section of the Chamber in the Multipole Magnet Shows Minimum Thickness of 2.0 mm and the Minimum Clearance of 0.5 mm

5) Design of Vacuum Chamber (PVCB-1) of Upstream Arc Section

The PVCB-1 bending chamber has a total length of 4.14 m, of which 3.31 m is CNC-machined (see Figure 4-21). To prevent damage to the vacuum chamber from synchrotron radiation, crotch absorbers (CRA-B1A and CRA-B1B) are installed at designated positions. For the extraction of synchrotron radiation from the Elliptical Polarization Undulator (EPU) in the standard straight section, a large vertical opening angle is required. To satisfy this requirement, the antechamber[28] gap below the bending magnet is widened to 13 mm at position A, and adjusted to 6.0 mm from position C to D to match the magnet pole geometry. With this configuration, vertical and horizontal aperture angles of ±1.0 mrad and

[28] Antechamber: A part of the vacuum chamber that is an additional space (or gap) next to the channel through which the beam passes. The antechamber is used to efficiently absorb or eject synchrotron radiation.

±2.0 mrad, respectively, are secured for synchrotron radiation generated by the insertion device, while accounting for an estimated misalignment of approximately 0.2 mrad.



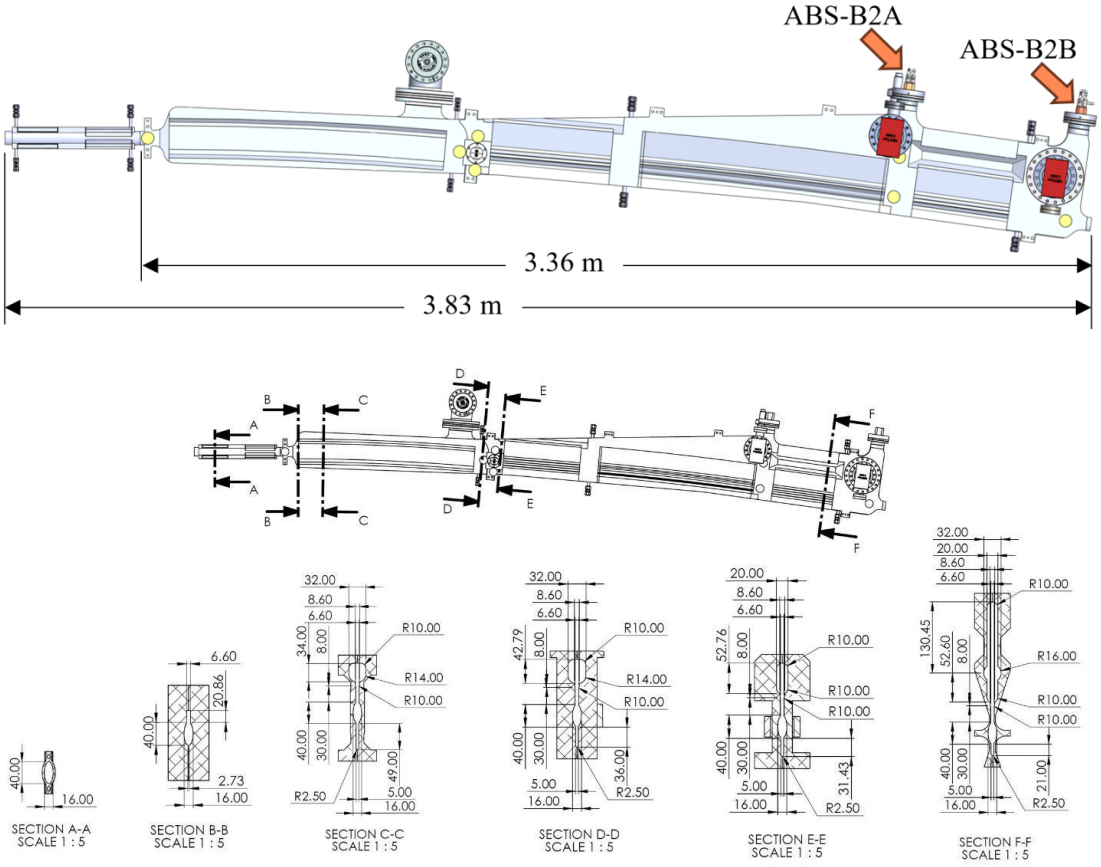
Source: SLRI

Figure 4-21 Schematic Diagram of PVCB-1 (Upper) and Cross Section of Bending Chamber PVCB-1 (Lower)

6) Design of Vacuum Chamber (PVCB-2) of Upstream Arc Section

The PVCB-2 bending chamber is a vacuum chamber installed in a section where no synchrotron radiation extraction is performed and therefore does not include a photon duct. As shown in Figure 4-22, the bending chamber has a total length of 3.83 m, with a CNC-machined section of 3.36 m. The lower part of Figure 4-22 illustrates the top view and internal cross section of the PVCB-2 chamber.

To protect the vacuum chamber from high-power and high-density synchrotron radiation, photon absorbers (ABS-B2A and ABS-B2B) are installed at specified positions. Even without a photon duct, there remains a possibility that bending radiation or scattered light may locally enter the chamber. Accordingly, the chamber is designed so that the absorbers intercept the thermal load while localizing the gas load generated by photon-stimulated desorption, thereby enabling efficient evacuation by the vacuum pumps.

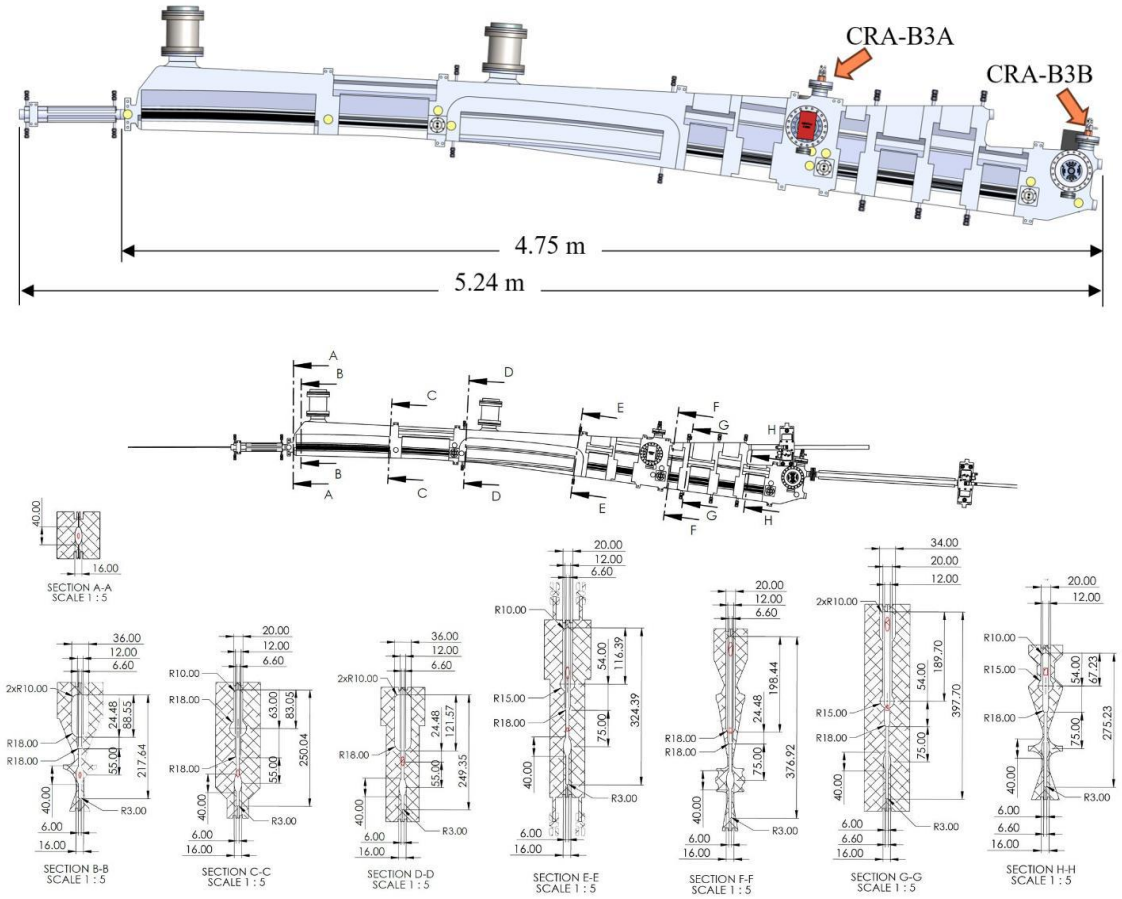


Source: SLRI

Figure 4-22 Schematic Diagram of PVCB-2 (Upper) and Cross Section of Bending Chamber PVCB-2 (Lower)

7) Design of Vacuum Chamber (PVCB-3) of Downstream Arc Section

Figure 4-23 shows an overview and cross-sectional view of the PVCB-3 bending chamber. This chamber is the longest vacuum chamber in the design, with a total length of 5.24 m, of which 4.75 m is CNC-machined. The PVCB-3 is equipped with two photon ducts to extract synchrotron radiation generated by the insertion device (ID) installed in the central straight section of the DTBA cell and by the bending magnet. The aperture angle for radiation generated by the ID is set to ±0.46 mrad vertically and ±2.25 mrad horizontally. For radiation generated by the bending magnet, the aperture angle is set to ±1.0 mrad vertically and ±2.3 mrad horizontally, providing a wider opening compared to the ID. In addition, to localize the thermal load and gas desorption caused by photon-stimulated desorption and to maintain the overall stability of the vacuum system, two step-type crotch absorbers (CRA-B3A and CRA-B3B) are installed at designated positions.

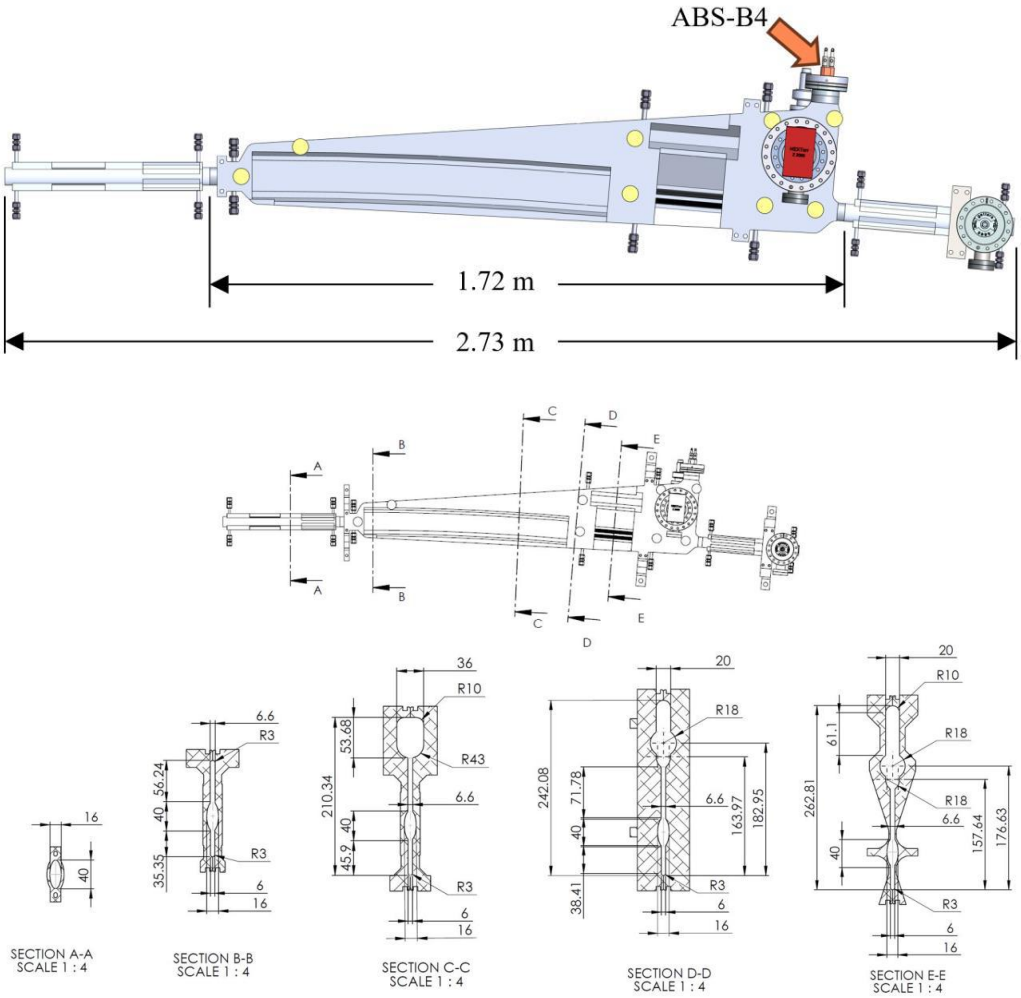


Source: SLRI

Figure 4-23 Schematic Diagram of PVCB-3 (Upper) and Cross Section of Bending Chamber PVCB-3 (Lower)

8) Design of Vacuum Chamber (PVCB-4) of Downstream Arc Section

The PVCB-4 bending chamber is designed without a photon duct. The CNC-machined section is 1.72 m in length, and the total chamber length is 2.73 m (see Figure 4-24). Given the short overall length, only one photon absorber (ABS-B4) is planned for installation in the designated position. This section is subject to a localized concentration of synchrotron radiation, which is expected to generate significant thermal loads and cause gas emissions through photon-stimulated desorption. Therefore, the absorber to be installed must be capable of withstanding synchrotron radiation of both high power and high-power density.



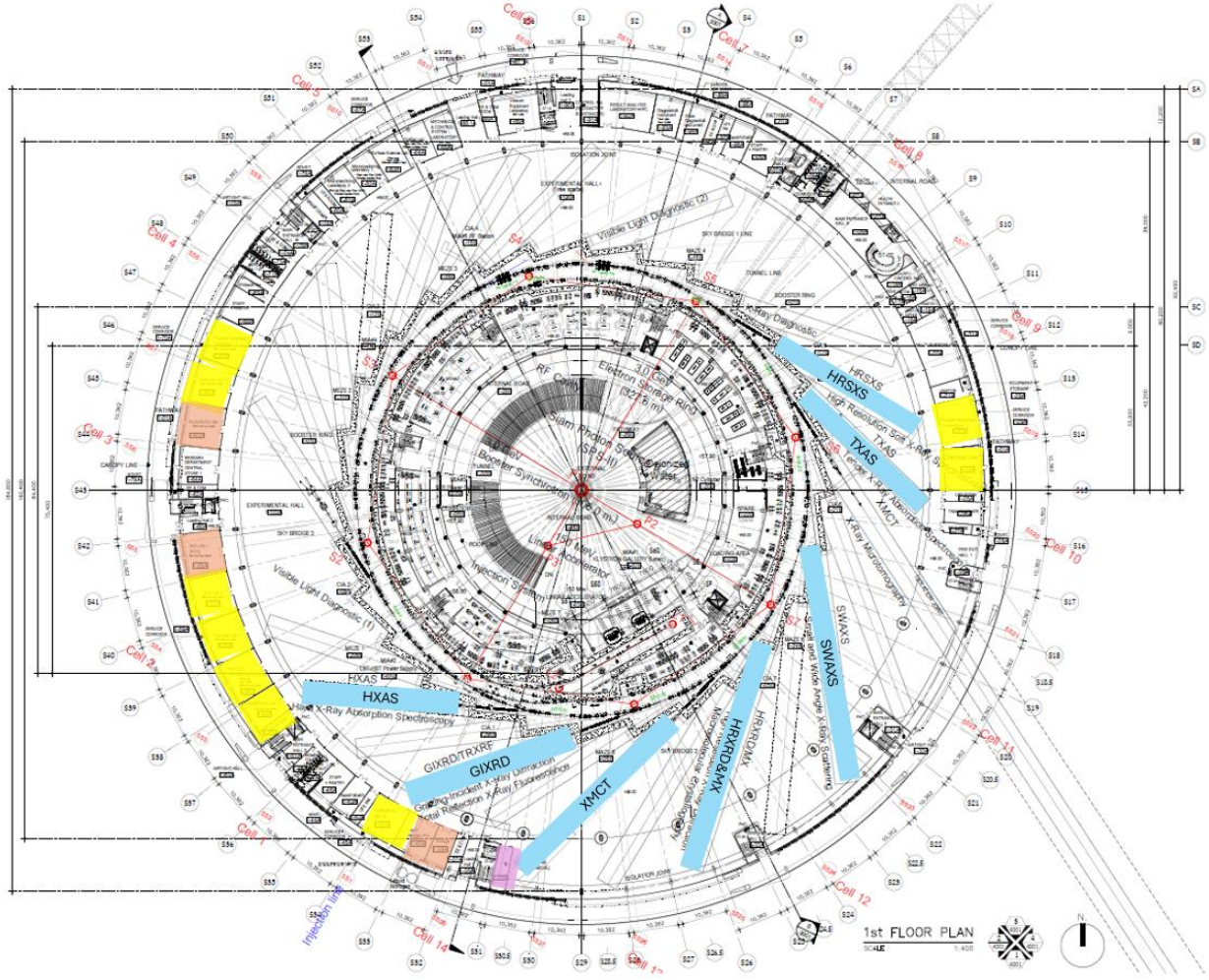
Source: SLRI

Figure 4-24 Schematic Diagram of PVCB-4 (Upper) and Cross Section of Bending Chamber PVCB-4 (Lower)

4.2 Preliminary Design of Beamline for SPS-II (in Phase 1)

4.2.1 Outline of the Beamline of SPS-I (in Phase 1)

Figure 4-25 shows a schematic layout of the planned beamlines in SPS-II. The SPS-II storage ring is designed to accommodate a total of 21 insertion devices (IDs), consisting of 11 long straight sections (corresponding to standard straights) and 10 short straight sections (corresponding to center straights). In addition, the figure indicates that 2 diagnostic beamlines and 10 bending-magnet beamlines are also available.



Source: SLRI

Figure 4-25 Schematic Diagram of Beamline Layout in SPS-II

SPS-II has In Phase I of SPS-II, a total of seven beamlines are planned for installation. Their lineup is shown in Table 4-18. These beamlines have been planned based on the results of a needs survey conducted among existing SPS users, prospective researchers, and industry stakeholders. As shown in Table 4-18, the SPS-II beamlines will consist of 5 hard X-ray beamlines, 1 soft X-ray beamline, and 1 grazing-incidence X-ray scattering/fluorescence detection beamline.

The X-ray spectroscopy beamlines HRXS, TXAS, and HXAS will be utilized for advanced materials research and development, as well as for studies on electronic devices, including semiconductor materials. The XMCT beamline will enable transmission imaging of internal structures and will be applied to the analysis of normally inaccessible regions, such as the internal behavior of fuel cells. The XRD and WASX beamlines will be applied to the analysis of internal microstructures across a wide range of materials, from biological macromolecules such as proteins to amorphous materials such as glass. The specifications of the insertion devices serving as the light sources for each beamline are listed in Table 4-19.

Table 4-18 Proposed Beamline for SPS-II (1st Phase)

Beamline	Technique	Energy range
HRSXS	High resolution soft X-ray spectroscopy	90.0 eV – 2.5 keV
TXAS	Tender X-ray absorption spectroscopy	1.8 -13.0 keV
HXAS	Hard X-ray absorption spectroscopy	6.0-35.0 keV
XMCT	X-ray microtomography	10.0-60.0 keV
HRXRD/MX	High resolution X-ray diffraction & Macromolecular crystallography	9.0 – 27.0 keV
SWAXS	Small & wide-angle X-ray scattering	8.0-20.0 keV
GIXRD/TRXRF	Proposed beamline: Grazing-incidence X-ray Scattering and Total Reflection Fluorescence	8.0 – 28.0 keV

Source: SLRI

Table 4-19 Specification of Insertion Devices

	HXAS, HRXRD/MX and GIXRD/TRXRF	SWAXS	HRSXS	TXAS	XMCT
Source type	IVU18	IVU20	EPU58	IVU23	IVW50
Period length (mm)	18	20	58	23	50
Peak field (T)	1.23	1.32	1.03	1.54	2.1
Min. magnetic gap (mm)	4.2	4.2	10	4.2	5.5
Total magnet length (m)	2.0	2.0	1.344	0.85	2.0
Period number	110	100	25	38	40

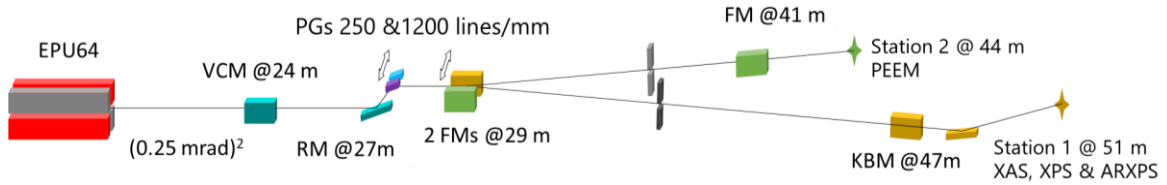
Source: SLRI

(1) High Resolution Soft-X-Ray Spectroscopy (HRSXS) Beamline

Table 4-20 High Resolution Soft X-Ray Spectroscopy (HRSXS)

Source	EPU58 (Apple II type undulator)	
Energy range	90 eV – 2.5 keV	
Energy resolution	E/ΔE: 5,000 – 10,000	
Beamline acceptance	0.25 mrad (H) x 0.25 mrad (V)	
Photon Flux	10^{12} – 10^{13} ph/s	
Monochromator	collimated plane grating monochromators250 lines/mm for 80-400 eV 1200 lines/mm for 400-2500 eV	
Focusing Mirror	Branch 1: KB Branch 2: Toroidal	
Spot size at sample	Branch 1: PEEM: 40μm (H) x 4μm (V) Branch2: XAS, XPS & ARPES :75μm (H) x 15μm (V)	
Measurement technique / Target users	XAS-XPS-PEEM imaging PES XMCD	Multilayered materials & 20 material Magnetic thin film Strongly-correlated system
Main detectors for the end station	PEEM: MCP/CCD detector with imaging energy analyzed (relocated from SPL) Soft-XAS: 4 elements silicon drift detector PES: Electron spectrometer (relocated from SPL)	

Source: SLRI



Source: SLRI

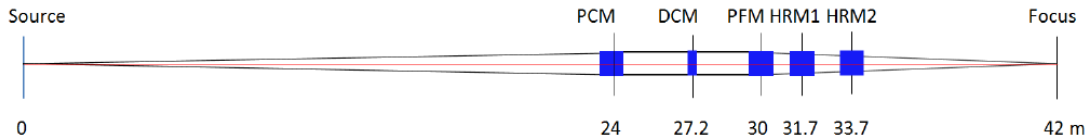
Figure 4-26 Schematic Diagram of HRSXS Beamline Optics Design

(2) Tender Energy X-Ray Absorption Spectroscopy (TXAS) Beamline

Table 4-21 Tender Energy X-Ray Absorption Spectroscopy (TXAS)

Source	IVU23 (In-vacuum undulator)	
Energy range	1.8 – 13.0 keV	
Energy resolution	ΔE/E : InSb(111): 3.0 x 10^{-4} @ 2keV Si(111): 1.4 x 10^{-4} @ 10keV	
Beamline acceptance	0.45 mrad (H) x 0.2 mrad (V)	
Photon Flux	5.0 x 10^{10} – 2.0 x 10^{13} ph/s	
DCM Crystal	Beryl (1010), KTP (011), InSb(111) & Si (111)	
Focusing Mirror	Paraboloid	
Spot size at sample	Focus: 110μm (H) x 60 μm (V) Unfocus: 13 mm (H) x 2 mm (V)	
Measurement technique / Target users	XANES, EXAFS & QEXAFS μXAFS &μXRF μANES & XRF imaging	Industrial catalytic & advanced materials Environmental pollution & mitigation Soil science & cultural heritage
Main detectors for the end station	13-elements silicon drift detector Main detectors for the end station	

Source: SLRI



Source: SLRI

Figure 4-27 Schematic Diagram of Optics Design for TXAS Beamline

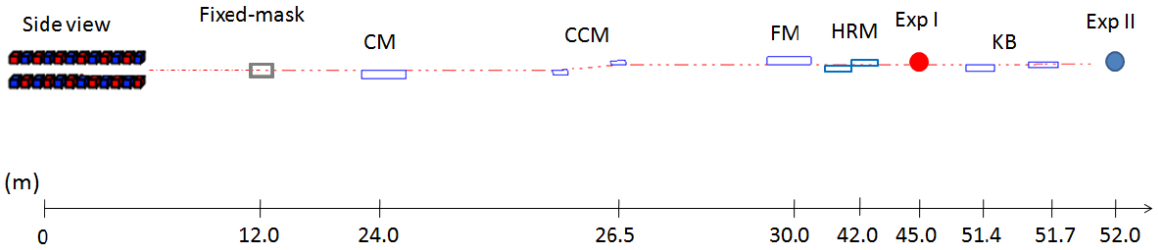
(3) High Energy X-Ray Absorption Spectroscopy (HXAS) Beamline

Table 4-22 High Energy X-Ray Absorption Spectroscopy (HXAS)

Source	IVU18 (In-vacuum undulator)
Energy range	6.0 – 35.0 keV
Energy resolution	ΔE/E : < 1 x 10^{-4} from Si(111), <4 x 10^{-5} from Si(311)
Beamline acceptance	0.6 mrad (H) x 0.1 mrad (V)
Photon Flux	10^{12} – 10^{13} ph/s
DCM Crystal	Si (111) and Si (311) Channel-cut
Focusing mirror	Toroid
Spot size at sample	120μm (H) x 120 μm (V)

Measurement technique / Target users	XANES, EXAFS & QEXAFS µXAFS &µXRF µANES & XRF imaging	Industrial catalytic & advanced materials Environmental pollution & mitigation Soil science & cultural heritage
Main detectors for the end station	7-elements silicon drift detector (relocated from SPL)	

Source: SLRI



Source: SLRI

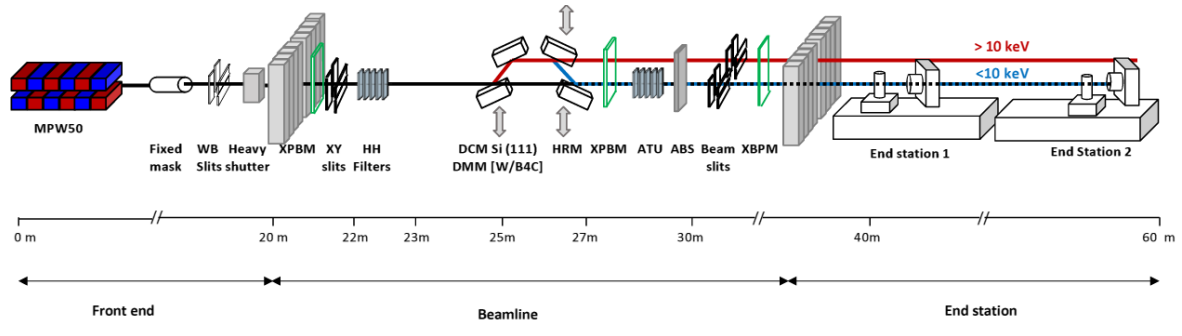
Figure 4-28 Schematic Diagram of Optics Design for HXAS Beamline

(4) X-Ray Microtomography (XMCT) Beamline

Table 4-23 X-Ray Microtomography (XMCT)

Source	IVU50 (In-vacuum undulator)	
Energy range	10.0 – 60.0 Kev	
Energy resolution	ΔE/E : DCM: ≤ 10^{-3} DMM: around 2-3 x 10^{-2}	
Beamline acceptance	0.6 mrad (H) x 0.16 mrad (V)	
Photon flux	10^{14} – 10^{15} ph/s	
Monochromator	DCM: Si (111) for 8 -30 keV DMM: ML (2% BW) for 30 – 60 keV	
Focusing mirror	None (with a future plan to use zone plates for nano X-ray imaging)	
Spot size at sample	Unforcus: 65mm (H) x (7-17) mm (V)	
Measurement technique / Target users	Phase & absorption contrast Nano X-ray imaging	Biological, medical & life science Paleontology
Main detectors for the end station	Scintillators: Gadox, CsI, LSO and YAG Microscopes: 5x, 10x with/without 2x eyepiece Cameras: Pco.edge 5.5, Pco.dimax	

Source: SLRI



Source: SLRI

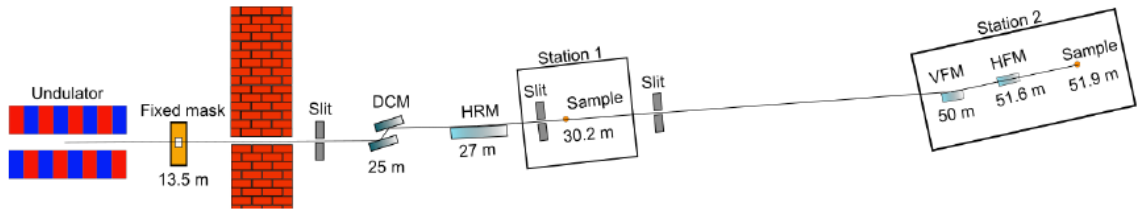
Figure 4-29 Schematic Diagram of Optics Design for XMCT Beamline

(5) High Resolution X-Ray Diffraction & Macromolecular Crystallography

Table 4-24 High Resolution X-ray Diffraction & Macromolecular Crystallography (HRXRD/MX)

Source	IVU18 (In-vacuum Undulator)	
Energy range	9.0 – 27.0 kev	
Energy resolution	1 x 10^{-4}	
Beamline acceptance	HRXRD: 27 µrad x 16 µrad, MX: 4 µrad x 18 µrad	
Photon flux	HRXRD: 10^{11} – 10^{13} ph/s MX: 10^{10} – 10^{12} ph/s	
DCM Crystal	Si (111) & Si (311)	
Focusing mirror	KB	
Spot size at sample	HRXRD: 1.4 mm (H) x 0.9 mm (V) MX: 1.7 µm (H) x 1.0 µm (V)	
Measurement technique / Target users	Micro & Macro XRD XRD imaging MAD & SAD	Material Science & engineering Earth science Pharmacological impurities & drug target
Main detectors for the end station	HRXRD: Scintillator with crystal analyzer, Dectris Myhen MX: Dectris 9m	

Source: SLRI



Source: SLRI

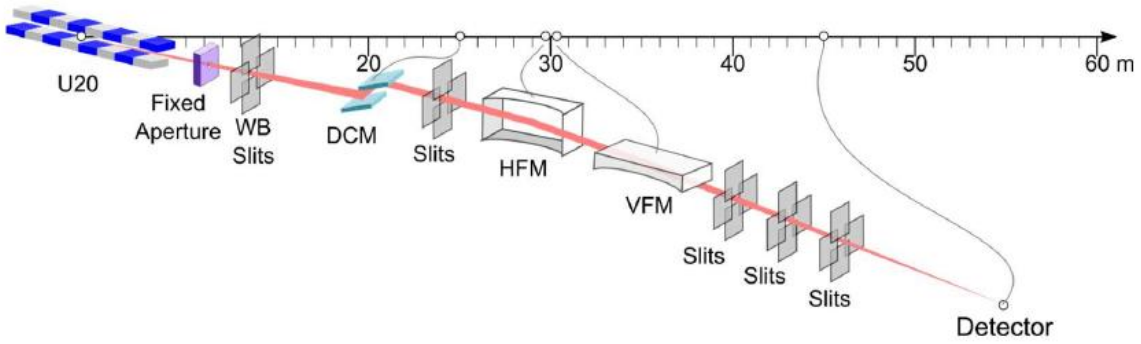
Figure 4-30 Schematic Diagram of Optics Design for HRXRD/MX Beamline

(6) Small & Wide-Angle X-Ray Scattering (SWAXS) Beamline

Table 4-25 Small & Wide-Angle X-Ray Scattering (SWAXS)

Source	IVU20 (In-vacuum Undulator)	
Energy range	8.0 – 20.0 keV	
Energy resolution	ΔE/E : 1.5 x 10^{-4} at 10 keV	
Beamline acceptance	117 µrad (H) x 115 µrad (V)	
Photon flux	8.0 x 10^{12} – 7.0 x 10^{13}ph/s	
DCM Crystal	Si (111)	
Focusing mirror	KB	
Spot size at sample	328 µm (H) x 180 µm (V)	
Measurement technique / Target users	SAXS & WAXS USAXS & GISAXS	Life science & Polymer science Thin films & Membrane proteins
Main detectors for the end station	In air C-shaped Pilatus 3, In vacuum Eiger 9M	

Source: SLRI



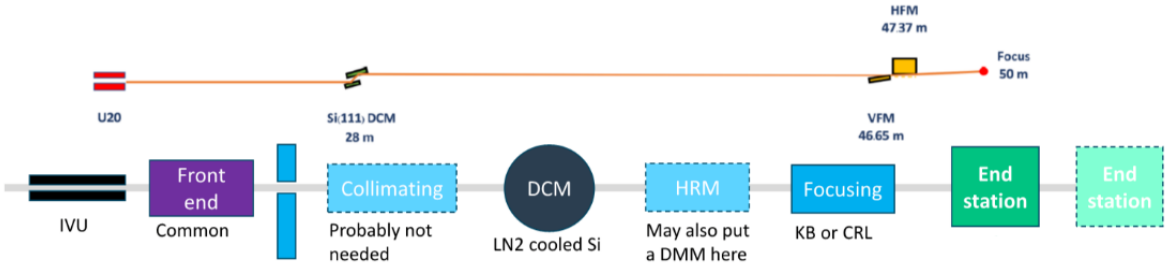
Source: SLRI

Figure 4-31 Schematic Diagram of Optics Design for SWAXS Beamline

(7) Grazing-Incidence X-Ray Scattering and Total Refection Fluorescence (GIXRD/TRXRF)

Table 4-26 Specification of Grazing-Incidence X-Ray Scattering and Fluorescence

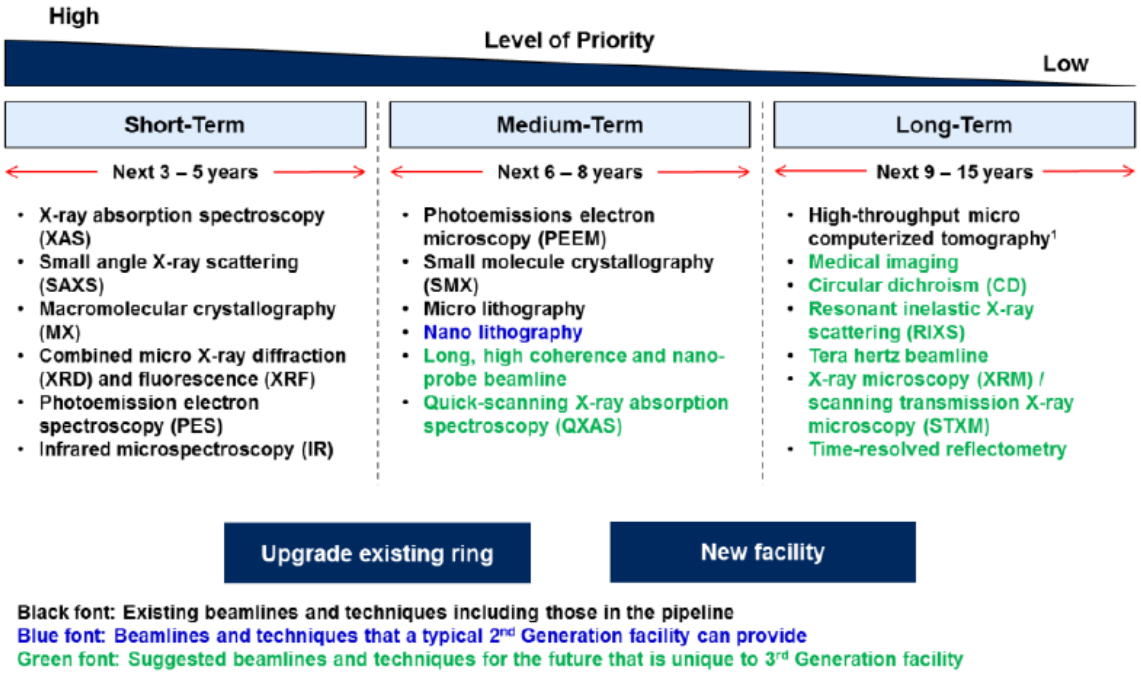
Source	IVU18 (In-vacuum undulator)	
Energy range	8.0 – 28 keV	
Photon flux	1.0 x 10^{13} ph/s	
Beam size	< 5μm (Under consideration)	
Target users	SAXS XRD XRF	Thin film characterization Perovskite photovoltaics Trace element analyses



Source: SLRI

Figure 4-32 Schematic Diagram of Optics Design for GIXRD/TRXRF Beamline

4.3 Future Plan of Beamlines in Phase 2 and More



Source: SLRI

Figure 4-33 Long-Term Beamline Development Plan

Figure 4-33 shows the planned future beamline layout for SPS-II. During the first three to five years following the start of commissioning, it is possible that the electron beam performance will not reach the target values. Therefore, the beamlines to be installed in Phase I are designed to operate under conditions equivalent to those of SPS-I. If the electron beam achieves the planned target values, the system will enable much higher-precision measurements than are possible at the existing SPS-I facility. Nevertheless, even if the target values are not reached, the beamlines are designed to operate without disruption.

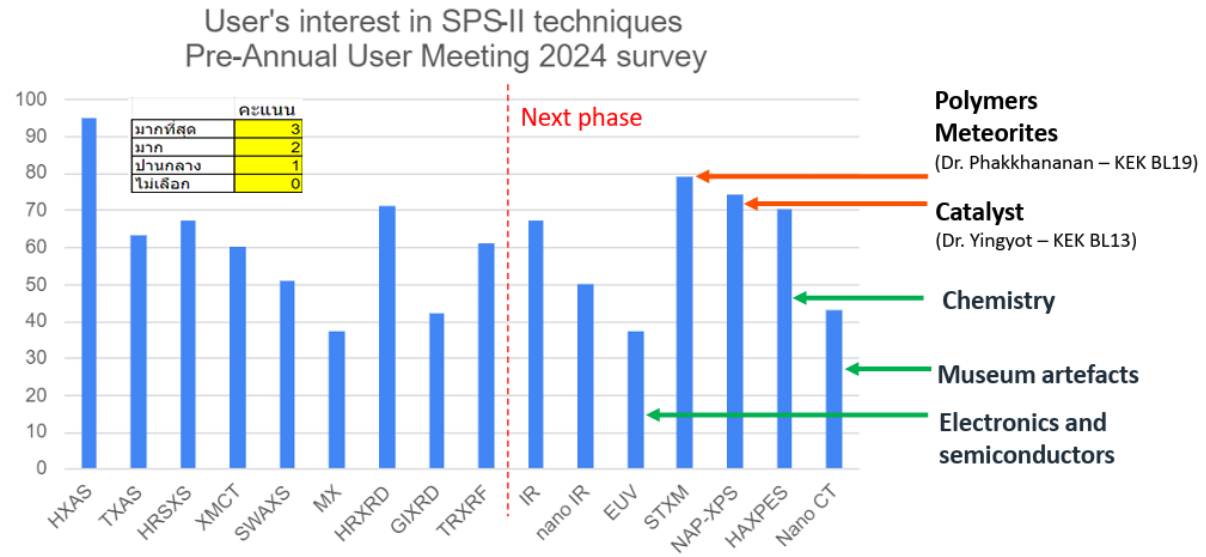
Following the installation of the Phase I beamlines, electron beam performance is expected to gradually improve, approaching the target values. In line with these improvements, the beamline lineup will be upgraded from Phase II onward to enable advanced measurements that fully exploit the capabilities of SPS-II as a third-generation synchrotron radiation facility. Table 4-27 provides an overview of the beamlines planned for introduction in Phase II and beyond.

Table 4-27 Beamline Installation Plan from Phase-1 to -3 (Tentative)

	Phase-1	Phase-2	Phase-3
Strategy in selecting techniques	Synchrotron techniques that are accessible to the existing SPS-I users are selected. The upgraded capabilities of the techniques benefit from the high-performance storage ring.	More advanced techniques which have been offered at third-generation synchrotrons.	Technologically advanced techniques that require unique capabilities of modern (4th generation) storage rings.
Requirements	• A storage ring that offers higher photon flux and wider photon energy range than SPS-I	• High electron beam stability in the storage ring. • High flux for photon-hungry measurements • Active X-ray optics • High-resolution image forming X-ray optics (e.g. zone plates)	• High stability of beamline components. • Coherence-preserving (adaptive) X-ray optics • Synchronization between the storage ring and beamline detectors
Technique lineups	• High-resolution photoemission spectroscopy (PES) • Photoemission electron microscopy (PEEM) • X-ray magnetic circular dichroism (XMCD) • X-ray micro computed tomography • X-ray absorption fine-structure (XAFS) • Quick-XAFS • Small/wide angle x-ray scattering (SAXS/WAXS) • High-resolution X-ray diffraction (XRD) • X-ray fluorescence (XRF) • Macromolecular crystallography (MX)	• Micro-beam measurements • Hard X-ray photoemission spectroscopy (HAXPES) • Near-ambient pressure X-ray photoelectron spectroscopy (XPS) • Resonance In-elastic scattering (RIXS) • Nano-resolution X-ray imaging • Surface X-ray scattering • Energy-dispersive X-ray diffraction (EDD)	• Nano-beam measurements • Ptychography • Coherent diffraction imaging (CDI) • Pair distribution function (PDF) • Ultra-fast measurements

Source: SLRI

The beamlines to be introduced in the future will be determined based on surveys of the needs of the academic and industrial communities that were conducted in June 2024 to July 2024. In the survey, respondents were asked to choose their top three techniques from the first phase, and other top three among the next phases' techniques. They scored the top technique 3 points, second top technique 2 points, and third top technique 1 point. Figure 4-34 shows the points of each technique as the result of the SPS-II beamline needs survey.



Source: SLRI

Figure 4-34 Plan for the Future Needs Survey of SPS-II Beamline

In order to conduct more effective needs assessments for next-generation measurement technologies, it is essential that SLRI beamline specialists gain up-to-date knowledge of global developments in beamline technologies, as well as to understand how synchrotron radiation techniques are being applied in research and development worldwide. This knowledge can be enhanced through various means, such as interacting with international researchers and engineers within the synchrotron community, and by consulting academic literature. Furthermore, visiting synchrotron facilities around the world that possess technologies unavailable at the existing SPS-I facility would provide SLRI beamline specialists with more practical training opportunities and further strengthen their expertise.

To upgrade the SPS-II beamlines and measurement methodologies in the future, it is necessary to develop specialists with advanced knowledge of beamline design and state-of-the-art measurement techniques. Improving beamline performance and measurement capabilities is expected to increase the utilization rate of beamlines in Thailand.

4.4 Risk Management and Backup Plan for Accelerator and Beamline

In this section, the risk management and backup plan will be discussed by each process and components for developing SPS-II.

4.4.1 Risk on the Design and Testing Process for Accelerator

(1) Magnet System

Risk description: Magnetic field strength and quality
• Develop magnet prototypes to confirm that all the specifications can be met. Development to prove the design. • Magnetic field strength and quality of the prototype will be measured under the guidance and training of NSRRC magnet group. • If the prototype does not perform as expected, cause of the problem will be investigated. • An expert will be invited to verify the cause of the problem. • If a major improvement is needed, the schedule for that magnet may be shifted by about 6 months, which should not affect the SPS-II project schedule (plan for installation in mid. 2027). • Magnet company can also revise or improve the design.
Backup plan
• If the prototype cannot be improved to perform as required, the magnets can be purchased from an international supplier

(2) Vacuum System

Risk description: Deformation of Chamber
• The chambers and other vacuum components are designed considering the deformation due to the effect of weight, force from atmospheric pressure, and temperature, using static simulation of ANSYS and Solidwork. • Chamber prototypes will be fabricated to verify the design and manufacturing tolerances. • If the deformation of the prototype exceeds the required tolerances, the manufacturing processes and/or the design will be improved.
Backup plan
• If the prototype cannot be improved to perform as required, the vacuum chamber can be purchased from an international supplier

(3) Girder System

Risk description: Structural vibration, Magnet alignment based on geometrical tolerances, Longitudinal and transverse alignment / girder alignment
• Develop girder prototypes to confirm the required specifications. • Increase mechanical vibration frequencies by lowering the center of mass of the girder by increasing girder weight. • Increase mechanical vibration frequencies by employing damping system between girder and pedestals. • Perform structural and modal simulations. • Measure the actual mechanical vibrations and girder deformation caused by magnet load (with the girder prototype). • Magnet alignment adjustment can be performed by shimming (shim plates). • Horizontal alignment system can be modified (using two opposing wedge mounts).
Backup plan
• If the girder system cannot be worked as required, the design of girder will be improved to the simplified design with the advice of the Advisory Team. • In case the manufacturing of girder cannot be achieved by Thai industry, the girder shall be manufactured by international industry.

4.4.2 Risk in the Installation and Commission Process

(1) Project Management

Risk description: Installation, integration and commission
• Preparation of Work Breakdown Structure (WBS) for installation, integration, and commissioning process • Establishment of the installation and integration procedure during the period of prototype development • Organization of collaboration and Supervision by International and/or national experts

(2) Accelerator

Risk description: Unstable beam
• Installation of axes injection system to perform initial injection in the storage ring • Machine would be firstly serviced with 150 mA • Operation of bunch-by-bunch feed back • Extension of commissioning period and postpones the beam services schedule

4.4.3 Planning for Radiation Safety Management

SLRI ensures both users and operators of radiation safety by using the As Low As Reasonably Achievable (ALARA) principle which considers both the safe use of radiation and the controlling of radiation level people are exposed to base on the International Commission on Radiological Protection (ICRP).

Therefore, to comply with ALARA principle and recommendations from similar facilities, SLRI decided to define a more challenging dose limits of 1 mSv per year for all staff and users, who has 2000 working hours in a year and environmental dose of 0.5 mSv per year at site boundaries for 6000 hours in a year.

For the radiation shield, concrete is used for the ring tunnel and metal panels for the beamline. The thickness of each of materials ware calculated using FLUKA (Fluktuierende Kaskade, German for Fluctuating Cascade).

As mentioned above, SLRI has made the basic policy plan but the specific operation plan and system have not been clarified yet.

(1) Current Situation

There are relevant regulations for radiation safety under Thai laws; Nuclear Energy for Peace Act, B.E. 2559 (2016), and the amendment, B.E.2562 (2019), and Ministerial Regulation related to radiation safety, B.E.2561, (2018). Under these regulations, SLRI set up the radiation protection system to be the guideline of safety radiation operation for radiation operators, users, and authorized visitors. The protection plan was issued on September 5th, 2022. This protection plan objects to the occupational exposure from Synchrotron and high performance X-ray machines. 5 Radiation safety officers (RSOs) are assigned to supervise the safety operations. Radiation areas are categorized into controlled areas and supervised areas. All-area access permissions are strictly implemented. Optically Stimulated Luminescence (OSL) personal dosimeters and radiation detection meter are used to monitor radiation safety areas in term of time based maintenance. Safety standard operation procedures are set up in case of radiation emergency. Safety training and emergency drill are also conducted annually.

(2) Organization for Radiation Safety Management

SLRI manages a radioactive protection according to the policy mentioned above. Occupational Safety, Health and Environment Committee has been set up in SLRI according to the regulatory requirement of ALARA. Radiation Safety Committee (RSC) experts work with executive management to implement the radiation safety program. RSC has been granted the necessary authority to fulfill its purpose of overseeing the radiation safety program. Under management of RSC, Radiation Safety Officer (RSO) implements the radiation safety program. Highest prioritized tasks for RSO are to ensure day-to-day operations and conducts to adequately protect public health and safety, and to maintain exposures ALARA. Duties and responsibilities of RSO indicates below.

- Ensure that all terms and conditions of license and their regulations are compliance
- Ensure that the seal sources are leak tested as prescribed by the license
- Ensure that radioactive materials are used only by individuals who are authorized by the license and that all individuals were required personnel monitoring equipment
- Maintain all records required by the license. This record shall include personnel monitoring records, leak tests records, inventory records, training records for users, and receipt, transfer disposal records
- Ensure that radioactive materials are properly secured against unauthorized access or removal,
- Ensure that all users read and understand emergency, operating, and radiation safety procedure.

Plan for radiation safety management within SPS-II consists of the following.

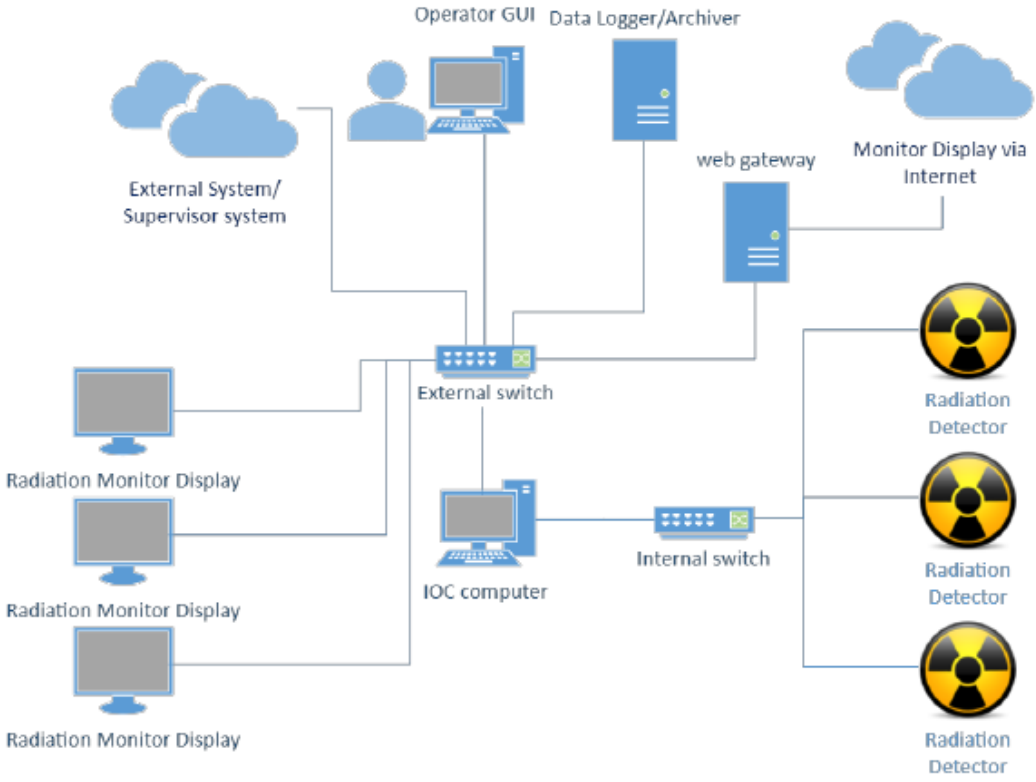
- Licensing of accelerator, beamline, radioactive sources, etc.
- Radiation monitoring such as gas, air induced radioactive materials, leakage
- Radiation and dosimetry of staff and users
- Radioactive waste management
- Radiation measurement and survey
- Radiation safety procedure, regulation and law
- Radiation inspection and audit
- Radiation preparation response procedure

(3) Radiation Monitoring

Radiation monitoring is carried out to assess workplace conditions and individual exposures to ensure acceptably safe and satisfactory radiological conditions in the workplace. It is necessary to keep the records of radiation monitoring for long time due to the radiation safety regulation. Radiation monitoring instruments are used both for individual monitoring and area monitoring.

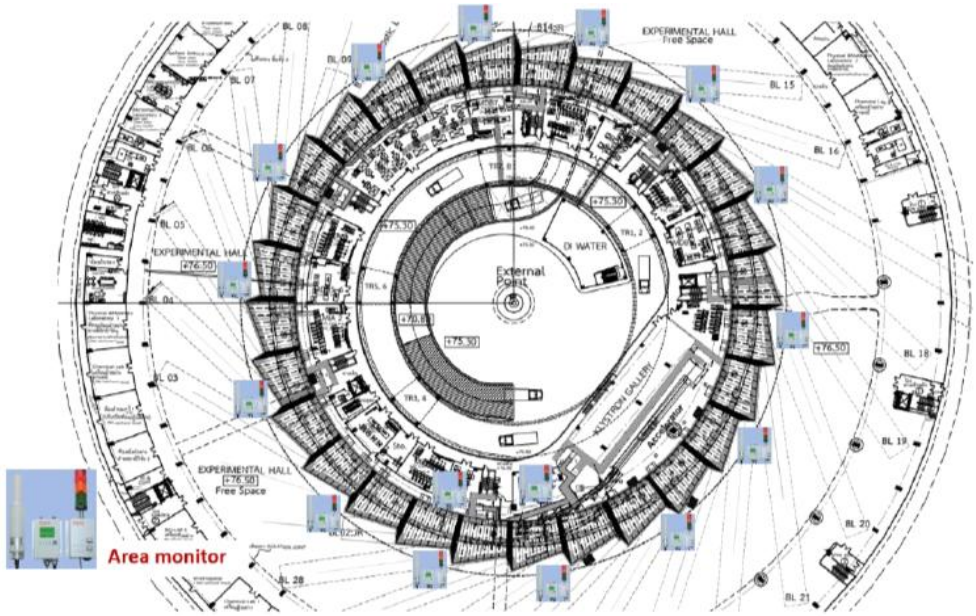
According to the radiation safety regulation, SPS-I set up the Radiation Area Monitoring System (RAMS) to provide exposure data. In addition, new monitoring system, which called Siam Photon Source Radiation Monitoring System-II (SPSRMS-II) will be developed for SPS-II by applying Experimental Physics and Industrial Control System – Input/output controller (EPICS-IOC). EPIC IOCs proposed in SPSRMS-II is a

control system which can monitor the exposure rates both in graphical and digital number in GUI. Figure 4-35 and Figure 4-36 show the layout plan of monitoring system for SPS-II.



Source: SLRI

Figure 4-35 Architecture of SPSRMS-II



Source: SLRI

Figure 4-36 Layout of Radiation Monitoring SPS-II

The following information about radiation monitoring is taken from "Radiation Safety Management" report by P. Aim-O of SLRI.

Warning devices

- Each location designated as controlled area, and each entrance shall be equipped with easily observable warning lights that operate when, radiation is being produced or used.
- Except in facilities designed for human exposure, each controlled radiation area shall have an audible warning device which shall be activated.

Administrative control/operating procedures

- Particle accelerators, when not in operation, shall be secured to prevent unauthorized use.
- The safety interlock system shall not be used to turn off the accelerator beam except in an emergency.
- All safety and warning devices, including interlocks, shall be checked for proper operation in accordance with a procedure at intervals not to exceed three months unless the facility has not been operating during this interval in which case the interlocks shall be tested prior to next use. Results of such tests shall be maintained at the accelerator facility for inspection.
- Electrical circuit diagrams of the accelerator and the associated safety interlock systems shall be kept current and maintained for inspection and shall be available to the operator at each accelerator facility.
- If the reason is necessary to intentionally bypass a safety interlock or interlocks, such action shall be:
  - Approved by authorized person who are the head of department of machine and radiation safety officer
  - Recorded in a permanent log and a notice posted at the control of accelerator or beamlines.
  - Terminated as soon as possible.

Configuration changes

System changes that may affect radiation exposure to personnel or the public should be documented and the scope of the registration submitted to the RSC for review prior to implementing the change.

Control of radioactive materials

Radioactive material may be present at an accelerator either as a result of accelerator operation or in support of accelerator operation. Examples include the use of radioactive targets, activation of beamline components, and use as calibration sources for instrument calibration or checks.

- The RSC manages the control of radioactive materials through either the initial registration or a separate authorization. The specific method depends on the nature and quantity of the material produced. In all cases, adherence to the requirements of the applicable registration or authorization is mandatory.
- Radioactive material required for the operation of the facility shall have a radioactive material authorization issued by the radiation safety committee.

Interlocks

- Each entrance into a controlled area shall be provided with a safety interlock that shuts down the machine under conditions of barrier penetration.
- Each safety interlock shall be on a circuit which shall allow it to operate independently of all other safety interlocks.
- All safety interlocks shall be designed so that any defect or component failure in the safety interlock prevents operation of the accelerators or beamlines.
- When a safety interlock system has been tripped, it shall be possible to resume operation of the accelerators by manually resetting controls at the position where the safety interlock has been tripped and, lastly, at the main control console so that the accelerators or beamlines cannot be restarted remotely.
- A scram button or other emergency power cutoff switch shall be located and easily identifiable in all radiation areas. Such a cutoff switch shall include a manual reset so that the accelerators or beamlines cannot be restarted from the accelerator control console without resetting the cutoff switch.
- The radiation safety interlock system comprises several subsystems, including the machine interlock system, beamline interlock system, and radiation monitoring system. These components are designed to prevent radiation exposure from the controlled area. If any part of the system is modified, the new design must undergo a safety review and be properly documented.
- The interlock system of SPS-II will be designed by SLRI, and the equipment will be procured in a separate package from the beamlines. The design of the communication system between the PLC and the sensors is under consideration by the SPS-II project team and SLRI control engineers.
- Conceptually, SPS-II will have two separate PLCs for personal safety and equipment protection for each beamline. Front ends, beamline optics and end stations will be parts of the same interlock logic for beamlines. The interlocks related to the insertion devices will be managed by the machine group. SLRI plans to adopt systems that support ethernet-based fieldbus (such as EtherCAT) to ease the problem of managing large number of signal and drive cables.

5 Preliminary Design Results for Facility

5.1 Current Status of the Site

The Project site is in Wangchan Valley, Wangchan District, Rayong Province, Thailand. It is located about 1.5 km off National Highway 344, which is currently undergoing land development for the construction of the facilities for the University of Science and Technology, a special economic zone, and an advanced technology research hub.

5.1.1 Natural Condition

(1) Meteorological Condition

Thailand belongs to the savanna (Aw) of a Köppen climate classification with the rainy season from May to October and the dry season from November to April. In Rayong Province, where the project site is located, temperatures do not vary widely throughout the year, with an average maximum temperature of approximately 30°C and an average minimum temperature of approximately 23°C. The average temperature ranges from 26°C to 28°C. The highest temperatures occur during the hottest season (from March to April) at the end of the dry season, when the maximum temperature rises to about 31°C. Average relative humidity ranges from 63% to 85%, making it hot and humid.

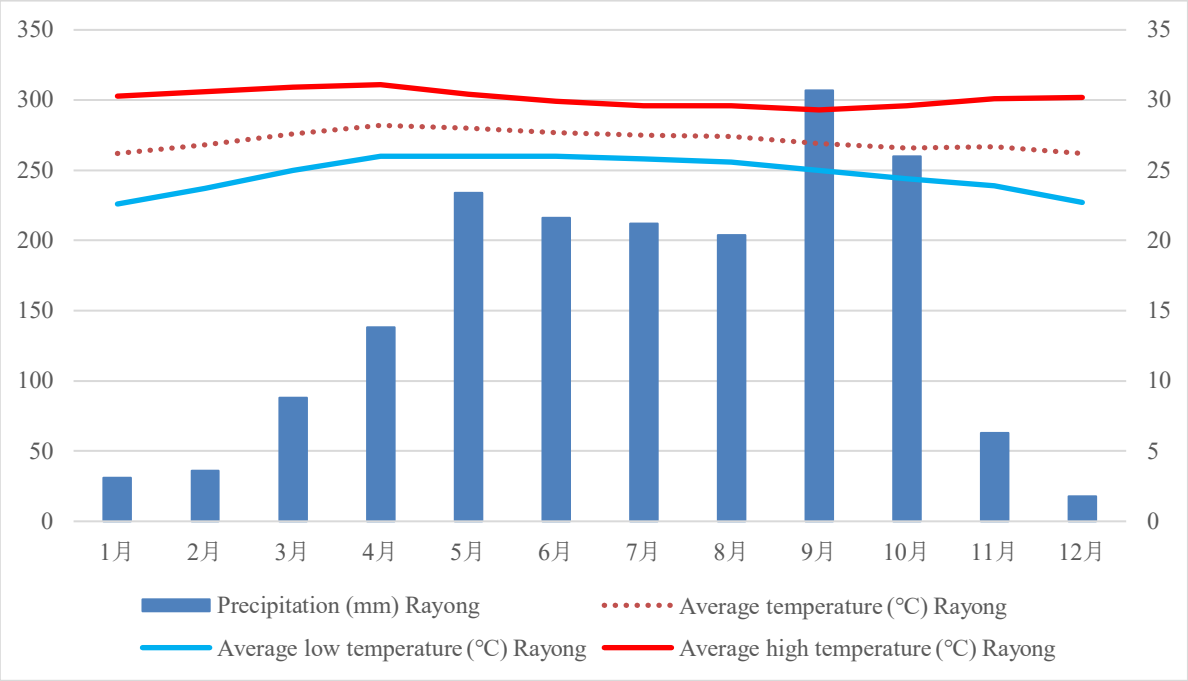
Rainfall is concentrated in the rainy season, which accounts for about 79% of the annual rainfall. Peak rainfall is 307 mm in September.

Table 5-1 Weather Data for Rayong Province

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	average /sum
Average temperature (°C)	26.2	26.8	27.6	28.2	28.0	27.7	27.5	27.4	26.9	26.6	26.7	26.2	27.15
Average low temperature (°C)	22.6	23.7	25.0	26.0	26.0	26.0	25.8	25.6	25.0	24.4	23.9	22.7	-
Average high temperature (°C)	30.3	30.6	30.9	31.1	30.4	29.9	29.6	29.6	29.3	29.6	30.1	30.2	-
Precipitation (mm)	31	36	88	138	234	216	212	204	307	260	63	18	1807
Number of rainy days (days)	5	6	11	14	18	18	18	19	19	17	7	3	155
Humidity (%)	66%	73%	77%	80%	82%	82%	82%	82%	85%	84%	73%	63%	77%
Daylight hours (hours)	9.0	8.6	8.7	9.1	9.4	9.8	9.9	9.8	9.1	8.7	9.1	9.3	110.5

*Average value for 30 years from 1991 to 2021, Sunshine hours for 20 years from 1999 to 2019.

Source: Climate-Data.org



Source: Climate-Data.org

Figure 5-1 Annual Average Weather Data for Rayong Province

Wind speeds in Rayong vary greatly seasonally throughout the year, with winds being strong from May to September and average wind speed is 18.7 km/h in the windiest month of July. From October to April, the winds are calm, and the average wind speed is 11.9 km/h.in the calmest month of October.

Table 5-2 Wind Speed in Rayong Province

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Wind speed (kph)	12.8	13.2	14.2	13.7	15.2	18.1	18.7	18.2	14.1	11.9	14.5	15.3	15.0

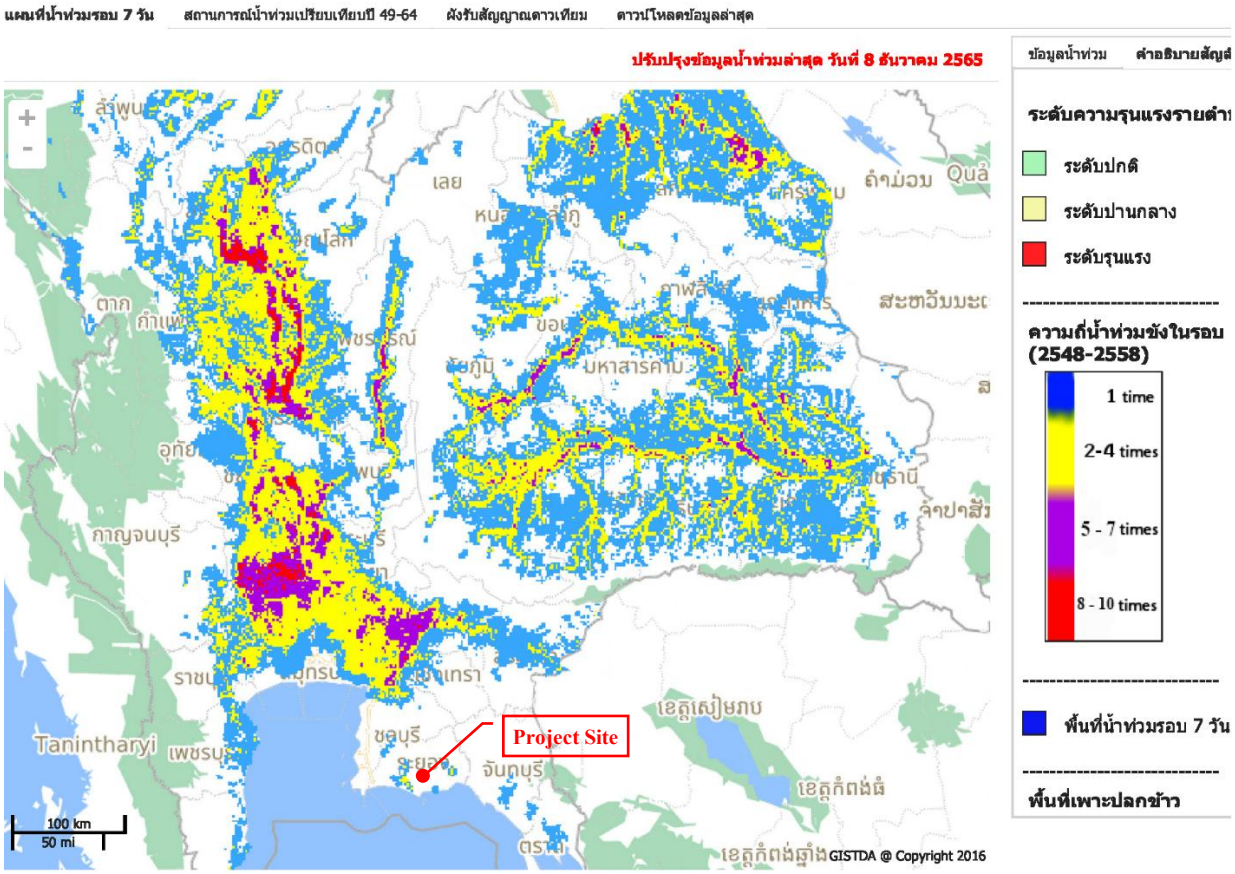
Source: Weather Spark

(2) Natural Disaster Survey

The main natural disasters in Thailand are floods and earthquakes that need to be considered for the project site, in particular:

1) Flooding

The most frequent natural disaster in Thailand is flooding. Flooding in Thailand is caused by monsoon tropical storms, tropical cyclones, and typhoons that cover the Andaman Gulf and Thailand from May to September. The heavy rains brought by these weather conditions cause flooding mainly in Chao Phraya River basins at central Thailand and Bangkok. A flood in 2011 caused extensive damage to the area. According to data from the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, Wangchan Valley, Rayong Province, where the project site is located, has not experienced flooding in the past, In addition, there is no rivers and high ground. Therefore, the site has a very low risk of flooding.



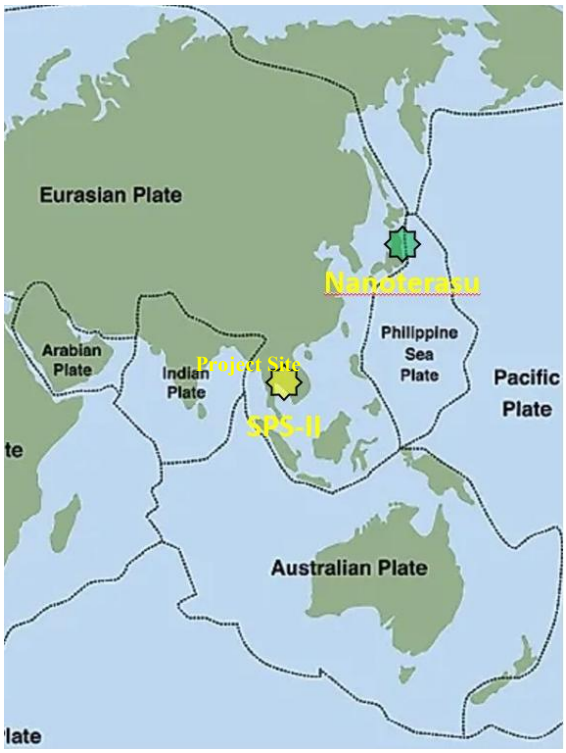
*No flooding has occurred at the project site since 2015

Source: GISTDA

Figure 5-2 Frequency of Flooding in Thailand Over the Past 11 years (2005-2015)

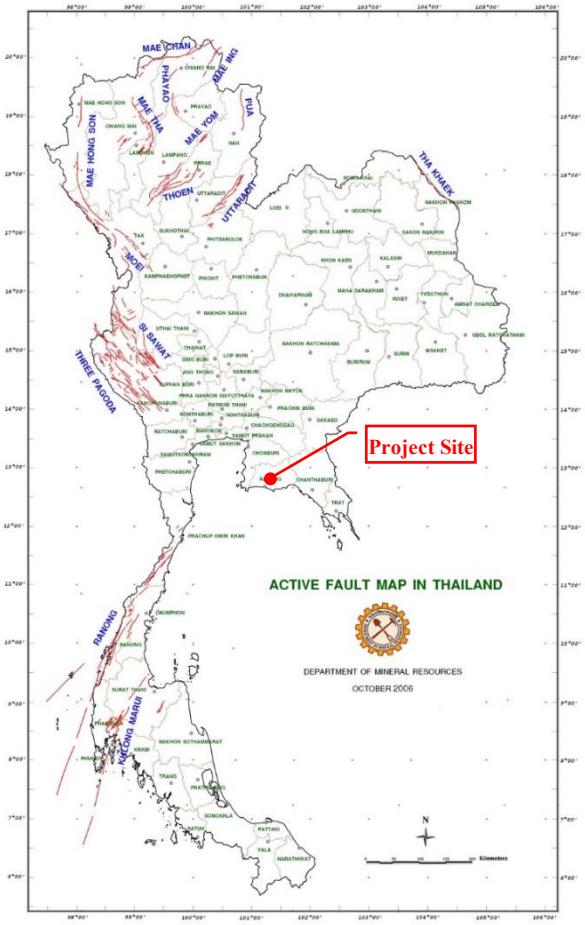
2) Earthquake

Thailand is located on the Eurasian Plate as shown in the エラー! 参照元が見つかりません。 Plate Map below, and there is no plate boundary directly below it. Plate boundaries around Thailand are in Myanmar, the Andaman Sea (western part of Thailand), and eastern Sumatra, which is more than 350 km away from the Thai border, therefore Thailand has a low risk of earthquakes. However, Thailand also has faults in the northern and western parts of the country that are the epicenter of intraplate earthquakes (see エラー! 参照元が見つかりません。 Fault Map of Thailand), and 14 active faults have been identified, causing frequent earthquakes in northern and western Thailand. In recent years, earthquakes of magnitude 5 or greater have been occurring with a frequency of approximately 6 to 10 years. In addition, earthquakes that occur outside of Thailand can also have a significant impact on Thailand. In the past, large earthquakes with magnitudes greater than 6 on the Richter scale that have occurred off the coast of Sumatra and in Myanmar have been observed in Bangkok, southern and northern Thailand in the past. Wangchan Valley in Rayong Province, where the project site is located, is an area without fault lines.



Source: SLRI

Figure 5-3 Plate Map

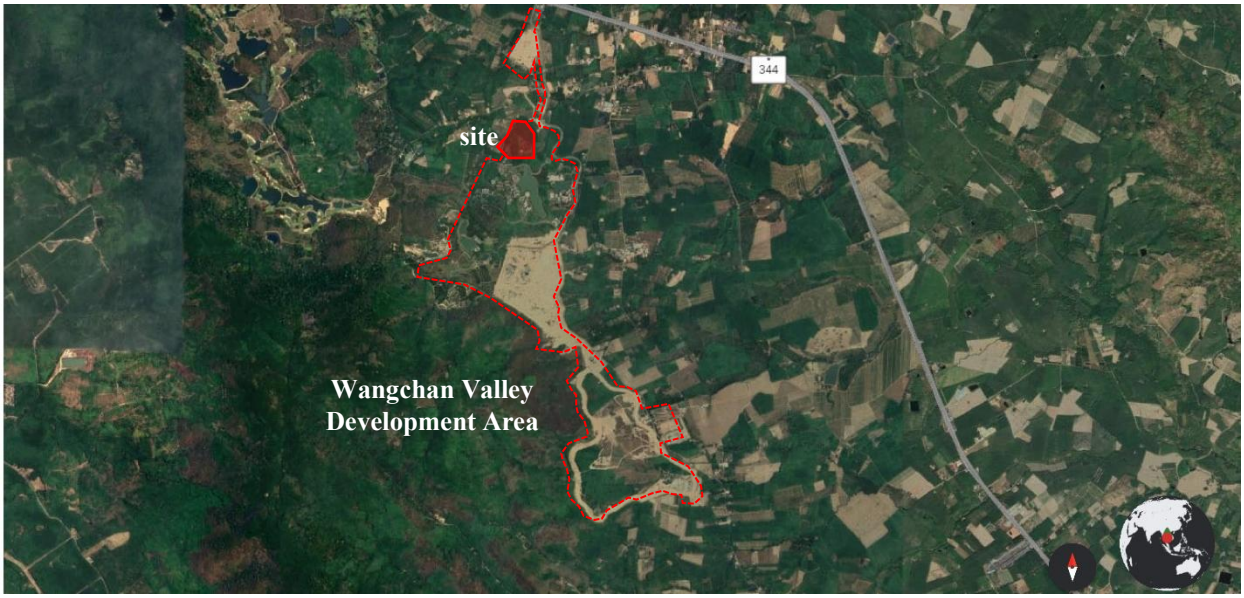


Source: SLRI

Figure 5-4 Fault Map of Thailand

(3) Hydrological Survey

There is a pond on the university campus around the site, but there is no river. In discussions with SLRI, it was confirmed that there are no plans to use water from rivers or other sources at the planned facility.



Source: Google Map, prepared by JST

Figure 5-5 Photograph of the Area Around the Site

(4) Topographic Survey

A site survey of the new site was conducted by SLRI in February 2023 (see **Attachment 3: Topographic Survey Result from SLRI**). The new site is a deformed rectangular shape with a circumference of approximately 1.6 km (370 m on the east, 390 m on the west, 380 m on the south, and 430 m on the north). The northeast portion of the site adjoins the EECi campus road, which provides access to the site. The ground elevation is approximately mean sea level +51.0 m to +59.0 m. The land is relatively flat, although the center of the site is high and there is a partial depression to the south of the site.

(5) Geological Survey

A geological survey of the new site was conducted by SLRI in February 2023. Boring surveys were conducted at one location in the center of the planned synchrotron facility site, four locations at the planned storage ring site, and six locations on the perimeter of the planned synchrotron facility site. In addition, 10 borings were conducted at the planned sites of ancillary facilities and landscape. The depth of boring was about 30 m at the center of the planned synchrotron facility site and the planned storage ring site, 12 m to 21 m at the perimeter of the planned synchrotron facility site, about 12 m at the planned ancillary facilities sites, and 10 m to 15 m at the planned landscape site. As a result of the survey, although there is ground with an N-value of about 30 at a depth of about 15 m in the planned landscape site on the south side of the site, a hard layer with an N-value of 50 or higher was confirmed at a depth of about 4 m to 8 m throughout the entire site. In the center of the planned synchrotron facility site and the planned storage ring site, a layer with an N value of 50 or higher has been confirmed at a depth of approximately 30m. Groundwater levels were observed at a depth of 4m to 10m at the proposed synchrotron facility site, and at a depth of 1.5m to 3.5m at the planned ancillary facilities site on the north side of the site and the planned landscape site on the south side of the site.

(6) Cadastral Map

The landowners, PTT (Petroleum Authority of Thailand) and VISTEC (Vidyasirimedi Institute of Science and Technology), signed a Memorandum of Cooperation (MOC) with SLRI on November 15, 2022, for a 30-year land use of the project. After that, the land lease agreement was signed between SLRI, PTT and VISTEC on July 31, 2024. The land lease is scheduled to be renewed in 30 years. Hence, the right of land use has been confirmed.



Source: SLRI

Figure 5-6 MOC for the Site Use

(7) Obstacle Investigation

In the site survey, it was confirmed that part of the site is a rubber plantation. Therefore, it is necessary to cut down trees and remove the roots. Trees in PTT's part of land were cut down and removed including tree roots. On the other hand, VISTEC will start the land clearing on their part of land before construction starts. There is no need for land acquisition and resettlement.

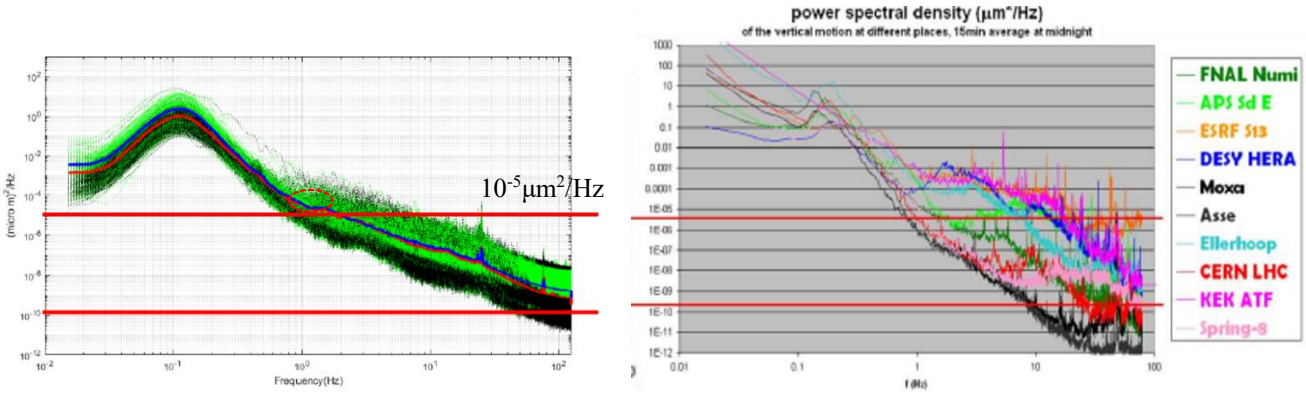


Source: JST

Figure 5-7 Current State of the Site (Left: Trees, Right: Rubber Plantation)

(8) Vibration Survey

A microtremor survey has been done by JST at the new site from 28 November to 1 December 2022 in the daytime (see **Attachment 2: Vibration Survey Report**). According to the Power Spectral Density (PSD) for the field data, the new site is as "Quiet Condition" as same as the research facilities in the world. The criteria of PSD for the "NanoTerasu" was "$10^{-5}\mu m^2/Hz$" in the higher frequency area than 1Hz. Comparing to the criteria, the PSD of the new site is slightly higher between 1Hz and 2Hz. Therefore, minimizing the vibration between 1Hz to 2Hz is recommended to address through structural design or facility viewpoint. Since EECi area near the project site is not fully operated, additional survey is proposed to verify the quietness of the area during implementation stage, especially at the time of next generation SRF development completion (Phase-1).



Source: JST

Figure 5-8 Left: PSD of the Site; Right: PSD of the World Research Facilities.

(9) Land Use Situation Around the Construction Site (Density, Types of Facilities, etc.)

The north and west sides of the site are farmland, the east side is the Wangchan Valley development area, and the south side is the campus of VISTEC, a university of science and technology. SLRI confirmed that Wangchan Valley development area and VISTEC have no development plans that would affect this Project facilities. In addition, the area surrounding the site is designated as rural community for agriculture, public organization where large-scale industries are not permitted, therefore there was no possibility of large-scale facility construction that would cause vibration or ground subsidence or any development with negative impact to this Project. However, as the facility of Wangchan Valley is developed, there is concern about micro-vibrations associated with the increased traffic on the campus road. Hence, regularly permanent microtremor survey shall be conducted.

5.1.2 Infrastructure

(1) Electric Power

A new special high voltage substation for 115KV/24KV have a plan to install near the entrance of the site. The total electrical capacity has been determined based on the required electrical capacity for building and radiation equipment.

The construction plan details for the new substation, whether it will be a stand-alone or open-type style, or detailed information regarding the site allocation for the substation and the related civil work, such as the installation of manholes, laying conduit, providing transformer and switchgear foundations, and the selection of electric poles, should be specified before the completion of detailed design documents.

- Prior to selecting the power supply company, SLRI must confirm the power supply capacity and determine who will bear the cost of constructing the transmission line up to the new substation.
- The power supply company will provide SLRI with information on the origin of the power supply line (which generation plant or substation) and the location of the connection point of the transmission line.
- SLRI needs to confirm that this 30MVA transformer (just supposed that PTT or PAE may use this type of transformer) can be transported into this planned outdoor substation area and that there is enough space to accommodate this transformer.
- Secondary power supply cable (24KV) shall be pulled from this substation to other secondary substations where 24KV high voltage will be downed to 400V/230V. Most probably secondary cable (24KV) will be pulled through conduit until tie in Room. Then these high voltage cables shall be laid separately from the other low voltage cables in order not to affect them and have enough safety distance from cables which run in parallel until each appointed substation.

(2) Telecommunications

- There are 3 telecommunication companies around the project site; SLRI is to select one of them and mention the condition on bidding documents.
- Since SLRI is planning to use 12 core fiber optical cable as main feeder of telecommunication system in this Project, JST suggested to reconfirm that 12 core will be sufficient for future use.

(3) Plumbing

Water intake:

Based on the current drawings, the water supply will be branched off from the water main maintained by PTT and will be supplied to the facility. The intake pipe is φ150, and the estimated daily water usage is 670m^3/day. The breakdown of water supply is 480 m^3/day of soft water (makeup water for the cooling tower), 100m^3/day of general water supply, 30m^3/day of DI water and 60 m^3/day of sprinkling water.

Drainage:

The drainage system is designed for recycling purposes, and any water used up through evapotranspiration by the cooling tower and irrigation is planned not to be discharged outside the project site.

(4) Gas System

PTT has no gas supply infrastructure.

(5) Fire Safety

A projector-type fire alarm device is useful to monitor the large space above the crane at experimental hall

5.1.3 Building Regulations

(1) Applicable Laws

Since the large-scale and special uses of the SRF, ordinary laws are applicable to the building design and construction. The followings are list of major Thailand laws that may be applicable:

- PTT city planning law
- Building law (Ministerial Regulation issued by virtue of the Building Control Act)
- Floor Area Ratio (FAR)
- Open Space Ratio (OSR)
- Building Boundary and setback
- Quantity parking lot (Phase 1)
- Universal design law (Building facilities for disabled person and elder, 2548 B.E.)
- OAP (Office of Atoms for Peace, the authorization for regulating of radiation and nuclear energy in Thailand)

(2) Characteristics Above Laws

- Since some provisions are added or modified occasionally in the “Building law”, it is necessary to conduct a thorough study to ensure that no important details are missed.
- For structural provisions that are not covered by Thailand law, mutatis mutandis “International law” is applied e.g. the United States.
- The building with more than 10,000 m2 area is required to have sprinklers systems, regardless of their use. However, if there are materials or equipment in a designated area that are incompatible with water, alternative fire suppression systems should be considered.

5.2 Planning for Radiation Safety Management

5.2.1 Radiation Regulations in Thailand and Design Dose Limit in SPS-II

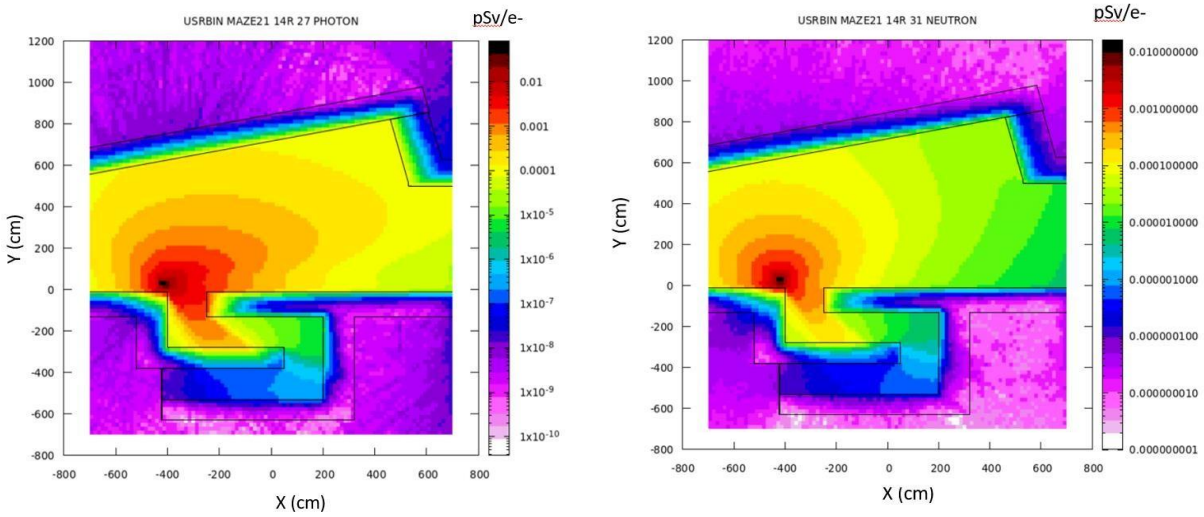
To prevent radiation hazards from machine operation, it is necessary to consider radiation shielding design. The SPS-II complies with the internal standard, the OAP (Office of Atoms for Peace, the regulatory authority for radiation and nuclear energy in Thailand), as well as the International Commission on Radiation Units and Measurements (ICRU), which has set a limit of 1 mSv per year for all staff and users.

5.2.2 Shielding Tunnel Design

To model the shielding design, the use of the Monte Carlo Code FLUKA has been employed. FLUKA is a powerful for particle transport and matter interaction calculations used in various applications, including electron accelerator shielding, target design, and dosimetry. Its application has been widely studied in

synchrotron facilities such as MAX IV, NSLSII, and TPS. For SLRI, this is the first time that FLUKA has been used to evaluate the shielding design of the SPS-II accelerator machine.

5.2.3 Dose Estimation of Shielding Tunnel Model



Source: SLRI

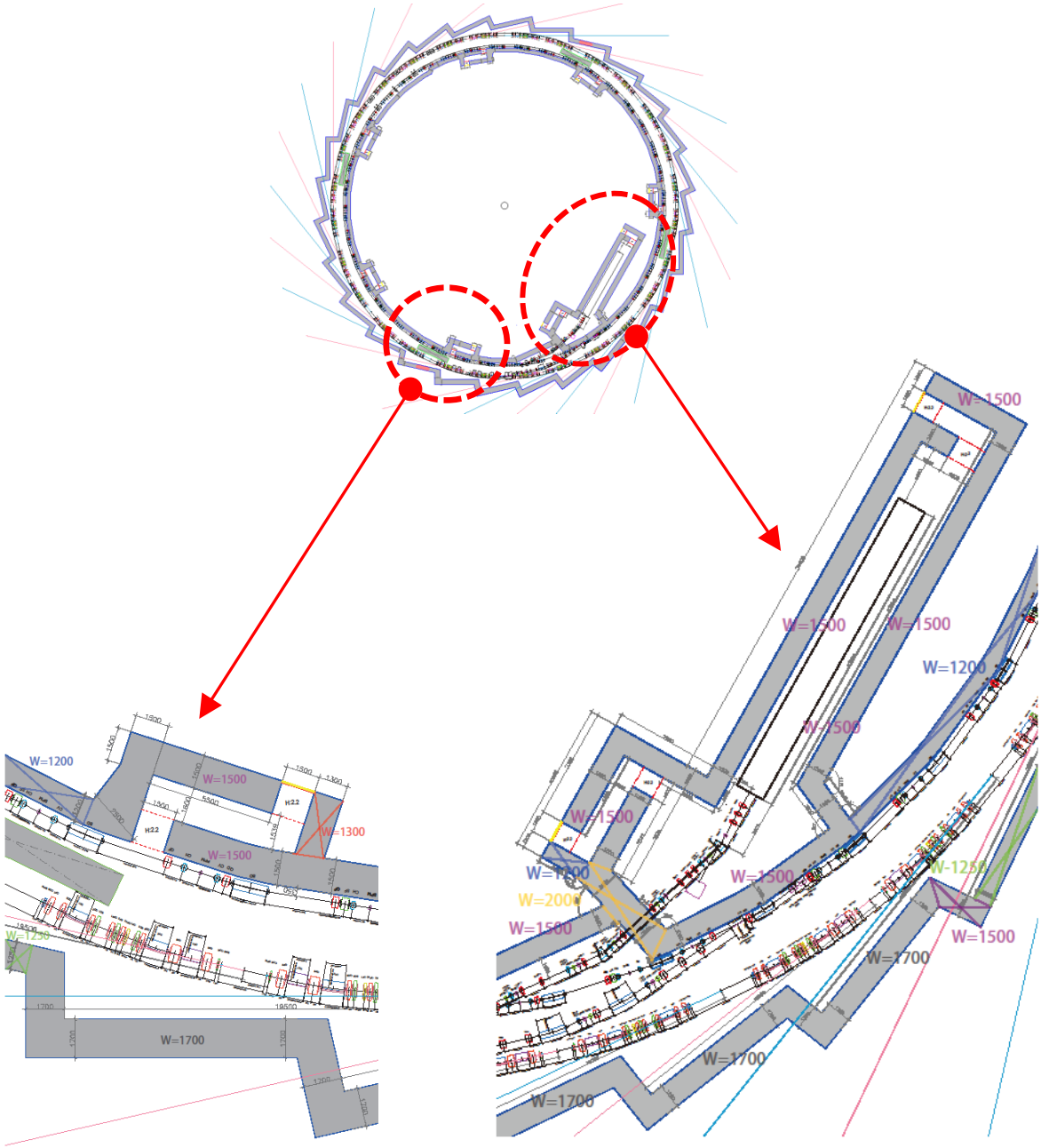
Figure 5-9 (Left) Gamma Dose Distributions of Shielding Tunnel and Maze Design (Right) Neutron Dose Distributions of Shielding Tunnel and Maze Design

The figure above エラー! 参照元が見つかりません。 illustrates the distribution of gamma doses along the X-axis of the Storage Ring and Maze entrance, respectively. The simulation results found that the average gamma dose equivalent outside the tunnel was approximately 5.0E-8 pSv/e-, while the average of neutron dose equivalent outside tunnel was found that 1.0E-7 pSv/e-. According to the SPS-II annual summation of electron loss rate per year of the normal operation, including unwanted beam trips, is 5.03E+15 e-/y, thus, the dose assessment of gamma dose equivalent is 5.03E-1 mSv/year and neutron dose equivalent is 2.51E-1 mSv/year. Therefore, the total dose equivalent is 7.55E-1 mSv/year, which is below the SPS-II safety dose limit at 1 mSv for 2000 working hours.

5.2.4 Shielding Tunnel Model

The shielding concrete thickness (physical density of 2.35 g cm^{-3}) requirement for the wall and roof of the LINAC tunnel is determined by the beam loss scenario. Specifically, the outer wall requires a thickness of 125-170 cm, the inner wall is 120-200 cm, the ceiling panel is 125 cm and the ceiling height is 3.5m.

The Maze entrance is designed as a crank and the concrete thickness is calculated using FLUKA, taking into account its design as a crank, as shown in the figure below.

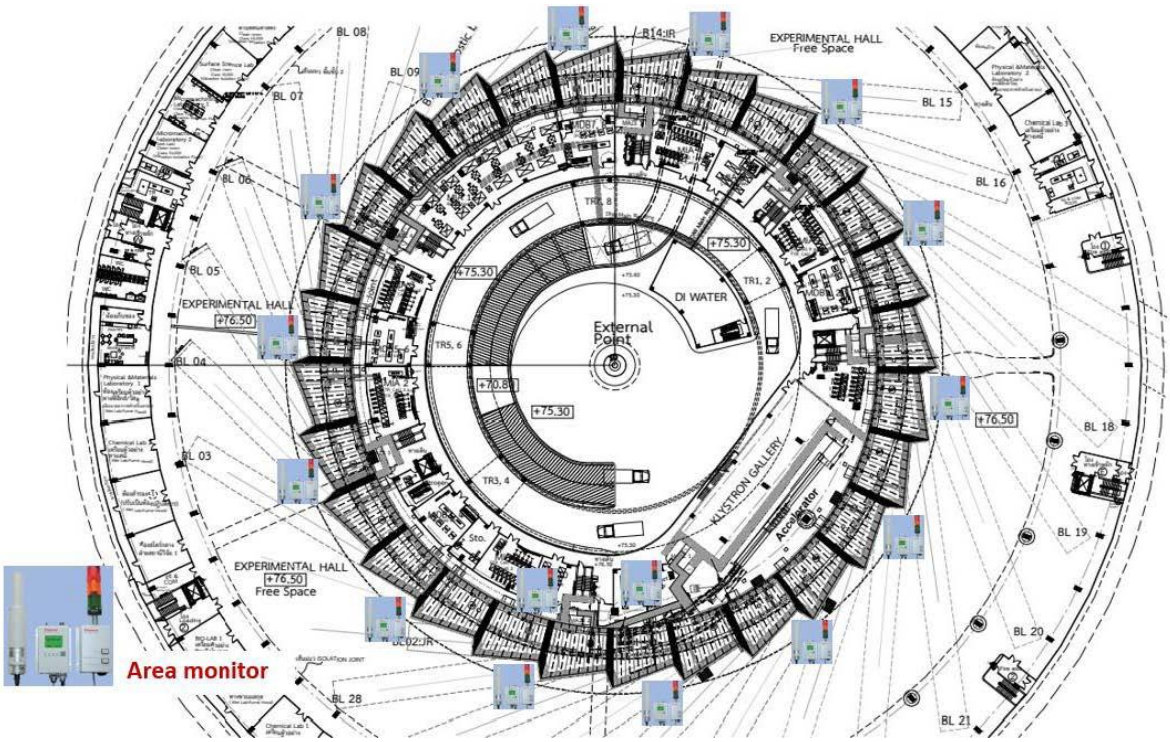


Source: SLRI

Figure 5-10 Concrete Shield Wall Layout and Thickness of Each Wall

5.2.5 Shielding Beamline Model

To provide radiation shielding, the beamline area in the experiment hall is covered with iron hatches and lead sheets. Radiation levels are monitored and controlled using an "area monitor". Furthermore, an anteroom will be installed at the hatch entrance, and access will be double-checked to ensure strict management.



Source: SLRI

Figure 5-11 Layout of Radiation Monitoring

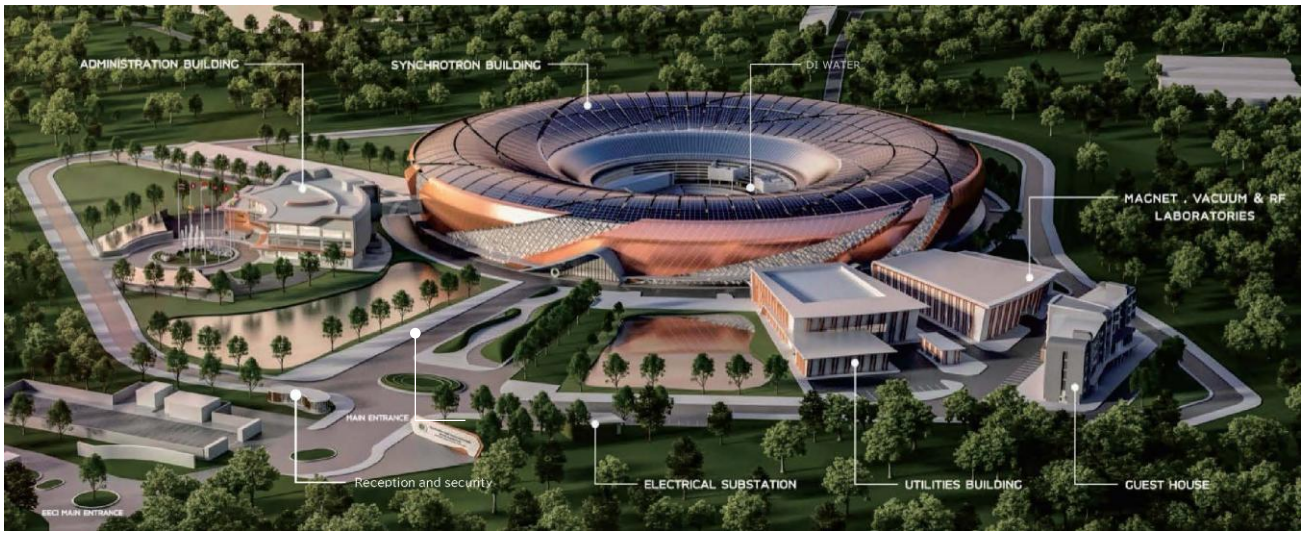
5.3 Preliminary Design of Building & Other Facilities

5.3.1 Next Generation SRF Building and Related Facilities

See **Attachment 4: Facility Design Documents Prepared by DKW Consortium**.

(1) Overall Plan

The figure below shows the eight buildings that will be developed sequentially.



Source: SLRI

Figure 5-12 SPS-II Facility Bird-View

(2) Facility Overview

1) 3 GeV synchrotron building (S Building)

(General information)

- Total floor area: 32,126 m^2
- Structure/Number of floors: 2-story Steel frame building (storage tunnel is RC structure)
- Exterior finishing: Metal panel wall, aluminum window
- Roof: Metal panel, Waterproofing sheet
- Rooms: Electron gun installation area, Storage ring, Experimental hall (beam line area), laboratory, office, meeting room, connecting bridge to the administration building

(Structure system)

- 2-story Steel frame building, 21.5m height
- Storage ring: RC structure
- Standard floor height: 1F/ 4.5m, 2F/ 4.5m, Experimental hall/ 19.7m
- Roof truss structure
- Foundation type: Direct foundation with soil improvement

(MEP system)

- Air conditioning and ventilation system: Heat source, Air conditioning, Chilled water, BMS and automatic control system
- Plumbing system: Cold and hot water supply, Drainage, Gas supply, DI water piping, Firefighting (sprinklers, inert gas fire extinguishers, indoor fire hydrants), Recycle water supply, Special gas supply
- Electricity system: Power generator, Main feeder, Power distribution, Lighting and outlet, Security monitoring, Access door system, Fire alarm, Lightning protection

(Special requirement)

- Meet the technical specification for the synchrotron equipment
- Structural design for building foundation based on the geotechnical report.
- Floor flatness: ±5.0mm or less over the entire 327.6 m storage ring tunnel
- Floor deformation: 100 μm/ 10 m/ year.
- Expansion joint system to keep isolation
- Temperature and Humidity setting:

	SPS-II
Storage ring & booster synchrotron tunnel	25.0℃±0.1℃, 50%±5%
Linac tunnel	25.0℃±0.1℃. 50%±5%
Experimental Hall	25.0℃±1.0℃, 55%±5%
Cooling Water for Synchrotron	25.0℃±0.1℃

- Radiation protecting system: wall thickness

Floor of linac tunnel, storage ring and booster synchrotron tunnel, thickness 1.3 m
Wall and ceiling of linac tunnel, thickness 1.2m
Wall and ceiling of storage ring and booster synchrotron tunnel, thickness 1.2 m
Wall of injection area of storage ring and booster synchrotron tunnel, thickness 1.5 m
Ratchet wall for beam lines, thickness 1.5 m

- Cooling system for synchrotron equipment

2) Utilities building (U Building)

- Total floor area: 7,214 m^2
- Structure/Floor: 3-story Concrete building
- Rooms: Water supply, Generator, Main Distribution Board, Cooling facility

3) Deionized (DI) water building (D Building)

- Total floor area: 814 m^2
- Structure/Number of floors: 3-story Concrete building
- Independently located in the courtyard of the synchrotron building

4) Magnet, vacuum, and RF laboratories building (L Building)

- Total floor area: 2,349 m^2
- Structure/Number of floors: 2-story Concrete building
- Connected to the synchrotron building

5) Administration and user service office building (A Building)

- Total floor area: 5,805 m^2
- Structure/Number of floors: 3-story Concrete building
- Designed space and layout according to the number of user, operation time, etc.

6) Guest house building (G Building)

- Total floor area: 3,950 m^2
- Structure/Number of floors: 3-story Concrete building
- Designed according to operation policy

7) Reception and security building (RS Building)

- Total floor area: 53 m^2
- Structure/Number of floors: 1-story Concrete building
- Located at the entrance of the site

8) Electrical substation 115 kV/22 kV building (ES Building)

- Total floor area: 932 m^2
- Structure/Number of floors: 2-story Concrete building

- Build simultaneously with Synchrotron building

(3) Others

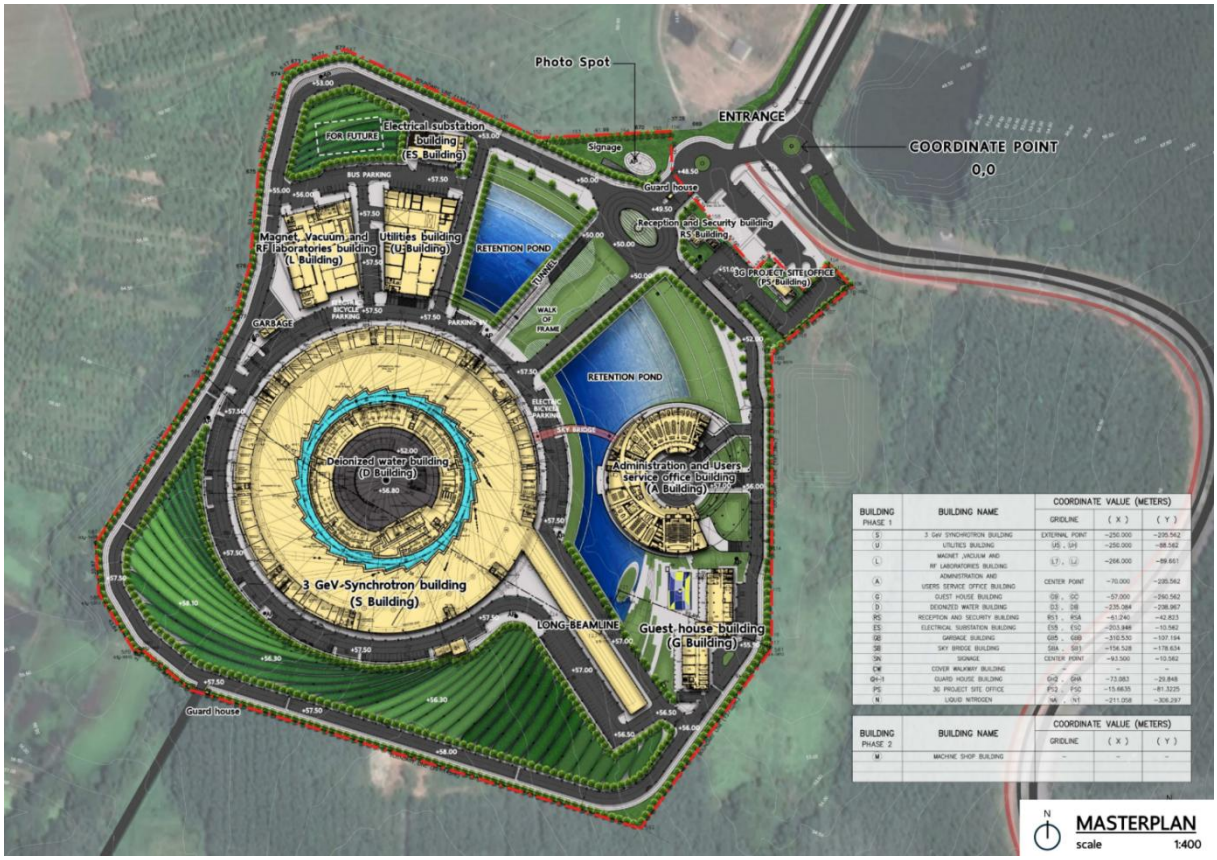
Ground preparation, landscaping, approach road, signage, and storage (garbage) are included in the scope of JICA Yen Loan.

(4) Facilities Design Conditions

The design conforms to the Thailand Building Law and meets the specific usage requirements of each room, activities, and operational time. On the other hand, the special specifications (such as vibration countermeasures, flat slab, humidity, and temperature control, etc.) required on the synchrotron facilities are referenced from the specifications of advanced SRF such as SIRIUS (Brazil) and TPS (Taiwan), to set each room layout and the vertical/horizontal dimensions according to the requirements of synchrotron radiation equipment. Since the drawings are highly detailed, design changes will be made to meet the new site in detailed design stage.

(5) Building Layout Concept

Due to the slightly smaller size of the new site, the planner on the Thailand side had to re-evaluate the building layout and make adjustments to reduce the space between buildings and make the overall design more compact. Despite these changes, all the originally planned functions have been maintained. The six buildings are planned around the synchrotron building facing approach road, and future extension area for laboratory or administration works are reserved.



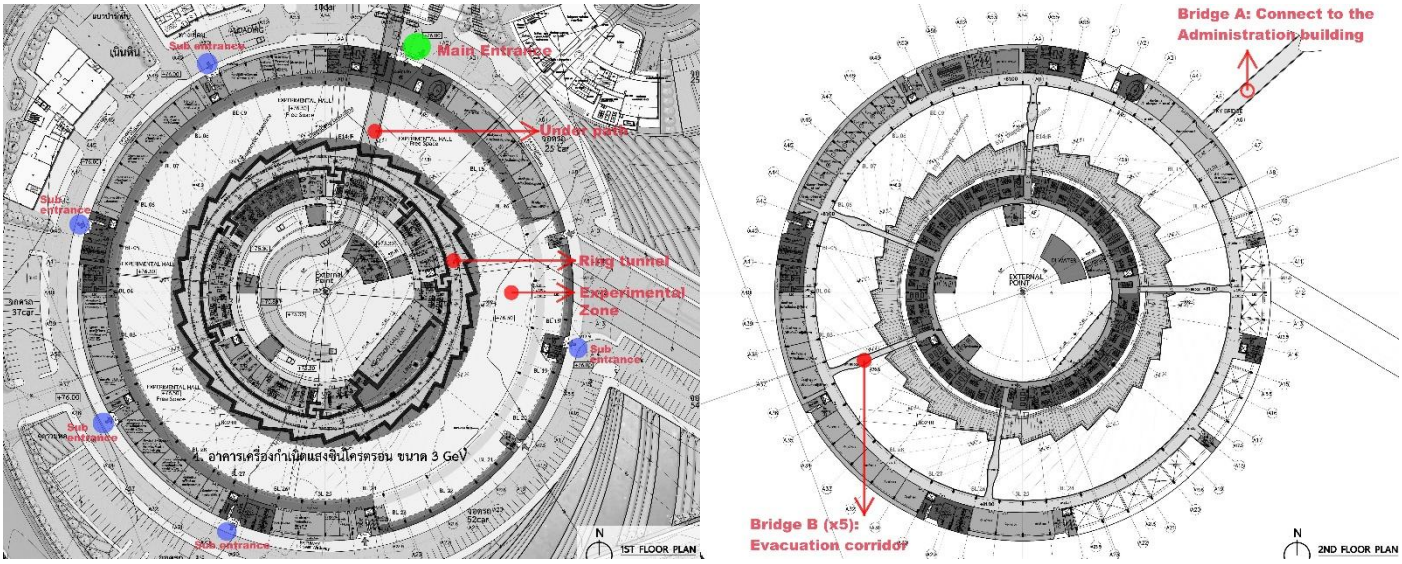
Legend: A: Administration Building and User Service Office, D: DI Water Building, G: Guest House, S: 3GeV Synchrotron Building, L: Magnet, Vacuum and RF Laboratories, U: Utilities Building, ES: Electrical Substation, RS: Reception and Security

Source: SLRI

Figure 5-13 Building Layout

(6) Flow Plan (for Synchrotron Building)

The movement flow of individuals, vehicles, and delivery items has been taken into account, and access security points have been established. An exclusive path for the delivery of equipment or materials has been designed beneath the synchrotron building, reaching to the central part of the building. In addition, synchrotron building is designed to connect to the administration building through Bridge-A at the second level. JST also has suggested to make prior adjustments at the connecting parts due to difference in construction schedules.



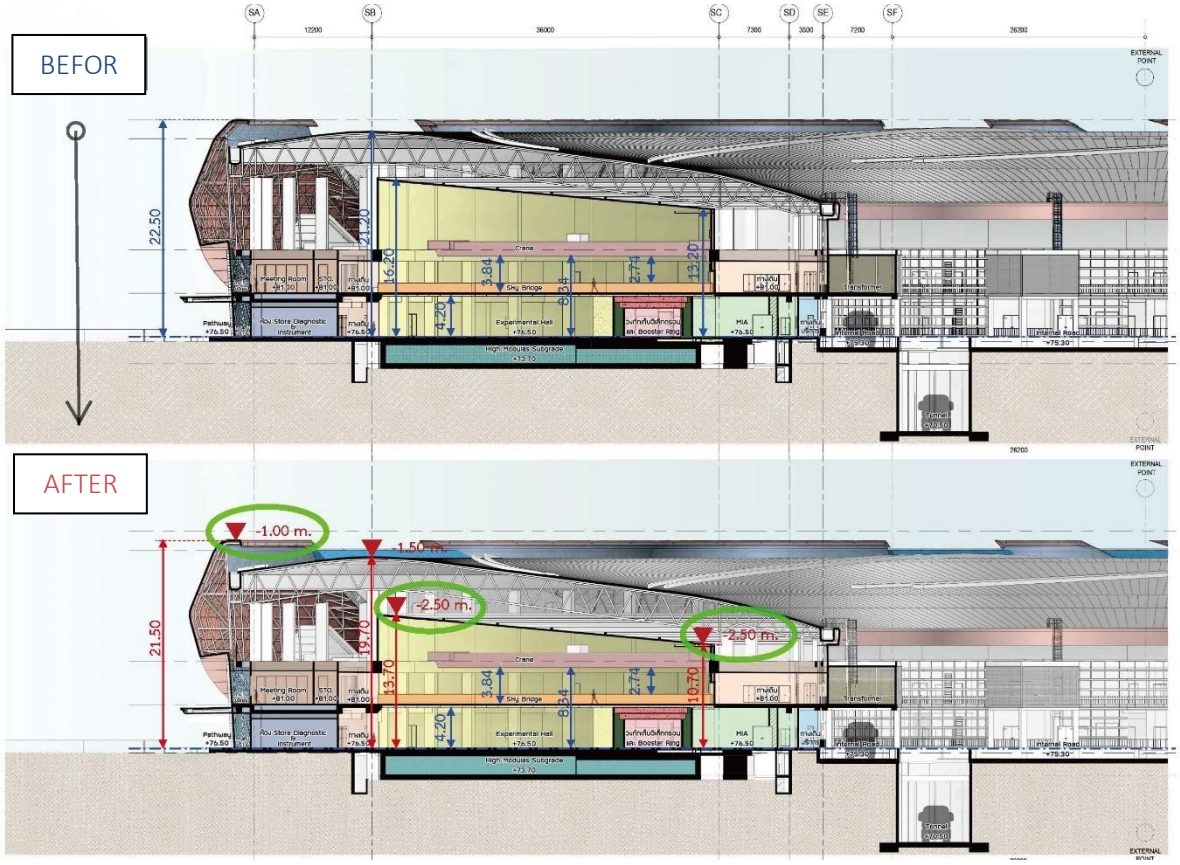
Source: SLRI

Figure 5-14 Access Points and Connecting Bridges (Left: 1F, Right: 2F)

(7) Review for the Floor Plan, Section, and Exterior Plan (for Synchrotron Building)

JST received feedback below from SLRI August 2024, and confirmed no concerns and uncertainties:

- Regarding the maintenance space for the synchrotron equipment, SLRI explained that 3.5 m for the accelerator and 1 m for the piping at the wall have been secured. Referring SIRIUS' specifications.
- SLRI has explained that the installation of an aerial bridge at 4.5m and a crane rail at 9m above the experimental space will not affect their experimental activities.
- The vibration generated from the delivery road and crane will not affect the synchrotron equipment, as they have a policy of not using them during experiments.
- Penetration treatment and vibration countermeasures have been appropriately taken at the radiation shielding wall and ceiling.
- JST has suggested shortening the minimum height of the experimental hall, as the high ceiling is costly. However, SLRI has explained that the space above the crane (around 5m) is necessary for temperature balance and humidity control. Nonetheless, SLRI proposed a reduction of 2.5m for the ceiling height, as it still includes extra space.
- JST has suggested an appropriate exterior grade for the research facility, and SLRI has accepted the offer and reconsidered the design. SLRI has proposed a reduction of 1m for the building height and has reduced the area of high-cost materials.



Source: SLRI

Figure 5-15 Proposed Reduction for the Stories-Height and Ceiling-Height

(8) Beamline

According to the plan of SLRI, of the 21 ID beamlines, No. 18-23 can be installed up to 70 m beamlines, and No. 3-9 and 9-24 can be installed up to 56 m beamlines.

The longest ID beamline of 60 m (SWAX), which will be installed in the first phase, will be installed at No. 19 (maximum 70 m).

(9) Local Construction Capabilities Survey

The synchrotron facility requires strict adherence to international quality control standards, and JST must ensure that local construction capabilities meet these standards. As reliable information was difficult to obtain from published materials and oral explanations, JST conducted direct interviews with practitioners and visited actual sites to confirm these capabilities.

1) Flat Slab

For general buildings, the error in concrete slab level is typically measured with an accuracy of ±5 mm over a single span (6-7 m). However, SLRI has required 5 mm or less over the entire 321 m storage ring tunnel. According to a local contractor, in the case of facilities that require smoothness in Thailand (for example, distribution centers: If the floor is not smooth, the displacement at the upper part of the

stepladder is large and interferes with work), it is common to outsource to a specialist in such type of construction. JST visited the construction site for the distribution center.

The concrete leveling machine is equipped with a monitor always senses the pouring concrete surface level, and if there is a difference of ±3 mm or more in the planned concrete slab level, a warning will sound and correction for the level will be made immediately. The work is performed every 100 m^2, but by repeatedly checking the level, even in a large space, the level difference can be suppressed to 3 mm or less. This equipment, manufactured in the USA, is used to achieve a flat slab. While handling the equipment requires specific know-how, JST confirmed that several local contractors can achieve the required level accuracy of less than 5 mm for this Project.



Source: JST

Figure 5-16 Flat Slab Construction (Left: Special Equipment, Right: Floor after Polishing)

2) Soil Improvement

Due to the change of site at the end of 2022, the foundation design has not been finalized yet, but it is crucial to secure stable ground and ensure foundation design in detailed design stage for the synchrotron facility. While pile construction is a commonly used method for buildings, ground improvement work is necessary depending on the ground's characteristics, so JST confirmed the procurement situation in Thailand.

Soil improvement methods commonly adopted in Thailand include Bearing Unit (placing a reinforced concrete slab on top of a grid of piles), Deep Cement Mixing (mixing cement with the soil using rotary auger and cement grout injection to create high-strength column), and Perforated Vertical Drain (inserting synthetic PVC strips vertically into the soft soil to provide drainage paths for water in the neighboring soil to move by capillary behavior). The Bearing Unit is the recommended method.

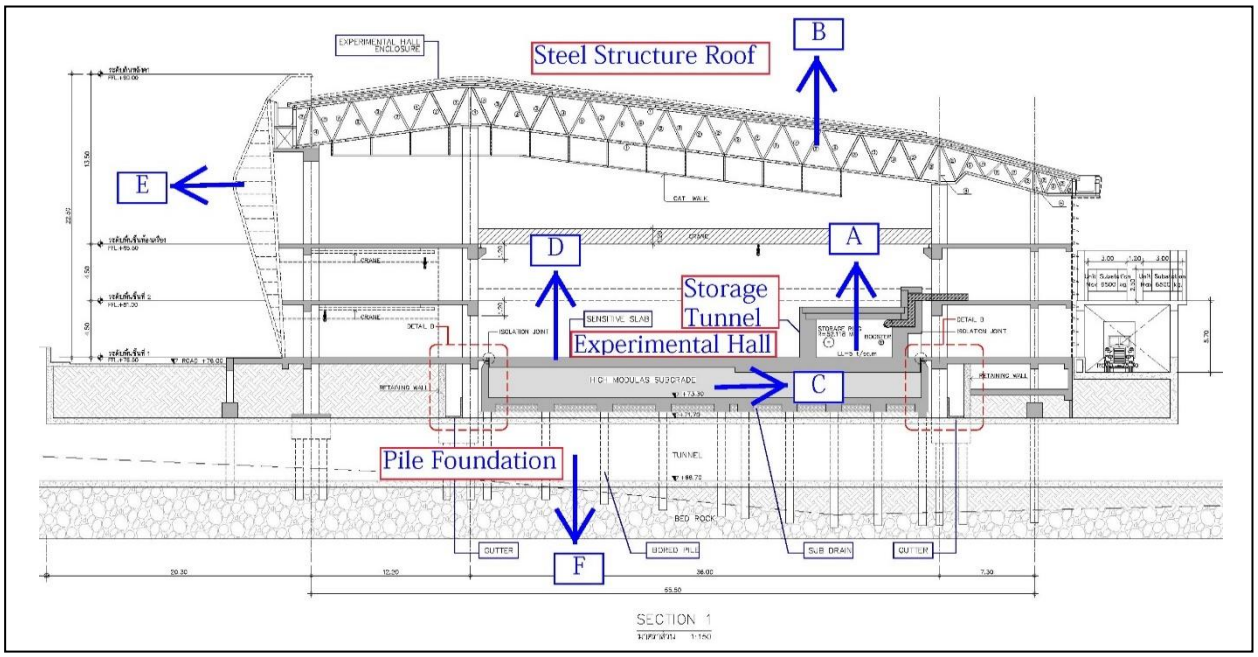
5.3.2 Structural Plan

(1) Current Status of Structural Design

Since the site was changed at the end of last year, the subsequent design changes based on the geological survey have not yet begun. Therefore, JST is unable to confirm the specific figures or detailed calculation results, and just offer feedback on the design concept and procedures.

(2) Building Overview (Synchrotron Building)

- Ground condition: The bedrock layer at GL-6 to 9m has been confirmed. The ground, including the upper part and topsoil, is mainly cohesive soil with an N value exceeding 20.
- Material properties
  - Concrete: Fc 27~31 N/mm2 (280~320 kg/cm2)
  - Rebar: D16~D32 SD50:Fy=490 N/mm2 (5,000 kg/cm2),
  - D12 SD40:Fy=390 N/mm2 (4,000 kg/cm2), φ6~φ9 SR24:Fy=235 N/mm2 (2,400 kg/cm2)
  - Steel: SS400 (TIS 1227-2539):Fy=235 N/mm2 (2,400 kg/cm2), SM 520 (TIS 1227-2539):Fy=348 N/mm2 (3,550 kg/cm^2)



Source: SLRI

Figure 5-17 Key Plan for Consideration Point on Structure Design

JST strongly suggests having a foundation with soil improvement in order to have a better stable ground. Pile and Ground-Improvement methods will be studied further in detail design stage.

(3) Live Load (A in Figure 5-17)

Live Loads are based on the Thailand standard, with the exception of special rooms which were provided by SLRI.

- Thailand Standard Live Loads
  - General rooms: 5,000 N/m2 (500 kg/m2)
  - Power supply/ Storage rooms: 50,000 N/m^2 (5,000 kg/m^2)
- Special Live Loads
  - Storage Tunnel: 50,000 N/m2 (5,000 kg/m2)
  - Experimental Hall: 10,000 N/m^2 (1,000 kg/m^2)

The crane's operating range and lifting capacity will be planned according to the specific conditions.

Table 5-3 Live Load List

น้ำหนักบรรทุกจร (Live Load)

	ประเภทพื้นที่	น้ำหนักบรรทุกจร (kg/sq.m)
1.1	พื้นที่ติดตั้งปืนยิงอิเล็กตรอน (Electron Gun) และท่อเร่งพลังงาน	5,000
2.1	วงกักเก็บอิเล็กตรอนและ Booster Ring	5,000
2.2.1	ห้อง Power Supply	5,000
2.2.1.1	Power Supply สำหรับ Bending - Storage ring	5,000
2.2.1.2	Power Supply สำหรับ Booster	5,000
2.2.1.3	Power Supply สำหรับห้องย่อยประจำ 14 Cell (1:2)	5,000
2.2.1.4	ห้อง UPS (สำหรับ Critical Load)	5,000
3.1	สถานีทดลองหลัก (Beamline)	1,000
3.2	สถานีทดลองส่วนต่อขยาย	1,000
4.1.1	Biological laboratory 1 - ห้องเตรียมตัวอย่างทางชีวโมเลกุลทั่วไป	500
4.1.2	Biological laboratory 2 - ห้องเตรียมตัวอย่างทางชีวการแพทย์	500
4.1.3	Chemical laboratory - ห้องเตรียมตัวอย่างทางเคมี	500
4.1.4	Micromachining laboratory 1	500
4.1.5	Micromachining laboratory 2	500
4.1.6	Optical laboratory - ห้องปฏิบัติการด้านทัศนศาสตร์	500
4.1.7	Physical & Materials laboratory - ห้องเตรียมตัวอย่างทางฟิสิกส์/วัสดุ	500
4.1.8	Surface science laboratory	500
4.1.9	ห้องเตรียมผลึกโปรตีน	500
4.1.10	ห้องทดสอบระบบเชิงกลและระบบควบคุม	500
4.1.11	ห้องประกอบ และทดสอบชิ้นส่วนสุญญากาศ	500
4.1.12	ห้องปฏิบัติการวิเคราะห์ผลการทดลอง + HPC	500
4.1.13	ห้องสโตร์กลางฝ่ายสถานีวิจัย	500
4.1.14	ห้องสถานีวิจัยร่วม	500
4.1.15	ห้องสำรอง (สำหรับปรับเป็นห้องปฏิบัติการ)	500
4.2.3	ห้องปฏิบัติการ Diagnostic & Instrument	500
4.2.4	ห้องสโตร์สำหรับ Diagnostic & Instrument	500
5.1	ห้องควบคุม (Control room)	500
5.2	ห้อง Data Center (Control server room)	500
5.3	ห้อง Control LAB	500
5.4	ห้อง Control Store	500
5.5	สำนักงานส่วนกลาง (ห้องปฏิบัติงานนักวิจัย และเจ้าหน้าที่)	250

หมายเหตุ :

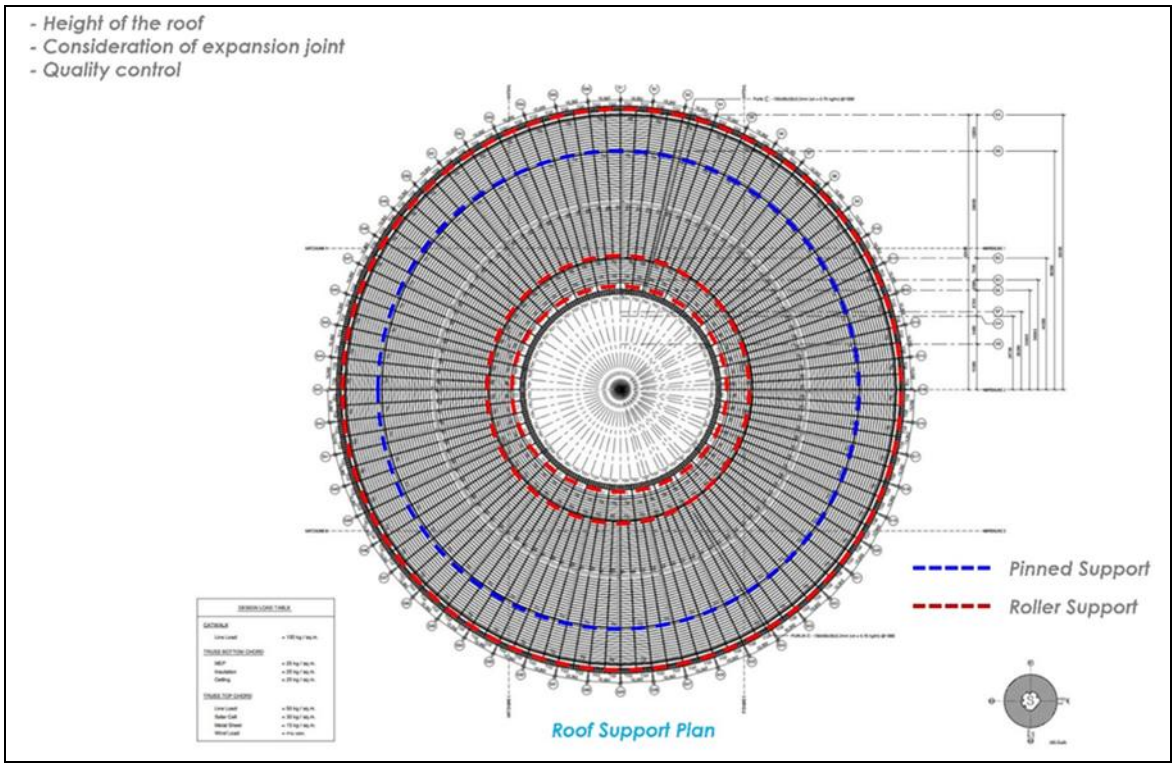
- บริเวณที่ต้องการน้ำหนักบรรทุกจร (Live Load) มีน้ำหนักมากเป็นพิเศษ จะมีการปรับเปลี่ยนน้ำหนักบรรทุกจรบริเวณนั้นๆ ให้เพียงพอและเหมาะสมกับการใช้งาน ในขั้นตอนถัดไป
- น้ำหนักบรรทุกคงที่นอกจากน้ำหนักของโครงสร้างตัวอาคาร (Superimposed Dead Load) จะมีการกำหนดน้ำหนักให้เพียงพอและเหมาะสมกับการใช้งาน ในขั้นตอนถัดไป
- สำหรับประเภทพื้นที่ 1.1 – 3.2 มีการออกแบบเป็นพิเศษตามมาตรฐานการสั่นสะเทือนระดับ VC-E และการทรุดตัวไม่เกิน 100 ไมโครเมตร/10 เมตร ต่อ 1 ปี

DESIGN+DEVELOP WEP

Source: SLRI

(4) Structural Truss Frame (B in Figure 5-17)

- Review of current design
  - The height and truss structure were determined by Architectural design. The unnecessary height spaces were adjusted.
  - The catwalk located below the truss structure was relocated.
  - Avoid complicated structural designs and attempt to reduce costs.
  - Since there was no roof expansion joint, so planned to provide it.
- The preliminary analysis in temperature deviation was very small and was not further studied in the detailed design.
- Additional considerations
  - Lowering the roof height results in a reduction of the required structural members and especially the architectural wall materials, leading to a further cost reduction. SLRI approve in lowering the height and will be included in the detailed design.
  - A roof of this size, the installation of an expansion joint (Exp. J) was planned, taking into consideration the effects of temperature changes, wind pressure, and horizontal loads.

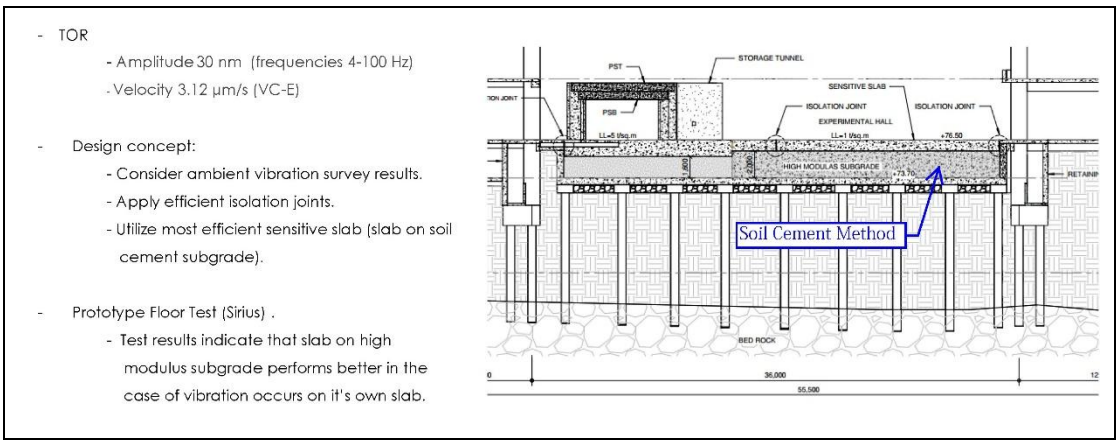


Source: SLRI

Figure 5-18 Steel Roof Plan

(5) Micro Vibration Countermeasures (C in Figure 5-17)

- Review of current design
  - Storage Tunnel and Experimental Hall was designed to be isolated by ① inserting an expansion joint between the building shell and by ② installing a soil-cement under these rooms.
  - Instead of conducting a detailed calculation, the design was based on comparisons with different existing SRFs around the world.
  - The type of bottom support was based on the one used in SIRIUS (Brazil)
  - The soil-cement method was employed to prevent moisture release from the soil, increase its strength, and enhance its elasticity.
  - Despite being cheaper, the Gravel method was not used, as it is of lower quality compared to the soil-cement method.
  - Although the required velocity (VC-E) within 3.12 μm/s required by SLRI was satisfied, the amplitude of less than 30 nm was not achieved yet.
- Additional considerations
  - The current EXP.J location is generally judged as acceptable.
  - The concept of the structure is referred from other projects, and the effect in this specific plan is currently unknown. SLRI approved for further confirmation during the detailed design stage.
  - The use of a mat slab with direct piles installed below it as the isolation base is the original plan, but JST strongly suggest having a mat slab with soil improvement to have more stable ground. The vibration transmission rate needs to be evaluated as there is no formal report on the vibration design, this will be addressed in the future detailed designs.
  - Further detailed analysis is required for the design of the soil cement construction method planned in the design. The selection of the foundation method under the Storage Tunnel and Laboratory Hall should be based on specific criteria, rather than solely comparing with other projects. It is crucial to verify the suitability of the review document for the site of this Project.



Source: SLRI

Figure 5-19 Micro Vibration Countermeasures

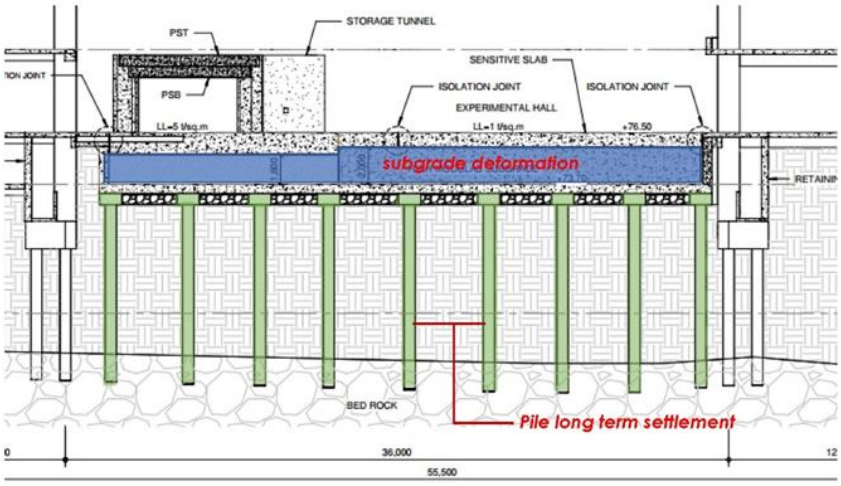
(6) Vertical Displacement of Structure (D in Figure 5-17)

- Review of current design
  - Slab deflection criteria are in accordance with the Thailand standard, except for the special rooms which were provided by SLRI.
  - According to SLRI's request, the accuracy of the finishing level of the 1F floor should be ±5 mm or less. According to the information from a local construction company, the general finishing target value for local construction is about ±3 mm.
  - According to SLRI's requirements, the vertical displacement of the foundations+1FL slabs of Beam line, Ring tunnel and Experimental area must not exceed 100 μm/ 10 m/ year.
  - Building foundation is designed to be supported by a rock layer with no settlement.
  - The new geotechnical survey indicates that bedrock with an N-value of 50 or higher is located at approximately GL-5.0 to 9.0 meters (in a sloping layer).
  - The structural design was redesigned based on the new soil investigation survey report, as the site location has been changed.
- Additional considerations
  - No methods have been planned to achieve the deflection tolerance for the Storage Tunnel and Experimental Hall, and it is necessary to evaluate a method that it is within the allowable tolerance. This was approved by SLRI to be considered in the future redesign stage.
  - The displacement of 0.1mm/10m/year also considers the concrete creep effect.
  - If the upper part of the building is a steel structure, and the bottom is reinforced concrete structure with a short foundation height (1.0 to 3.0 meters) and has a large cross-section, then the vertical load acting on it would be relatively low. As a result, it is considered highly unlikely that the foundation will experience significant creep. Therefore, it is reasonable to limit the creep-induced vertical deflection of beams and slabs to 0.1mm/10m/year or less.

- TOR, floor deformation < 100 μm/ 10 m/ year

- Design concept :
  - Stiff supporting layer at pile tip.
  - Hight modulus and consistent subgrade for the sensitive slab.

- Settlement calculation of the whole structural system to be calculated to confirm the TOR.
  - Pile long term settlement
  - Subgrade (Soil-cement) long term deformation.



Source: SLRI

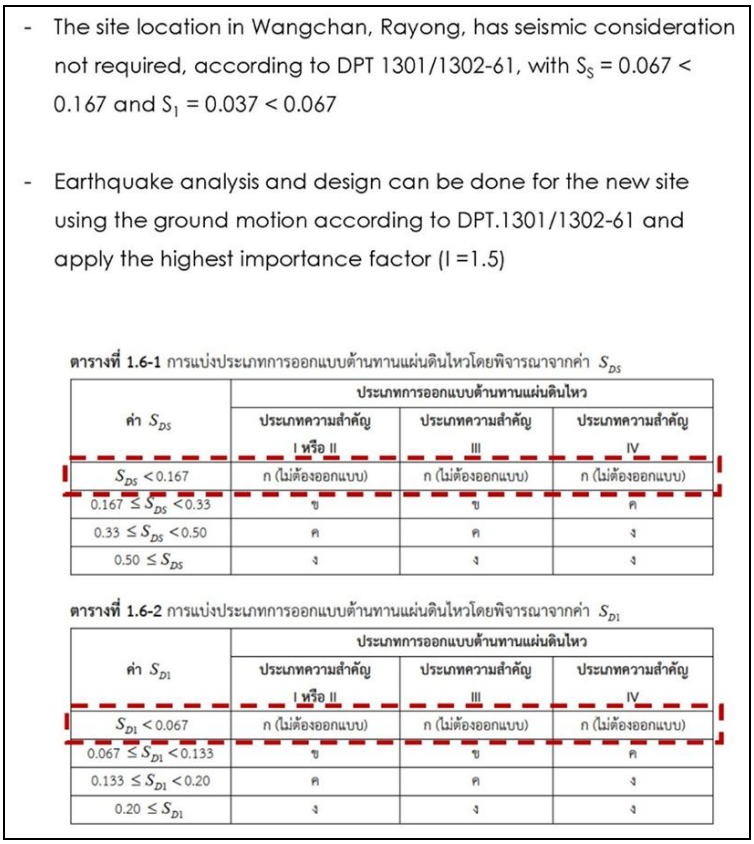
Figure 5-20 Vertical Displacement Countermeasures

JST strongly suggest having a foundation with soil improvement in order to have a more stable ground. Pile and Ground-Improvement method will be studied further in detail design stage.

(7) Earthquake and Wind Design (E in Figure 5-17)

- Review of current design
  - The earthquake and wind design for this Project generally adhere to standard practices, in accordance with DPT. 1301/1302-61 (Thailand standard). Based on this standard, earthquake design is not required for the project's location. However, considering the importance of the building, seismic forces were evaluated based on the earthquake data for this region.
  - Wind design, which considers vibration and deflection, follows the standard building codes.
  - According to the design, horizontal deformation, such as wind load, is only 0.8 mm (H/500), which is extremely small and should be confirmed in the detailed design calculation.
- Additional considerations
  - Buildings with special requirements and functions should be designed with additional considerations beyond standard requirements, hence the building's performance must exceed the minimum requirements set by law. This is particularly important as a rare earthquake event could result in severe damage to critical equipment, which would be costly and wasteful.

- In terms of wind design, it is desirable to increase the current wind load (500-year Return Period, etc.) to account for worst-case scenarios and to ensure the safety of the building in its lifetime. Approved by SLRI to consider in the detail design.
- In all cases, the vertical deflection of the building must be within permissible limits.
- SLRI approved all the above changes and will be included in the detailed design.



- The site location in Wangchan, Rayong, has seismic consideration not required, according to DPT 1301/1302-61, with $S_S = 0.067 < 0.167$ and $S_1 = 0.037 < 0.067$

- Earthquake analysis and design can be done for the new site using the ground motion according to DPT.1301/1302-61 and apply the highest importance factor (I =1.5)

ตารางที่ 1.6-1 การแบ่งประเภทการออกแบบต้านทานแผ่นดินไหวโดยพิจารณาจากค่า S_{DS}

ค่า S_{DS}	ประเภทการออกแบบต้านทานแผ่นดินไหว		
	ประเภทความสำคัญ I หรือ II	ประเภทความสำคัญ III	ประเภทความสำคัญ IV
$S_{DS} < 0.167$	ก (ไม่ต้องออกแบบ)	ก (ไม่ต้องออกแบบ)	ก (ไม่ต้องออกแบบ)
$0.167 \le S_{DS} < 0.33$	ข	ข	ค
$0.33 \le S_{DS} < 0.50$	ค	ค	ง
$0.50 \le S_{DS}$	ง	ง	ง

ตารางที่ 1.6-2 การแบ่งประเภทการออกแบบต้านทานแผ่นดินไหวโดยพิจารณาจากค่า S_{D1}

ค่า S_{D1}	ประเภทการออกแบบต้านทานแผ่นดินไหว		
	ประเภทความสำคัญ I หรือ II	ประเภทความสำคัญ III	ประเภทความสำคัญ IV
$S_{D1} < 0.067$	ก (ไม่ต้องออกแบบ)	ก (ไม่ต้องออกแบบ)	ก (ไม่ต้องออกแบบ)
$0.067 \le S_{D1} < 0.133$	ข	ข	ค
$0.133 \le S_{D1} < 0.20$	ค	ค	ง
$0.20 \le S_{D1}$	ง	ง	ง

Source: SLRI

Figure 5-21 Region's Earthquake S-wave

(8) Necessity for Ground Improvement (F in Figure 5-17)

- Review of current design
  - The current design plan is to have piles and ground improvement of about 3m above. A decision will be made at the next design stage based on the results of a geological survey of the new site.
- Additional considerations
  - No detailed study has been conducted about the potential impact on the building of microtremors, etc., and approved to consider it in the future detailed design stage.
  - Regarding the ground condition of the new site, the supporting layer is confirmed to be a bedrock layer with a height of approximately GL-6 to 9m. The upper part of the ground, including the topsoil, is made up mainly of clayey soil with an N value of over 20. A groundwater level has been confirmed near the top of the bedrock layer, but if the building

foundation can be firmly supported by this bedrock layer, it is judged that there will be no concern about subsidence.

- Also, since the bedrock that is the supporting layer is shallow (about GL-10m), direct foundation and ground improvement is the appropriate construction method.

5.3.3 Electrical Plan

(1) Power Distribution System

Power is received at 22 kV from the power company PTT and then distributed to each building. Our plan is to use loop wiring for the main line and ensure that the power supply remains uninterrupted during maintenance or renewal of the main line. There are three main lines: LOOP 1 for the heat source building, LOOP 2 for the synchrotron, and LOOP 3 for general building power supply and future use.

It is planned to install four 2000kVA generators. Although the voltage of the generator is 400V, it will be boosted to 22kV and connected to the mains. Additionally, uninterruptible power supplies (UPS) are to be installed in various places to supply stable power to the synchrotron and experimental equipment.

(2) Transformer Design Concept

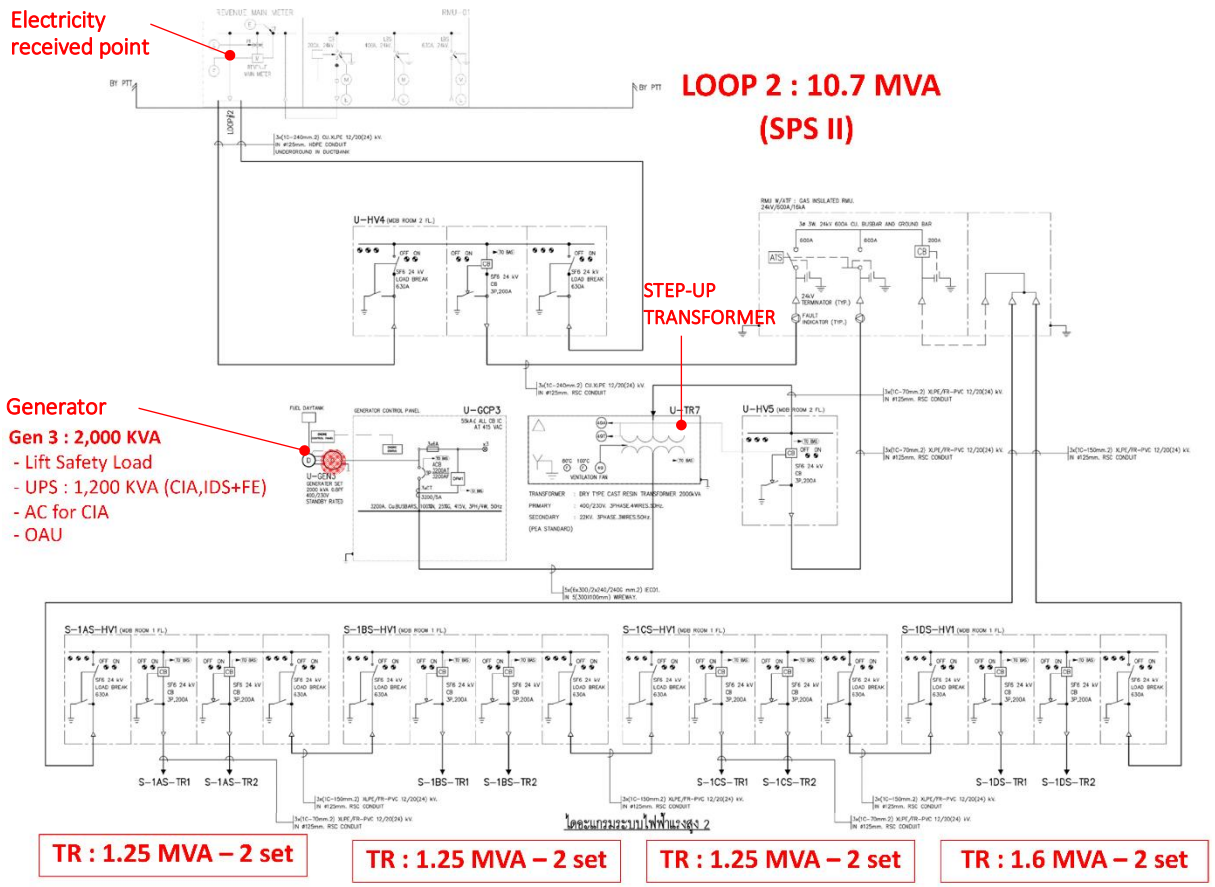
The current design includes a single 30MVA transformer, however, it is recommendable to install two instead, which will be confirmed in detailed design stage. In the case of a single unit, when a power outage would result in a complete loss of power, and even if a generator or UPS (uninterruptible power supply) is available, their capacity could be too large to be able to adequately supplement. Thus, by connecting two transformers and utilizing them, the power receiving facility becomes more stable and reliable

(3) Capacity of Engine Generator

A capacity for each generator is confirmed to be calculated based on the breakdown of each load and covered area.

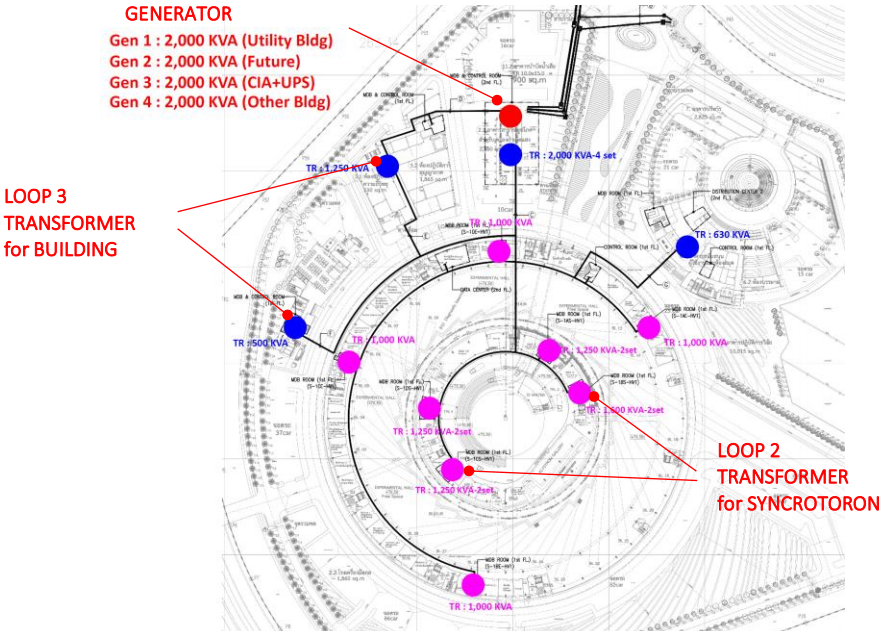
(4) Capacity of UPS

UPS will be installed for equipment which cannot tolerate any power failure. If power is restored within one minute of a power outage, equipment that is still operational will be powered by the generator.



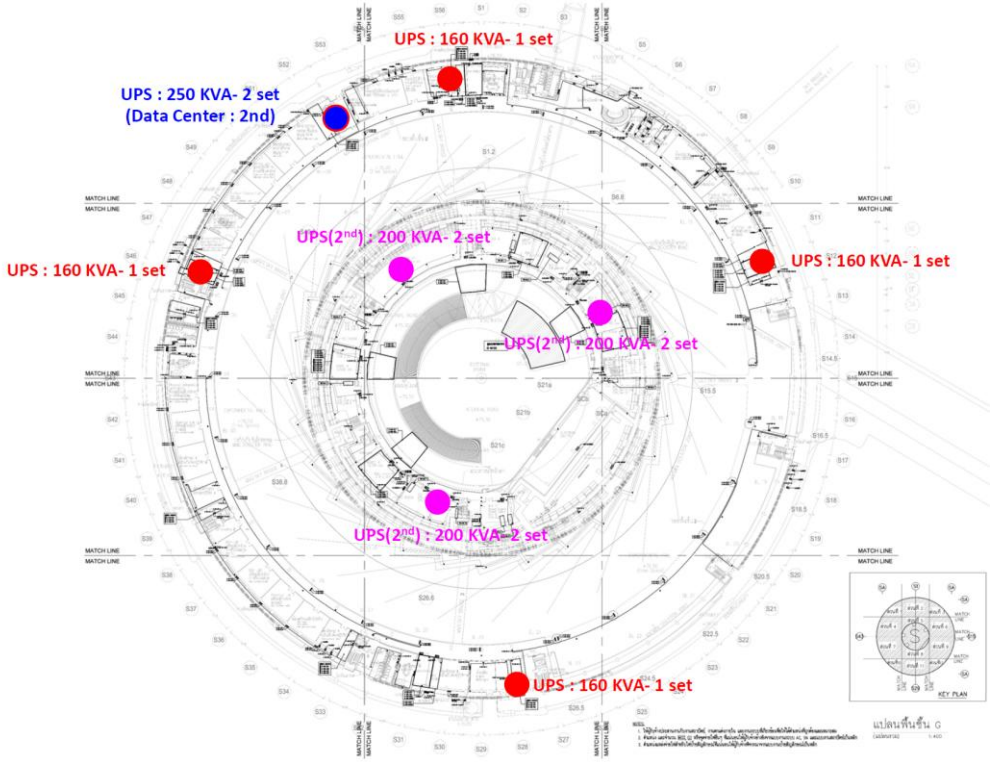
Source: SLRI

Figure 5-22 Single Line Diagram (LOOP 3)



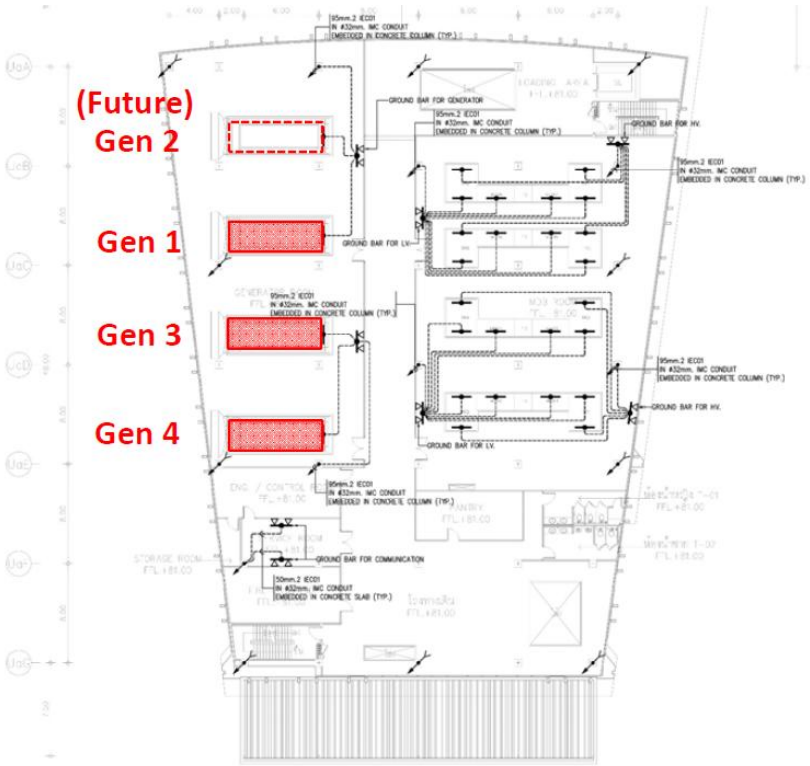
Source: SLRI

Figure 5-23 Layout for Generator and Transformer



Source: SLRI

Figure 5-24 Layout for UPS



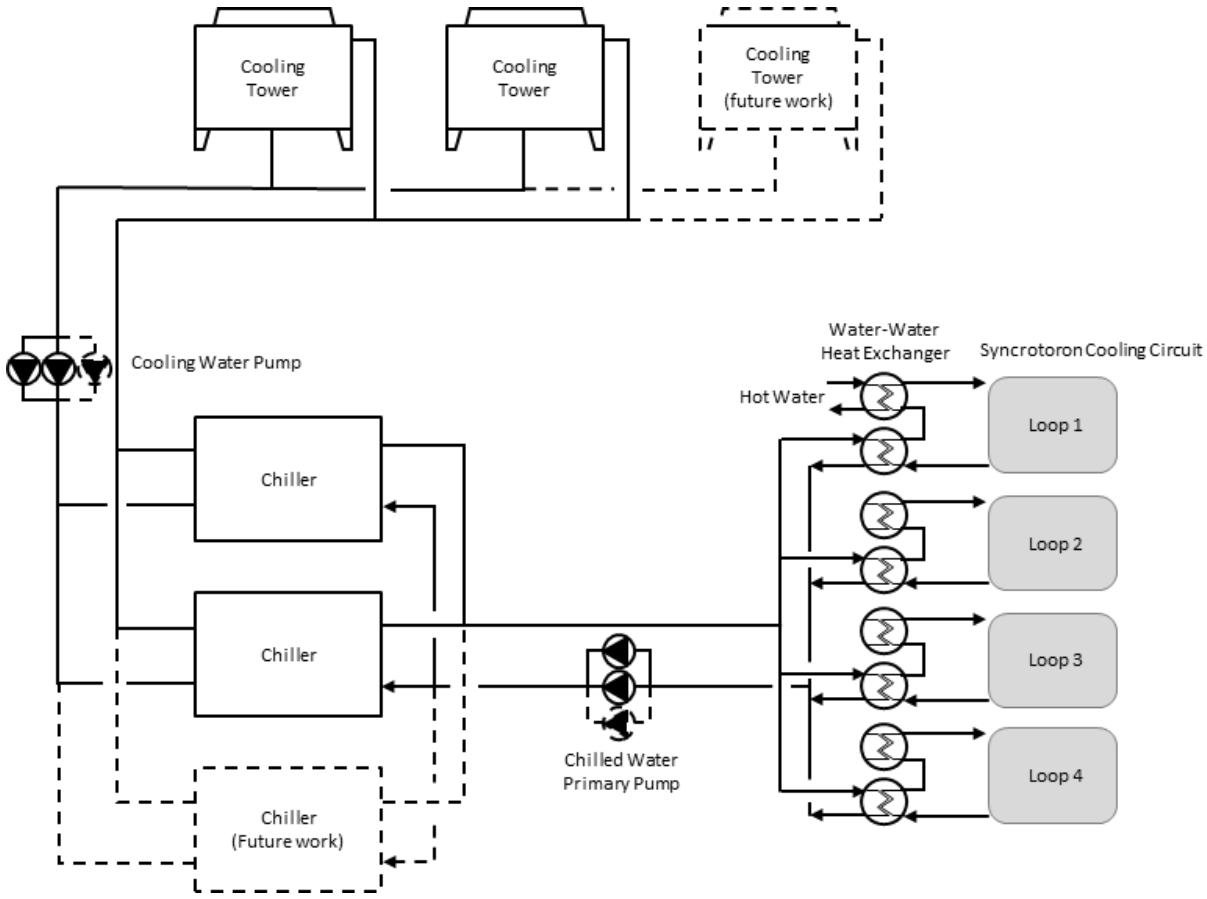
Source: SLRI

Figure 5-25 Layout for Generator

5.3.4 Cooling Plan

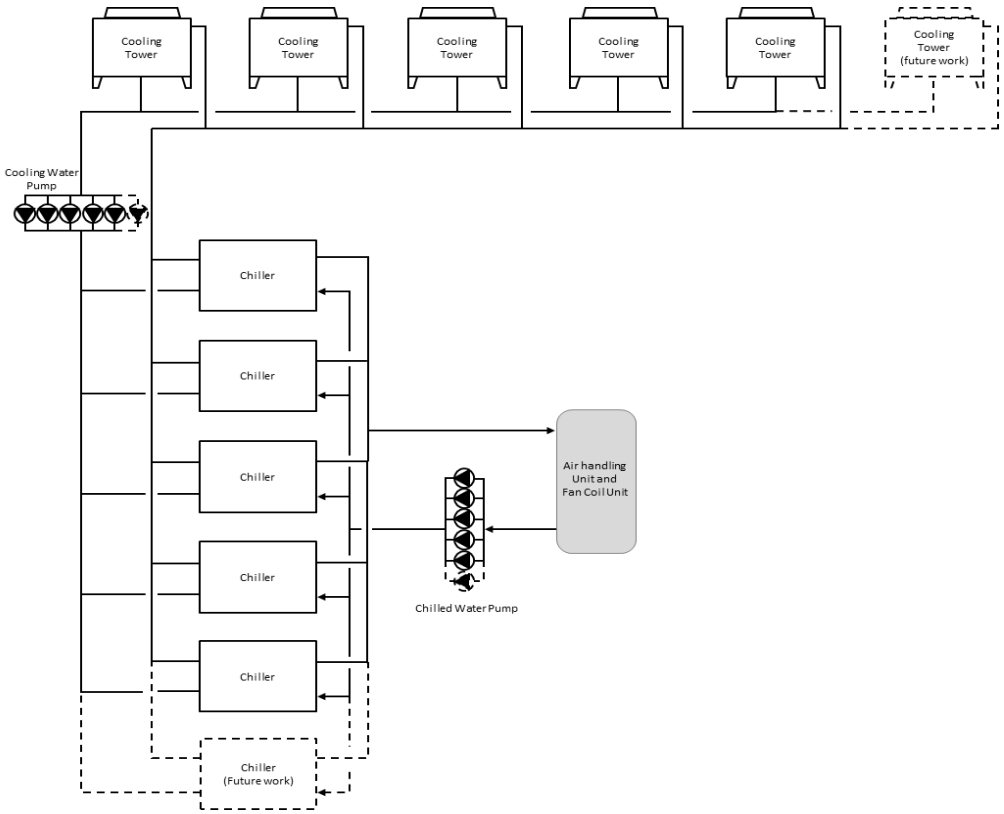
(1) Chilled Water Source

- One 1,000RT water-cooled turbo chillers are installed in the Energy Building as heat sources for cooling the synchrotron, and prepared extra space for one additional chiller in the future.
- The cold water on the primary side taken out from the chillers has a temperature of 7° C appropriately and is cut off from the secondary side via a heat exchanger. Regarding the cooling water temperature on the secondary side, it includes one system with a temperature range of 40°C ± 0.1°C and three systems with a temperature range of 25°C ± 0.1°C, which are employed for the cooling water of the synchrotron equipment. In addition, to ensure that the temperature of the cooling water on the secondary side remains constant, a hot water exchanger is installed.
- The cooling water on the secondary side uses DI water, and it is planned that 5 to 10% of the circulation amount will be replaced with newly produced DI water.
- In addition, the Energy Building is equipped with five 1,000RT water-cooled turbo chillers for building cooling, with one unit kept as a spare (In the future, one more unit will be installed). The chilled water pump distributes cold water to each air conditioner and fan coil unit, maintaining the temperature of the chilled water at 7°C.



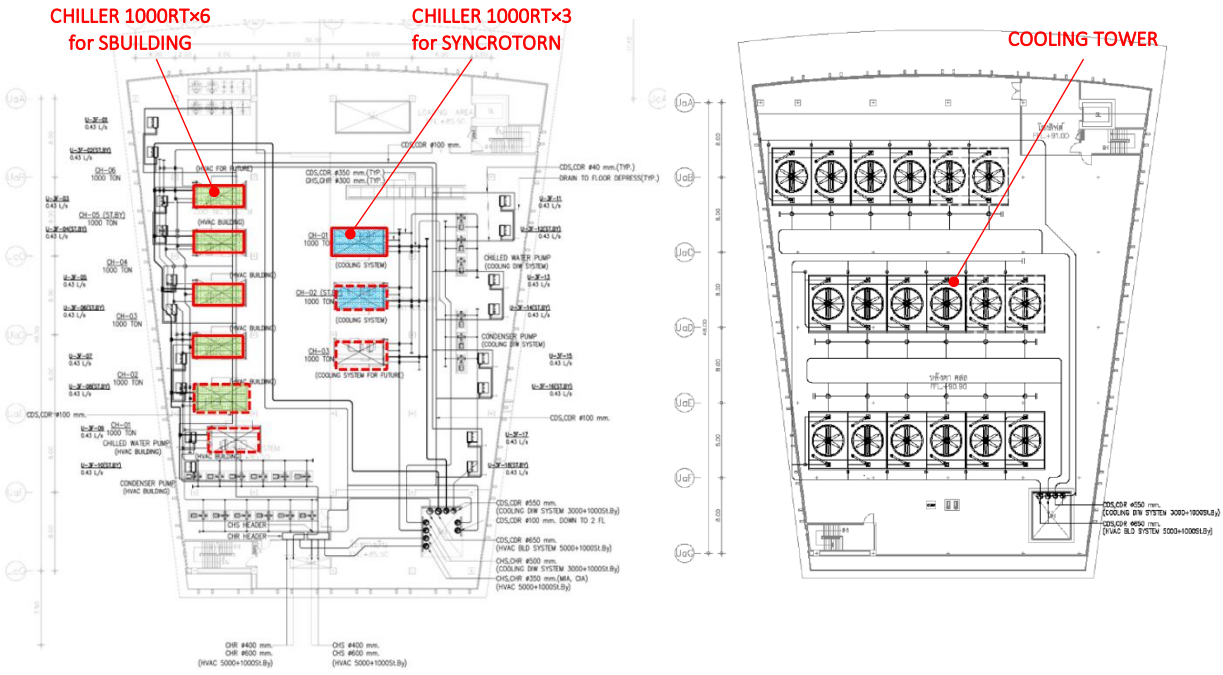
Source: SLRI

Figure 5-26 Synchrotron Cooling Water System Diagram



Source: SLRI

Figure 5-27 Building Cooling Water System Diagram



Source: SLRI

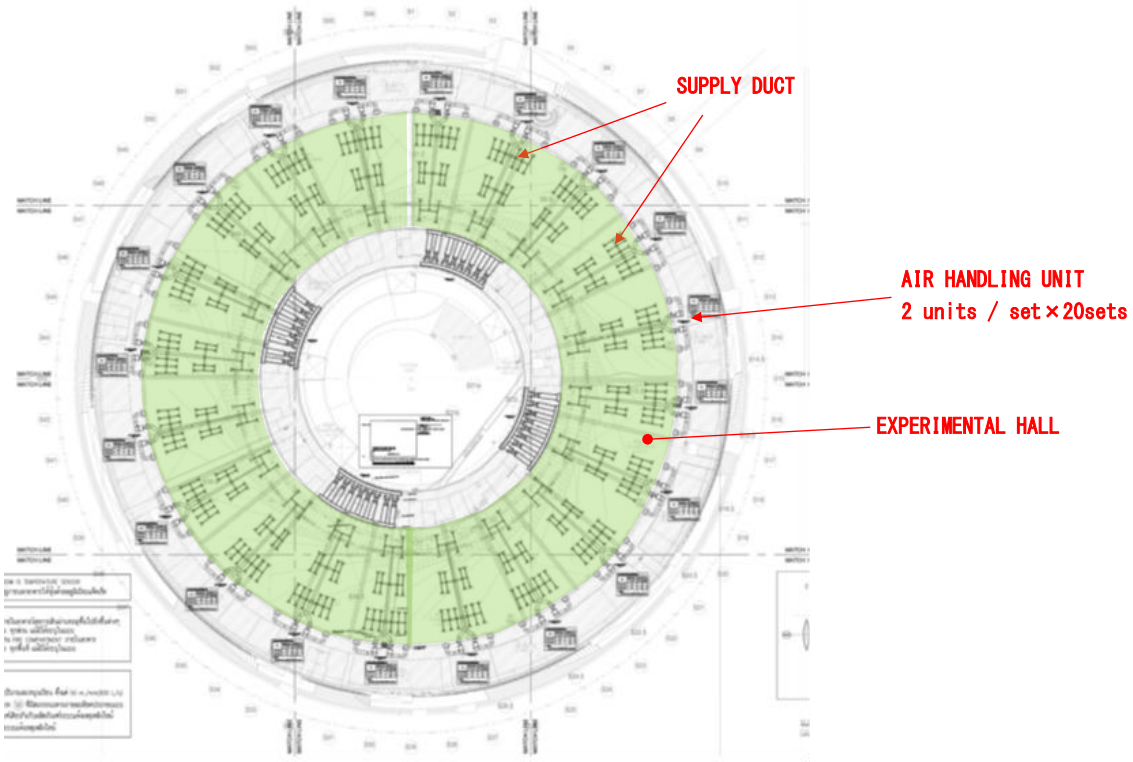
Figure 5-28 Utilities Building Plan (Left: for Chiller, Right: for Cooling Tower)

(2) Air Conditioning

1) Temperature and Humidity Setting

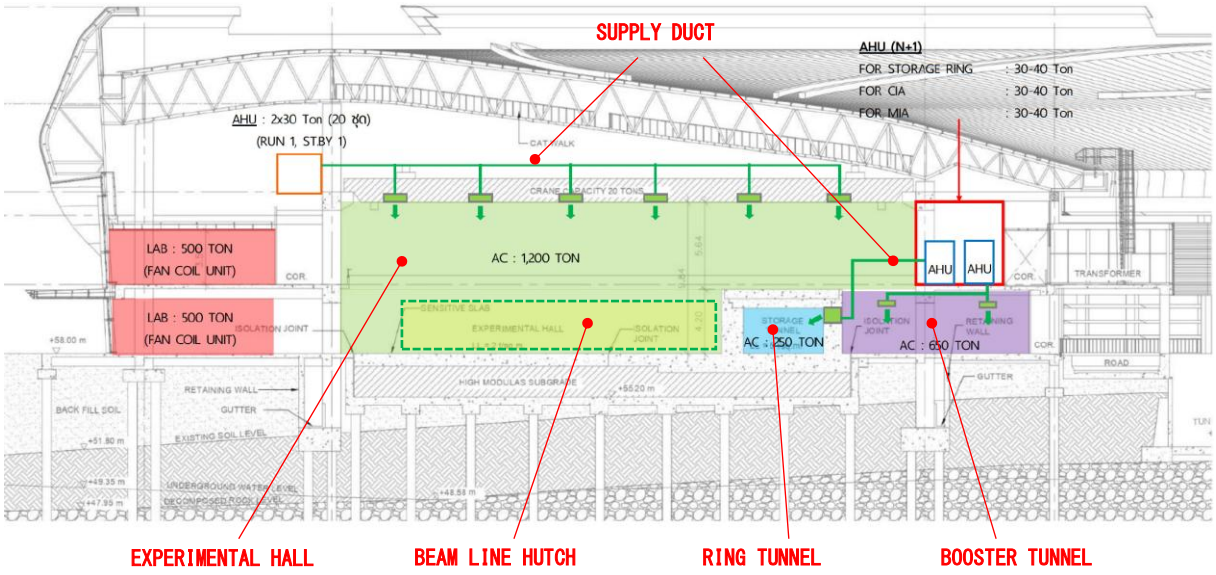
The temperature and humidity conditions of each room are 25.0±0.1℃ and 50±5% for Linac tunnel, Storage ring and Booster Synchrotron Tunnel (Beamline Hutch), and 25.0±1.0℃ and 55%±5% for the experimental hall.

These rooms are cooled by an air conditioner + single duct system. The ring tunnel is cooled by 45 air conditioners installed inside the ring, while the experimental hall is cooled by 40 air conditioners installed outside the ring. A two-way valve is provided for the air conditioner's cold water, and an indoor temperature sensor controls its degree of opening to maintain a constant room temperature.



Source: SLRI

Figure 5-29 Air-Conditioning Duct in Experimental Hall



Source: SLRI

Figure 5-30 Air-Conditioning Duct in Ring Tunnel

2) Anti-Vibration Suspension

Since the equipment inside Linac tunnel and Storage ring is extremely sensitive to vibration, the ducts and pipes installed in the vicinity are fixed using vibration-isolating materials.

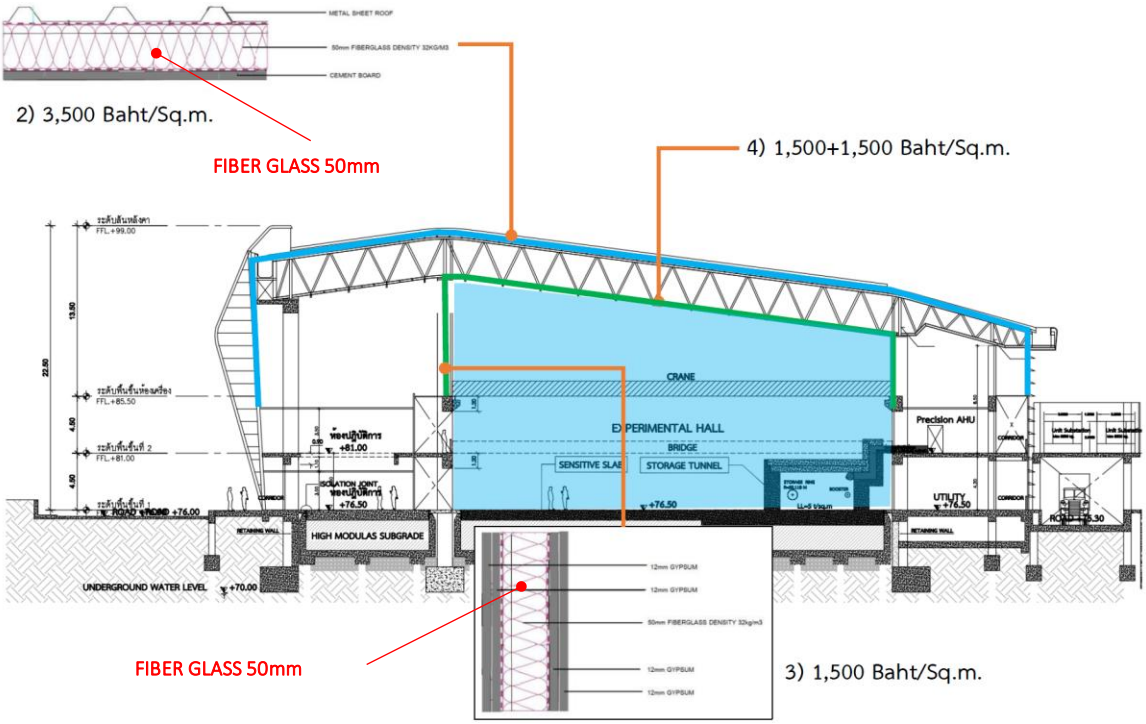


Source: SLRI

Figure 5-31 Anti-Vibration Suspension (Left: for Pipes, Right: for Ducts)

3) Insulation Plan

The synchrotron facility is located in an area with strict natural temperature and humidity conditions. Therefore, it is necessary to insulate the exterior walls to reduce susceptibility to external disturbances. In particular, the high temperature in the region throughout the year requires that sufficient insulation is provided for reducing operating costs. To achieve this, the project utilizes building materials with 50mm of glass wool sandwiched between the roof and walls, and double-skinned with an air layer in between.

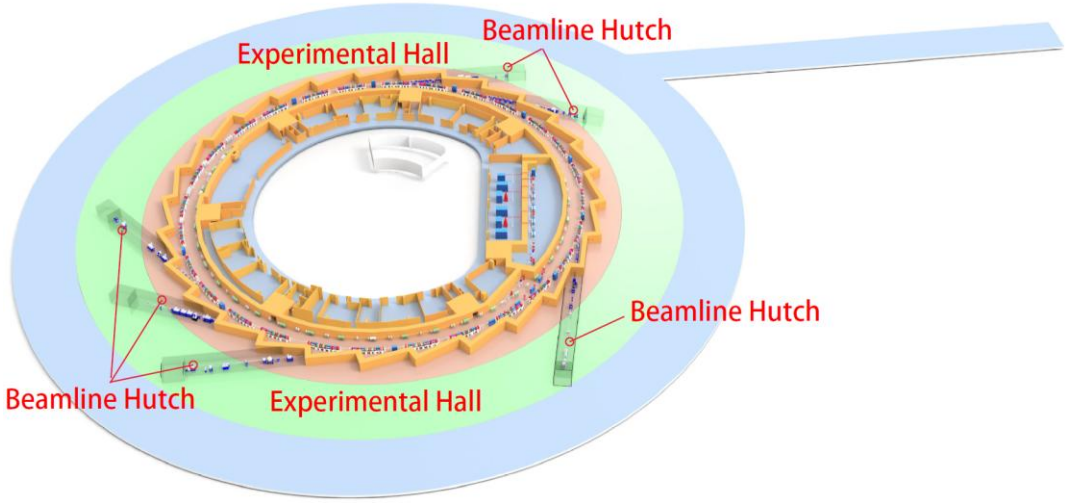


Source: SLRI

Figure 5-32 Insulation Plan Building Section

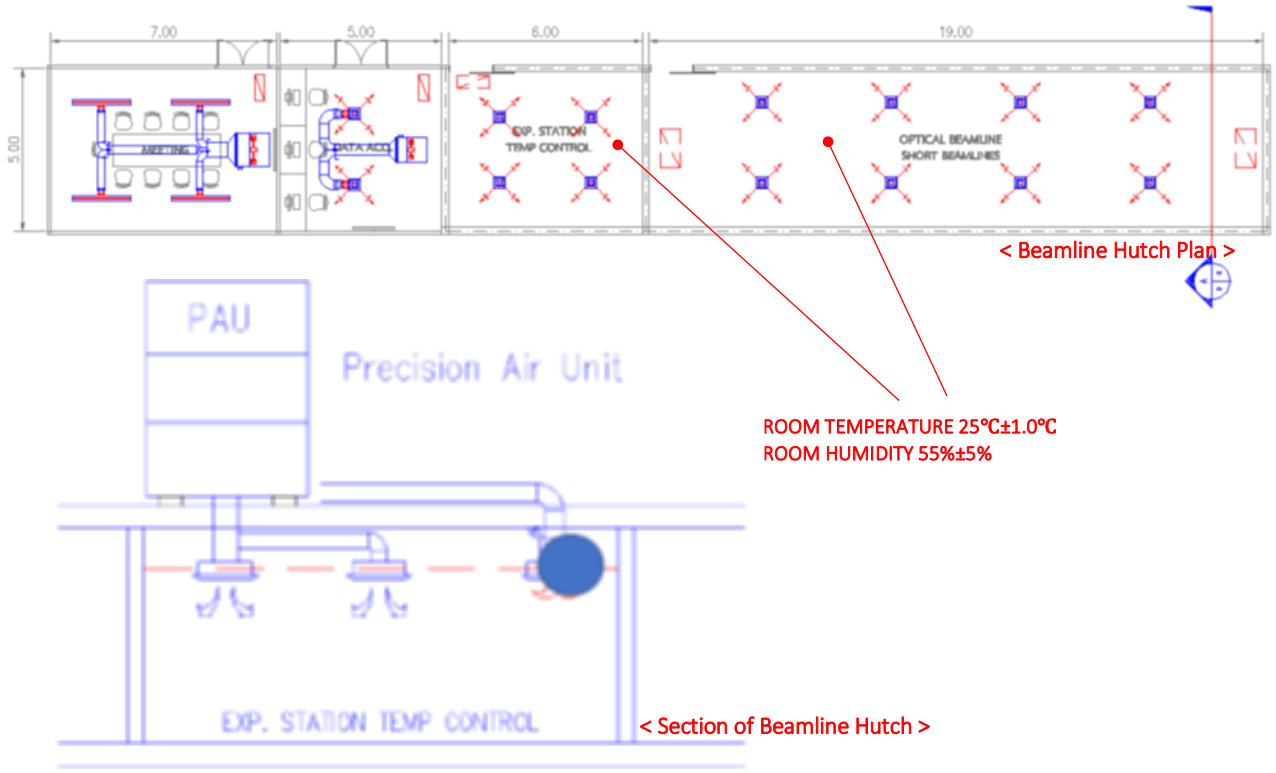
4) Temperature and Humidity Control for Beamline Hutch

A container room known as a beamline hutch is installed in the experimental hall and is designed to be controlled to a temperature of ±1.0°C, as required. Since it is installed in the experimental hall, which air-condition system has an accuracy of ±1.0°C, it is minimally affected by fluctuations in the outside temperature, making it an ideal spatial configuration.



Source: SLRI

Figure 5-33 The Layout of Beamline Hutch



Source: SLRI

Figure 5-34 Diffuser Plan for Beamline Hutch

(3) Automatic Control System and Central Monitoring System

All equipment undergoes temperature and humidity control, water volume control, operation monitoring, operation, and alarm issuance through an automatic control system and central monitoring system.

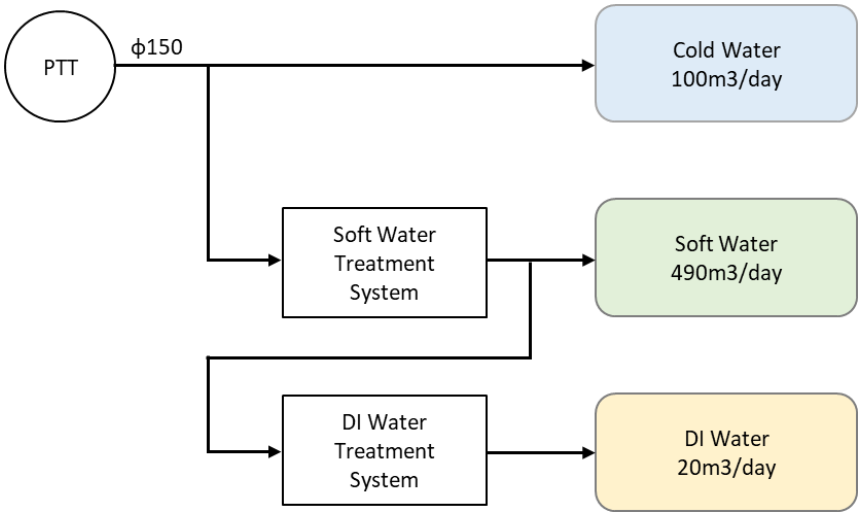
(4) Points of Consideration

- In room temperature control, there are many areas where an accuracy of ±0.1°C is required, so it is necessary to consider the position of the air valve, the room temperature sensor, and the control accuracy of the two-way valve.
- The high ceiling of the experimental hall and the air conditioning blowing from the ceiling surface can cause instability in the room temperature. However, this issue can be mitigated by installing a beamline that requires strict and proper room temperature control from a beamline hutch within the experimental hall.
- The humidity condition in areas such as Linac tunnel and Storage ring is set to 50%±5%. However, an additional dehumidification system is required to maintain this condition.
- The air conditioning system for the beamline hutch room is unclear based on the current documents. The detailed plan will be confirmed in the detailed design stage.
- It is important to consider the shape of the penetration part of the removable ceiling slab of Storage ring since a thick air-conditioning duct is planned to pass through this part. This is necessary to ensure proper radiation shielding. The details will be reconfirmed in the detailed design stage.

5.3.5 Plumbing

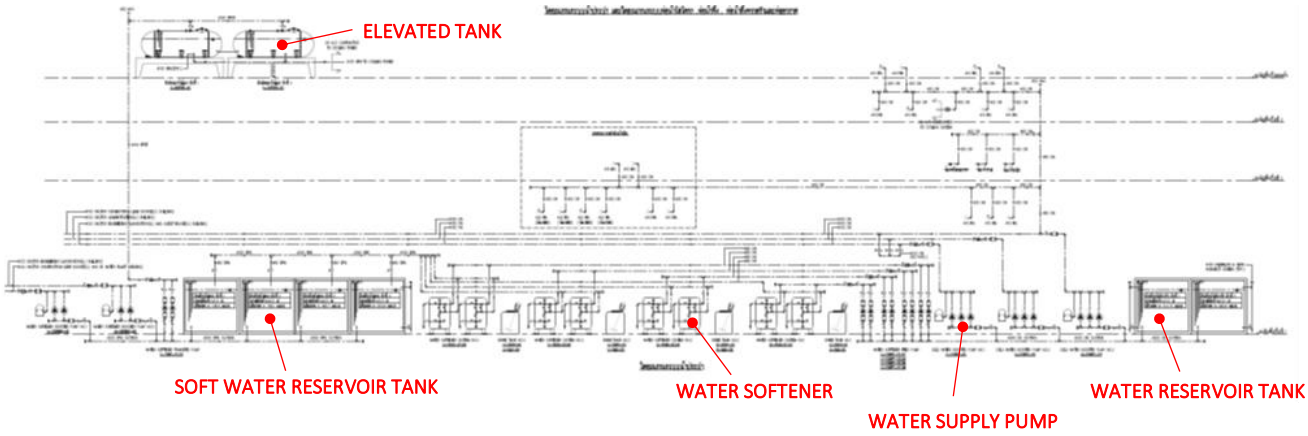
(1) Water Supply System

City water will be brought into the site from the PTT at a φ150 and temporarily stored in two water tanks, at the northern side. After that, water is distributed to each building as domestic water by three pressure pumps. A portion of the water is softened and stored in four soft water reservoir tanks, and then sent as cooling tower make-up water by two systems of pressure pumps. The softened water is also sent to the DI water production system, purified, and then used as make-up water for the four synchrotron cooling water systems. The capacity of the water receiving tank is designed for two days.



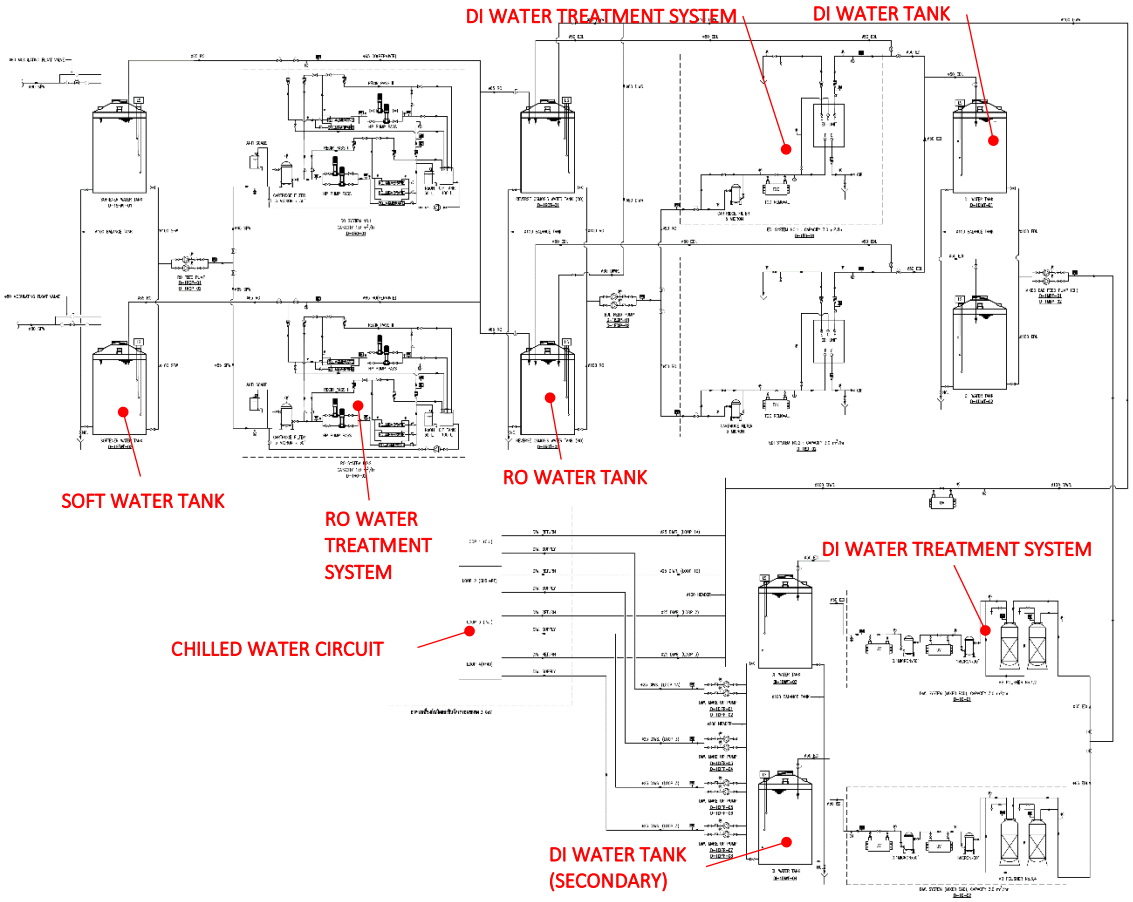
Source: SLRI

Figure 5-35 Water Supply Flow Diagram



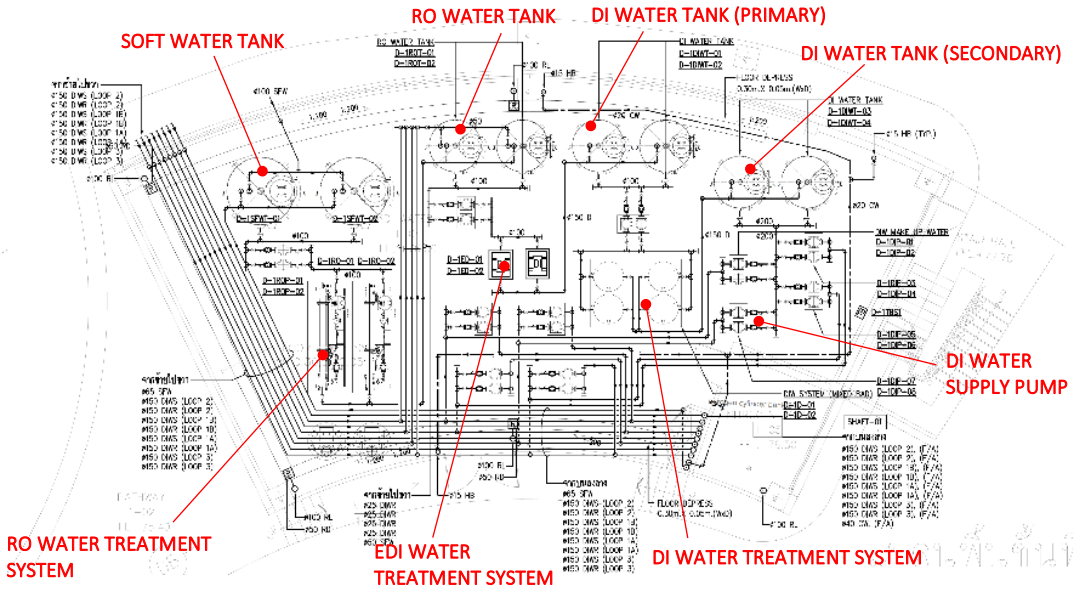
Source: SLRI

Figure 5-36 Water Supply System Diagram



Source: SLRI

Figure 5-37 DI Water Treatment System Machine Flow

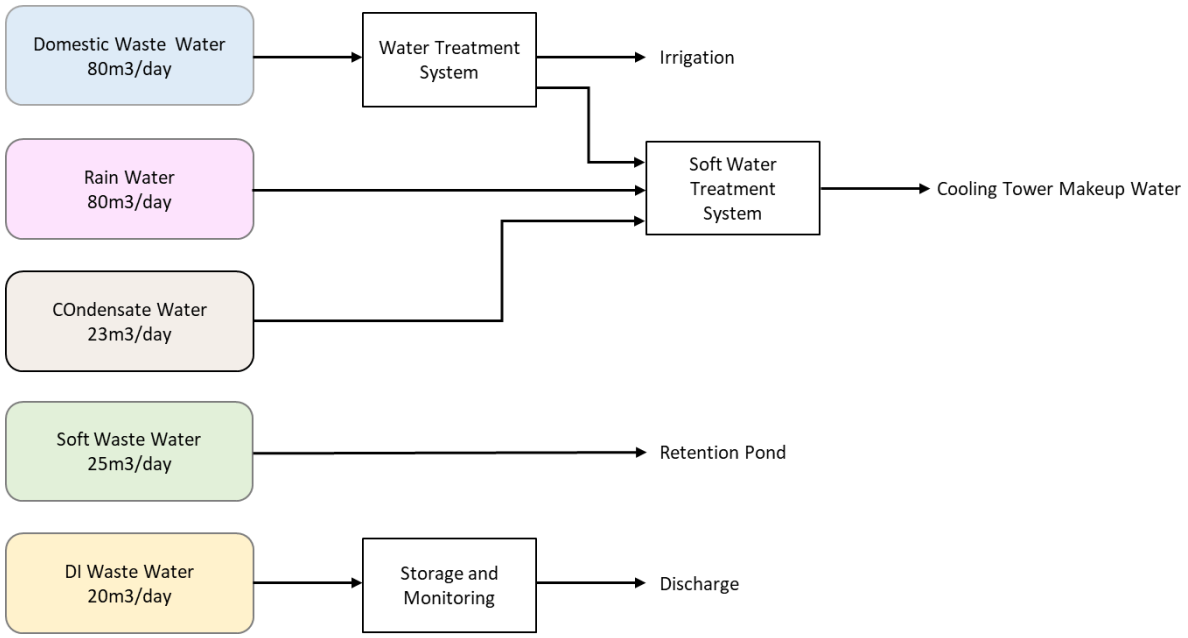


Source: SLRI

Figure 5-38 DI Water Treatment System Machine Room Layout

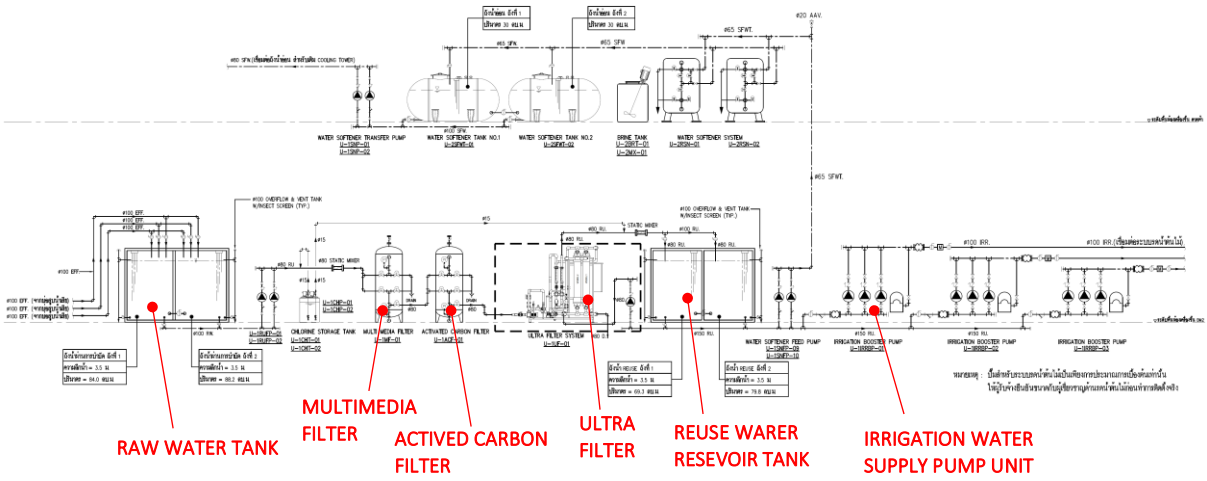
(2) Drainage Equipment

Domestic wastewater discharged from each facility is treated in septic tanks installed in about 10 locations. Experimental wastewater is neutralized by a neutralization device installed in each facility, and then treated in a septic tank by combining it with domestic wastewater. After the treated wastewater is temporarily stored in a wastewater tank, it undergoes advanced treatment at a wastewater treatment facility. Excess drainage will be discharged from the north side of the site into the rainwater drainage channel.



Source: SLRI

Figure 5-39 Drainage Flow Chart

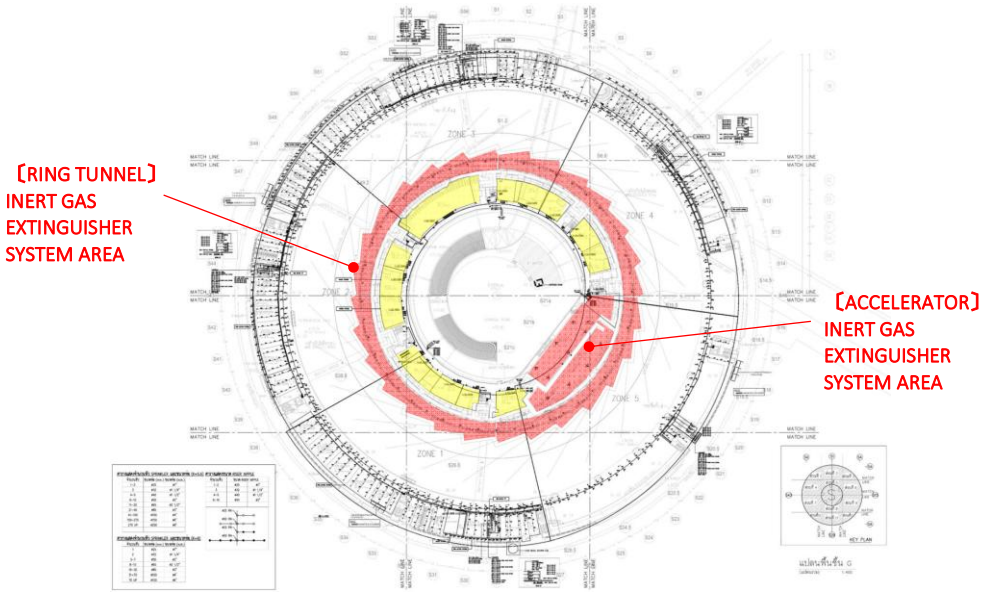


Source: SLRI

Figure 5-40 Recycle Water Machine

(3) Fire Extinguishing Equipment

The facility is equipped with a fire-fighting water tank that distributes fire-fighting water to the entire building via a motor pump and an engine pump. While most areas have sprinklers installed, the accelerator and ring tunnels are equipped with nitrogen fire extinguishers instead. Furthermore, due to its high ceiling, the experimental hall has pre-activated sprinklers.

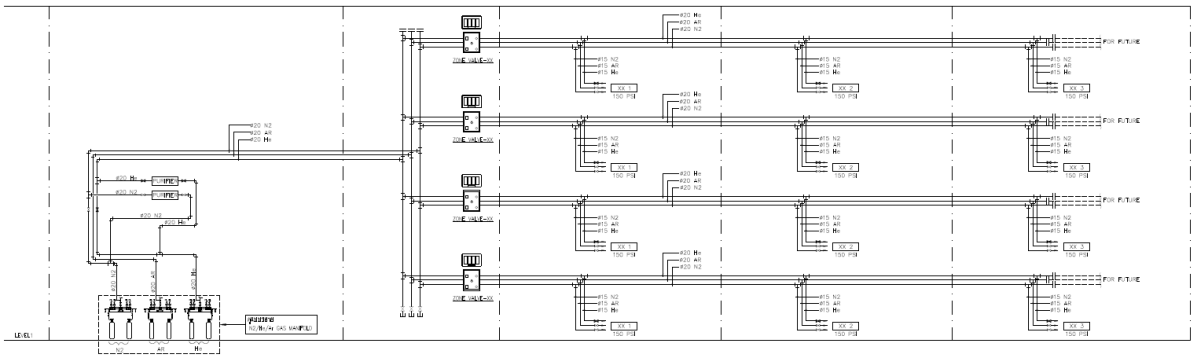


Source: SLRI

Figure 5-41 Fire Extinguishing System Diagram

(4) Special Gas Equipment

This facility supplies helium, argon, nitrogen, and liquefied nitrogen.



Source: SLRI

Figure 5-42 Special Gas System Diagram

(5) Points of Consideration

There is a proposal to treat the facility's wastewater and utilize it as makeup water for the cooling tower. However, if the treatment process is inadequate, it may result in the accumulation of debris in the cooling tower and pipes. Therefore, it is required to establish and maintain a reliable water treatment system for the proper operation of the facility's cooling tower.

5.3.6 Equipment Design and Planning for Electricity, Cooling, AC, Maintenance, Disaster Prevention, and Synchrotron Radiation Monitoring

(1) Electrical Equipment

1) Counter Measure Against Power Failure

- In case of Power failure, important equipment that cannot tolerate an instant shutdown will be supported by UPS instantly whereas others that can restart if power supply is recovered within one minute will be powered by Engine Generators.
- The oil tank capacity of the generator is 8 hours.
- The UPS must have a capacity of at least 10 minutes to ensure uninterrupted power supply in case of a power failure. Additionally, the engine generator will send power to the UPS within one minute after the power failure, allowing the UPS to continue supplying power for an extended period.

2) Mechanical Equipment

In the event of a power outage, the plan is to reduce the load and supply power to critical systems, such as one chiller and one cold water pump. In addition, the water reservoir tank will have enough capacity for two days.

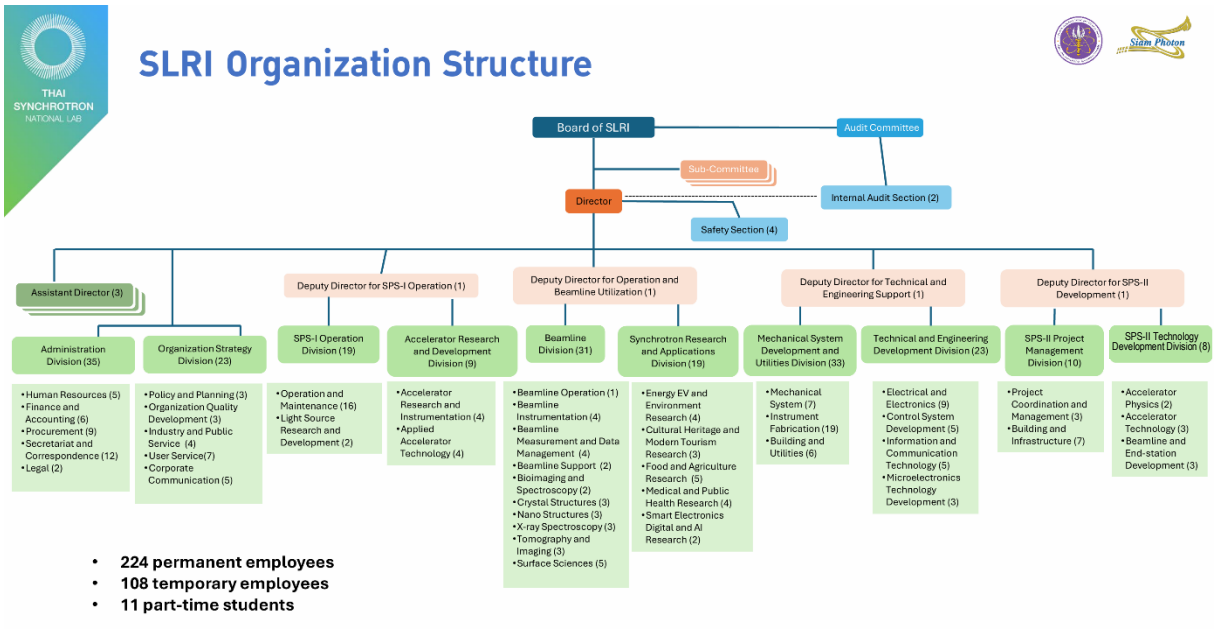
As for the main equipment, N+1 units of equipment are installed to ensure that there is always a spare, and consideration is given so that the capacity remains unaffected even in an event of equipment failure or replacement. Also, the loading and unloading of the equipment is planned with consideration given to the loading route.

3) Regarding Running Cost

To calculate the electricity charges, water charges, and sewage charges for the facility, the consumption amount must be estimated and multiplied by the unit price. In particular, the electricity usage fee for this facility is particularly high, but it greatly depends on the usage rate of the facility. Thus, it is essential to estimate a value as close to reality as possible by referring to other similar facilities.

6 Project Plan

6.1 Project Implementation Organization



Source: SLRI

Figure 6-1 SLRI New Organization Chart (as of December 2024)

GOJ (JICA) is the development partner and GOT (Ministry of Finance) is the Borrower. The main agencies in this ODA Loan scheme is explained below.

6.1.1 Main Agencies in Project Implementation

(1) Project Executing Agency

SLRI will be the Executing Agency of this Project, the responsible government body and the communication point with JICA. SLRI is responsible for all financial and key administrative matters (signing of contracts) for the Project in accordance with the ODA Loan Agreement and applicable JICA guidelines.

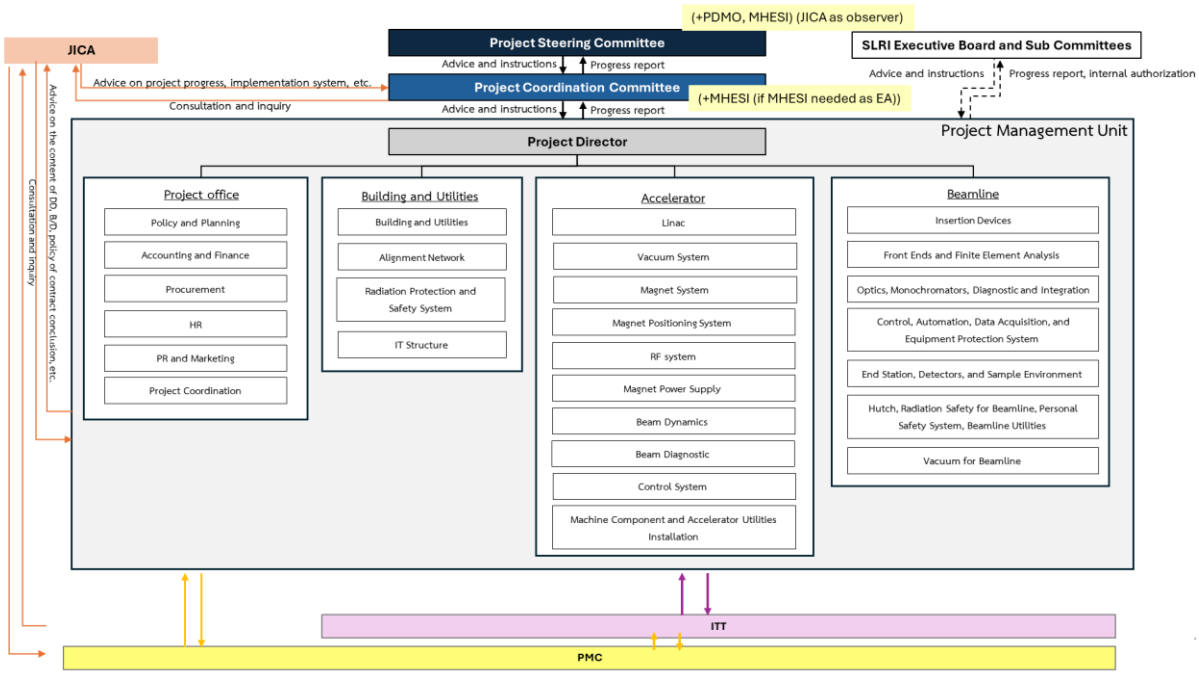
(2) Project Management Unit (PMU)

The Project Management Unit (PMU) will be formed by SLRI which is the Project Executing Agency and Project Implementing Agency under the supervision of MHESI. During Project implementation, the PMU will manage communication among the Project Management Consultant (PMC), Design Consortium, Construction Supervision Consultants (CS), the contractors, suppliers of equipment and service providers, and coordinate with other related agencies as well as JICA.

SLRI is responsible for all technical and key administrative matters of the Project, including procurement (such as the selection of consultants, procurement of contractors/ suppliers for all packages, supervision of contractors and consultants' works), reporting, management of disbursement including Request for

Reimbursement (RFR), and preparation of reports (Quarterly Progress Report, Project Completion Report, etc.) in accordance with the Loan Agreement and applicable JICA guidelines, and reporting to JICA.

SLRI, together with the SPS-II team, particularly the Systems Integration and Subsystem Compatibility Team, will be fully responsible for the assembly, systems integration and commissioning of the next generation synchrotron radiation facility.



Source: JST

Figure 6-2 Project Organization Structure

(3) Project Steering Committee (PSC)

The Project Steering Committee consists of authorized representatives from OPS-MHESI, PDMO, JICA Thailand Office, and moreover SLRI Director, Project Director, and other members to be named from their expertise to advice and instruct the project at a high level, also to discuss issues that affect the implementation or completion of the project, such as budget overrun, taxation issues.

(4) The Advisory Team

The Advisory Team is an external expert team consisting of experts from the National Research and Development Agency of Japan (RIKEN) and the National Synchrotron Radiation Research Center of Taiwan (NSRRC). In their expected role, RIKEN and NSRRC will provide technical guidance whenever SLRI proactively seeks their input; however, the ultimate responsibility for preparing and finalizing all project documents (such as the Detailed Design) remains with SLRI. Crucially, it must be noted that the Advisory Team's guidance carries no legal commitment or responsibility, and their timely availability is not strictly guaranteed due to potential internal commitments, meaning SLRI must be prepared to drive the project forward through its own efforts and PMC's support if necessary.

6.1.2 Implementation System for Building Construction

The following building construction works are the scope of JICA's loan:

- 3GeV Synchrotron building (S Building)
- Utilities building for synchrotron light source (U Building)
- DI Water Building (D Building)
- Electrical substation 115 kV / 22 kV building (ES building)
- Guest House building (G Building)
- Magnet, Vacuum and RF Laboratories (L Building)
- Administration and Users service office building (A Building)
- Reception and security building (RS Building)
- Others: infrastructure work, landscape including garbage storage, signage work

The construction and its Construction Supervision Consulting Service costs are prepared based on ICB scheme. Selection method for procurement of contractors for civil works shall be implemented according to JICA Standard Bidding Documents for Procurement of Works under Japanese ODA Loans

6.1.3 Implementation System for Equipment Procurement

The following Accelerator equipment is proposed under the scope of JICA's loan.

- Linear Accelerator
- Magnet Power Supplies
- Instrumentation
- Control
- RF
- Radiation Safety
- Magnet
- Vacuum
- Mechanical Positioning
- Utilities

The following Beamline equipment is proposed under the scope of JICA's loan.

- Source
- Front End
- Beamline
- End Station
- Hutch
- Beamline Central Utilities (7 beamlines)

The accelerator and beamline equipment's costs are prepared based on both ICB and LCB schemes. Selection method for procurement of suppliers for equipment shall be implemented according to JICA

Standard Bidding Documents for Procurement of Goods under Japanese ODA Loan and Thailand's public procurement standards.

6.2 Construction Method and Construction Plan

Buildings to be constructed under the Project is summarized below.

Table 6-1 Facilities to be Constructed in this Project

No	Building	Floor Number	Structure	Floor Area (m^2)
1	3 GeV synchrotron building (S Building)	2	Steel frame (storage tunnel is RC)	32,126
2	Utilities building (U Building) for synchrotron light source (including wastewater treatment building)	3	RC	7,214
3	Deionized (DI) water building (D Building)	3	RC	814
4	Magnet, vacuum and RF laboratories building (L Building)	2	RC	2,349
5	Administration and user service office building (A Building)	3	RC	5,805
6	Guest house building (G Building)	3	RC	3,950
7	Reception and security building (RS Building)	1	RC	53
8	Electrical substation 115 kV / 22 kV (ES Building)	1	RC	932
			Total	53,243

Others: Infrastructure work & landscape including garbage storage (91 m^2), signage work

Source: JST

6.2.1 Construction Situation

The construction site for the new synchrotron facility planned in this Project is located north of Vidyasirimedhi Institute of Science and Technology (VISTEC) campus at Rayong Province, about 150km southeast of Bangkok. The campus is lined with new educational facilities, and other facilities are still under construction.



Administration Building in VISTEC



Intelligent Operation Center in VISTEC



Water treatment facility



Under construction site in campus

Source: JST

Figure 6-3 Development Situation on the VISTEC Campus

The above building was constructed by a local construction company and the construction of the new facility will be done by a local Thai construction company from a comprehensive perspective of technology and safety management, confirming that it is quite possible.

SPS-I which is similar to this facility has also been constructed by a Thai construction company in the past.

In addition, it was confirmed that there are many local subsidiaries of Japanese contractors in Thailand, and that they are mainly engaged in construction work such as private factories and office buildings.

Furthermore, it was confirmed that the country's top-ranking construction companies have a track record of constructing facilities with an order amount equal to or greater than the construction cost of this new facility, and that they have sufficient financial capacity.

Regarding the procurement of building materials and equipment, MEP materials, laborers, construction machinery, furniture, etc. necessary for the construction of the new facility, it has been confirmed that it is possible to procure sufficient materials from Rayong Province where the site is located and the capital Bangkok.

6.2.2 Construction Labor Condition

The Labor Law and the Working Conditions in Thailand for Construction workers are regulated by the Labor Protection Act, B.E. 2541 (A.C.1998) (Revised B.E. 2562 (A.C.2019)), and the Ministry regulations No.3, B.E.2541 (A.C.1998), which main items are shown as follows.

- Normal working hours are 8 hours/day and must not exceed 48 hours/week.
- Total overtime working hours on holiday must not exceed 36 hours/week.

Wages during leave:

- Paid wages for sick days must not exceed 30 working days/year
- Paid wages on leave after sterilization
- Paid wages on leave for military service, but not more than 60 days/year.
- Paid wages on maternity leave until 45 days/pregnancy

Salary for night shift workers

The Ministry of Labor has stipulated labor laws such that an employee that works at night from 10:00 p.m. to 6:00 a.m. must receive at least 1.1 times higher salary than an employee working during the day. Additionally, the disbursement of salary or wages must be signed by the recipient and disbursed on time.

Overtime Wages

According to labor laws and wage rates, overtime wages on ordinary working days are divided into 2 periods: from 5:00 p.m. to 8:00 p.m., during which the wage will be increased by 1.5 times the normal amount and from 8:00 p.m. to 6:00 p.m., it will increase to 2.0 times the normal wages. Similarly, for overtime pay during weekend holidays and public holidays are also divided into 2 periods: from 8:00 a.m. to 8:00 p.m., with an increase corresponding to 2.5 times the normal wage, and from 8:00 p.m. to 6:00 p.m., in which the standard wage will be increased by 3.0 times.

6.3 Procurement Method/ Procurement Plan

6.3.1 Examination of Selection Methods

The selection methods of the consultants, contractors and suppliers which applied to ICB shall be based on the JICA Guidelines on Bidding Methods of Yen Loan Projects and standard bidding documents for Works and Goods, and standard request for proposals for the selection of consultants published by JICA. LCB will be discussed later in 6.3.3 Procurement of Construction Works.

Table 6-2 JICA Guidelines on Bidding Methods of Yen Loan Projects

Item	Guidelines
Building Construction	Chapter2: Guidelines for Procurement under Japanese ODA Loans
Procurement of Equipment	Chapter2: Guidelines for Procurement under Japanese ODA Loans
Selection of Consultants	Chapter1: Guidelines for the Employment of Consultants under Japanese ODA Loans

Note: The HANDBOOK for Procurement under Japanese ODA Loans has been revised in October 2023

Source: JICA

Table 6-3 Standard Bidding Documents (SBD) for Works, Goods, and Consultant

Item	SBD
Building Construction	Standard bidding documents under Japanese ODA Loans Procurement of Works, October 2019
Procurement of Equipment	Standard bidding documents under Japanese ODA Loans Procurement of Goods, May 2021
Selection of Consultants	Standard request for proposals under Japanese ODA Loans Selection of Consultants, October 2019

Note: the above table shows the latest version at the time of writing, but in accordance with the guidelines, the latest version of SBD should be used at that time.

Source: JICA

Component under LCB shall applied to Regulation of the Ministry of Finance on Public Procurement and Supplies Administration B.E.2560 (2017) Clause 28 (1) General solicitation notification method, (2) Selection method.

Procurement procedure of building works and related equipment by LCB in Thailand is shown below.

Table 6-4 Procurement Procedure of Building Works and Related Equipment by LCB in Thailand

Item	Description	Short Brief
1.1	General Procedure	Thai public procurement for building works in Thailand can go with 3 method including: (1), (2), (3)
1.1.1	General Solicitation Notification Method can be conducted by following;	
(1)	e-market (not eligible)	Purchasing or hiring for the uncomplicated parcels or standardized goods or services and it is in the list and defined in the product information system (e-catalog). - purchase by Quotation for budget THB 500,000 - 5,000,000 - purchase via e-bidding for budget over THB 5,000,000
(2)	e-bidding (eligible)	For the procurement with an amount exceeding THB 500,000 baht and is a product or service that does not specify the specific characteristics of the parcel in the product information system (e-catalog), must be conducted in an electronic bidding system. (Electronic Bidding: e - bidding) according to the method specified by the Comptroller General's Department.
(3)	price inquiry (not eligible)	Cover a procurement in budget of THB 500,000-5,000,000. This can be done in the event that the government agency is located in an area where there is a limitation on the use of the Internet signal. Making it impossible to operate through the electronic market system or the electronic bidding system.
1.1.2	Selected Method	Solicitation by a State agency made specifically to at least three business operators possessing qualifications determined by the State agency for tendering proposals, except that there exist less than three business operators possessing the determined qualifications for such particular work.

Item	Description	Short Brief
1.1.3	Specific Method	Solicitation by a State agency made to a particular business operator possessing qualifications determined by the State agency for tendering a proposal or for price bargaining negotiations, including procurement of supplies made directly with a business operator where it involves such a small cost estimate. Or from the tenderer in procurement by means of a General solicitation announcement or Selection method which has been canceled to submit a new bids. However, if it is seen that an entrepreneur deems appropriate to purchase or hire a price higher than the market price or estimated price or the price that the committee deems appropriate to negotiate the price as much as possible.
1.2	Necessary Documents	In line with Article 22 of the "Regulations of the Ministry of Finance on Government Procurement and Supplies Management B.E. 2560 (2017)"
(1)	Reasons and necessity for procurement	
(2)	Scope of work or details of specific characteristics of materials or forms of construction work to be procured, as the case may be.	
(3)	the standard price of materials to be procured;	
(4)	Amount of budget for procurement by specifying the budget amount. If there is no such limit, specify the limit estimated to buy or procure at that time.	
(5)	specifying the time required for the work to be completed;	
(6)	the method of procurement and reasons by that method;	
(7)	criteria for consideration and selection of proposals	
(8)	Other proposals such as requesting approval for the appointment of various committees necessary for the procurement, issuing announcements and invitation documents and invitation letter. For the major group of technical documents, to be prepared shall including:	i) Details of specific characteristics, Term of reference, general contract condition (cover page paper ≈10 pages) ii) Technical specifications iii) Drawings iv) Bill of Quantity and cost estimation

Source: JST

Timeline of Procedure for LCB is shown below.

- For THB 500,000 - 5,000,0000 project cost, total processing day shall not less than 41 business days
- For THB 5,000,000 - 10,000,0000 project cost, total processing day shall not less than 46 business days

- For THB 10,000,000 - 50,000,0000 project cost, total processing day shall not less than 48 business days
- For over THB 50,000,000 project cost, total processing day shall not less than 56 business days, see next detailed table.

As shown in the following table, the steps remain the same, but the time required for bidders to prepare their bidding documents and the time required to prepare the contract and signature will vary depending on the cost of the project.

Step 8 in the following table states, "The Committee submit the report to head of agency, Head of agency approve the procurement and announce the winner," and a request for confirmation is scheduled to be made to MHESI, the head agency of SLRI.

Table 6-5 Timeline of Procedure for LCB

ding for over THB 50,000,000 project cost		Business Day
	Business Day	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Description	56	
Procurement plan preparation	1	
TOR preparation/appoint a committee	1	
e-bidding document preparation/head of agency consideration and give a green light		
Make a request for procurement report and submit to head of agency		
Upload the draft procurement plan announcement in website for public sounding		
Announcement of draft electronic tender documents (not less than 3 working days) with no comment to be revised	3	
Prepare a memorandum of information to announce the tender documents.	1	
Publish the electronic tender documents and tenderers prepare their proposal	20	
Tenderer query and clarification period (3 days befor Bidding Date)		
The Bidding Date, the tenderer submit their proposal	1	
The Committee conderder and verify proposals	7	
The Committee submit the report to head of agency	1	
Head of agency approve the procurement and announce the winner		
Waiting period of appeal	7	
Notify the winners to prepare for the contract (no more than 7 working days)	7	
Sign the contract (no more than 7 working days)	7	
Total (Days)	56	

Source: JST

6.3.2 Bidding Package (Non-Disclosure)

(This section is concealed for a certain period.)

6.3.3 Procurement of Construction Works (Non-Disclosure)

(This section is concealed for a certain period.)

6.3.4 Procurement of Equipment

JICA yen loan handbook (Ver 1.1), Chapter 2: Guidelines for Procurement under Japanese ODA Loans, Section 1.02 International Competitive Bidding (ICB) considers that in most cases International Competitive Bidding (ICB) is the best method for satisfying the requirements regarding procurement of goods and services for projects stated in Section 1.01 (3) such as the principles to be considered as basic

procurement philosophy. In addition to economy, efficiency, and non-discrimination, transparency is specified in line with the growing recognition of the importance of transparency in the procurement process. It is also one of the general considerations in the World Bank's Guidelines for Procurement. above. JICA, therefore, normally requires Borrowers to obtain goods and services through ICB in accordance with the procedures described in Part II of these Guidelines.

In addition, in Section 1.03 Procedures Other than International Competitive Bidding (ICB), There may be special circumstances in which ICB may not be appropriate, and JICA may consider alternative procedures acceptable in cases of the following:

(a) Where the Borrower wishes to maintain reasonable standardization of its equipment or spare parts in the interests of compatibility with existing equipment.
(b) Where the Borrower wishes to maintain the continuity of services related to goods and services provided under an existing contract awarded in accordance with procedures acceptable to JICA.
(c) Where the number of qualified contractors, suppliers or manufacturers (hereinafter collectively referred to as "Contractor(s)") is limited.
(d) Where the amount involved in the procurement is so small that foreign firms clearly would not be interested, or that the advantages of ICB would be outweighed by the administrative burden involved.
(e) Where, in addition to cases (a), (b), (c) and (d) above, JICA deems it inappropriate to follow ICB procedures, e.g. in the case of emergency procurement.

In the above-mentioned cases the following procurement methods, may, as appropriate, be applied in such a manner as to comply with the ICB procedures to the fullest possible extent:

(a) Limited International Bidding (LIB), which is essentially international competitive bidding by direct invitation without open advertisement.
(b) International Shopping, which is a procurement method based on comparing price quotations obtained from several (usually at least three) foreign and/or local suppliers to ensure competitive prices.
(c) Direct Contracting.

These Guidelines will not apply in the case of procurement of goods and services which are, by nature or scope, unlikely to attract foreign firms and, thus, to be domestically procured. Procurement of such goods and services shall, however, be affected with due attention to the considerations stated in Section 1.01 (3). JICA deems it appropriate that such procurement be affected through Local Competitive Bidding (LCB) in accordance with the procurement procedures generally used in the Borrower's country.

As a result, this Project will be implemented in accordance with the JICA ODA Loan Handbook, and for equipment procurement that falls under special circumstances where JICA may approve other methods, the Project will plan for LCB. The equipment procurement schedule will be based on detailed design, pre-qualification (P/Q), bidding/evaluation, procurement, ICB and LCB procurement procedures, including equipment installation supervision.

(1) Possibility of Utilization of Thai Domestic Companies for Developing Each Component in Accelerator (Non-Disclosure)

(This section is concealed for a certain period.)

(2) Possibility of Introducing Japanese Technology for Accelerator and Beamline (Non-Disclosure)

(This section is concealed for a certain period.)

6.3.5 Procurement of Project Management Consultant (PMC)

In order to facilitate the Project, the PMC will be hired to assist SLRI PMU and provide project management service. The employment of consultants will be carried out in accordance with the latest version of the general principles and procedures laid down in the Guidelines for the Employment of Consultants under Japanese ODA Loans (hereinafter called Consultant Guidelines). The Quality- and Cost-Based Selection method (QCBS) will be applied for the selection.

6.3.6 Procurement of Construction Supervision Consultants

Construction Supervision Consultants for buildings construction are planned to be selected by SLRI and implemented according to the GOT's guidelines. The cost is included under the PMC.

6.4 Confirmation of Tax Exemption

The principal taxes levied by the central government in Thailand are as follows.

6.4.1 Direct Taxes

Personal Income Tax, Corporate Income Tax and Petroleum Income Tax

6.4.2 Indirect Taxes

Value Added Tax (VAT), Specific Business Tax, Customs Duties (Import Tax), Excise Tax and Stamp Duties

The principal tax law in Thailand is the Revenue Code, which governs personal and corporate income taxes, value added tax, specific business tax, and stamp duties. Customs duties are regulated by the Customs Act; the Excise Act governs excise tax. According to Section 12 of the Customs Tariff Royal Decree B.E. (No. 6), regarding the reduction of duty rates and exemption of customs duties, Notification of the Ministry of Finance announced on January 5, 2023, the following items are subject to tax exemption. The equipment to be procured under the Project is categorized as item (d), which means that it is subject to tax exemption.

(a) Newspapers, publications and documents
(b) Artifacts and collectibles related to scientific or cultural studies;
(c) Educational, scientific or cultural audiovisual aids;
(d) Scientific materials and tools or utensils
(e) Items for people with disabilities

(f) Musical instruments, sports equipment and skill accessories.
(g) Arts and architecture educational materials.

To qualify for a duty exemption, goods must be used for education or research and be certified by MHESI. Additionally, these goods must not be produced domestically, unless MHESI determines that importing them is absolutely necessary.

The applicable law for tax-exemption is "Notification of the Director-General of the Revenue Department about VAT (No. 28): Establishing criteria. The method and conditions of sale of goods or services to ministries, bureaus, departments, local governments or state enterprises pursuant to loan schemes or foreign grants under Section 80/1(4) of the Revenue Code."

Tax exemption application to MHESI will be prepared by SLRI. Import tax is to be managed by the Customs Department.

6.5 Project Implementation Schedule and Approximate Project Cost

6.5.1 Consideration of Project Implementation Schedule

The project implementation schedule has been confirmed as follows.

Table 6-6 Project Implementation Schedule

Key Milestones	Schedule
Signing of Loan Agreement	April 2026
Procurement of Consultant (PMC) (Package 4)	March 2026 – November 2026
Bidding for Building Construction (Package 1)	December 2026 – February 2028 (14.5 months)
Bidding for Accelerator Equipment (Package 2)	October 2026 – January 2030 (39.5 months)
Bidding for Beamline Equipment (Package 3)	January 2027 – April 2030 (39.5 months)
Building Construction (Package 1)	March 2028 – April 2031 (38 months)
Defect Notification Period	May 2031 – April 2032 (12 months)
Procurement of Accelerator Equipment (Package 2) (Including 12-month warranty period)	October 2027 – April 2034 (79 months)
Procurement of Beamline Equipment (Package 3) (Including 12-month warranty period)	March 2028 – November 2033 (69 months)
Beamline Installation	February 2033 – October 2033
First beam (without IDs (Insertion Device))	March 2033
Beamline Commissioning Including Final Machine Commissioning	November 2033 – July 2034
Project Completion Date – Start of Beam Services (1st Phase Operation)	August 2034
Completion of Consulting Services (Package 4)	August 2034

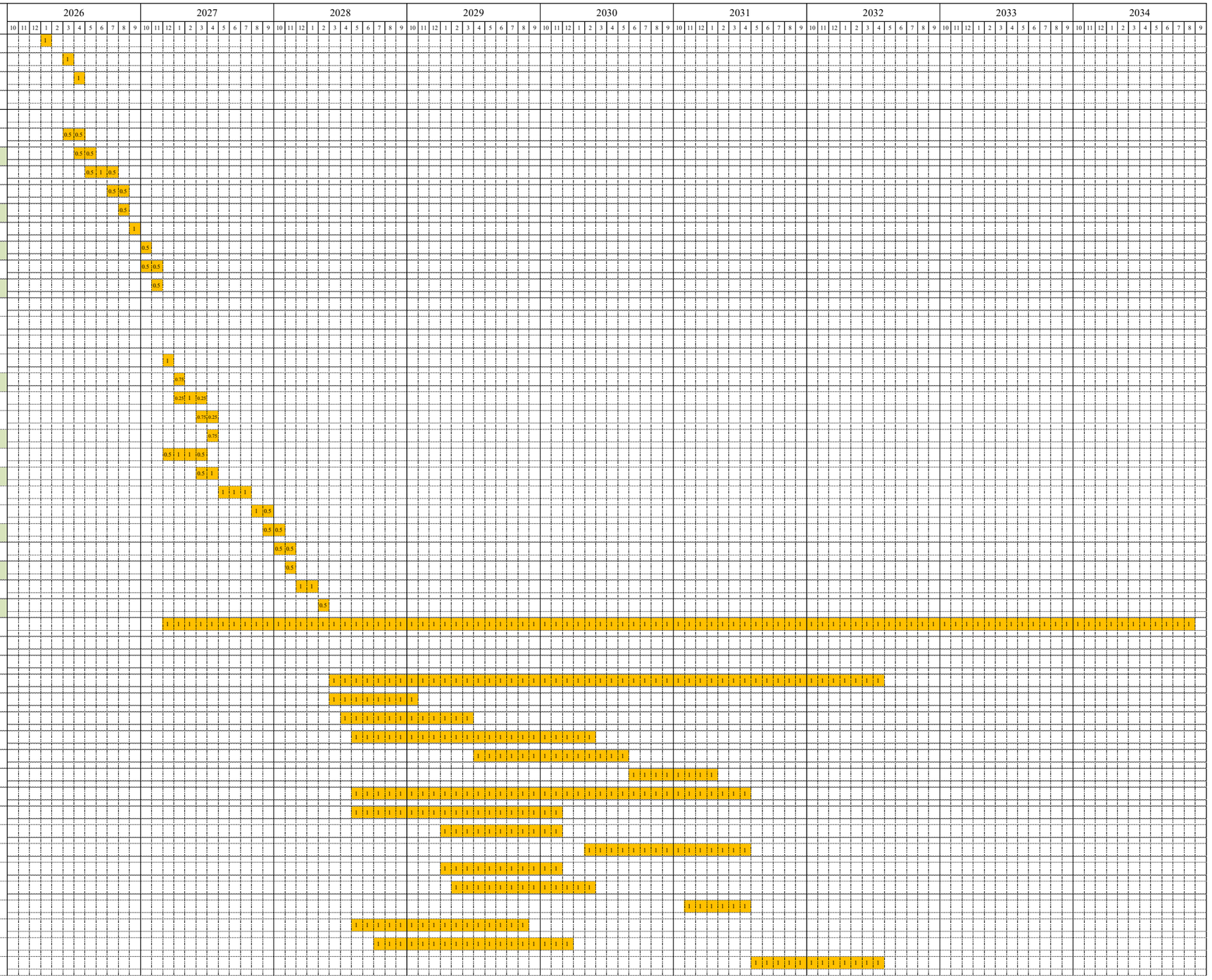
Note 1: The planned period for Procurement of Consultant and Bidding has been set in accordance with the standard implementation period set by JICA.
Note 2: Detailed design by SLRI needs to be adjusted to fit the project implementation schedule.

Source: JST

The project implementation schedule planned by JST is shown below.

Implementation Schedule

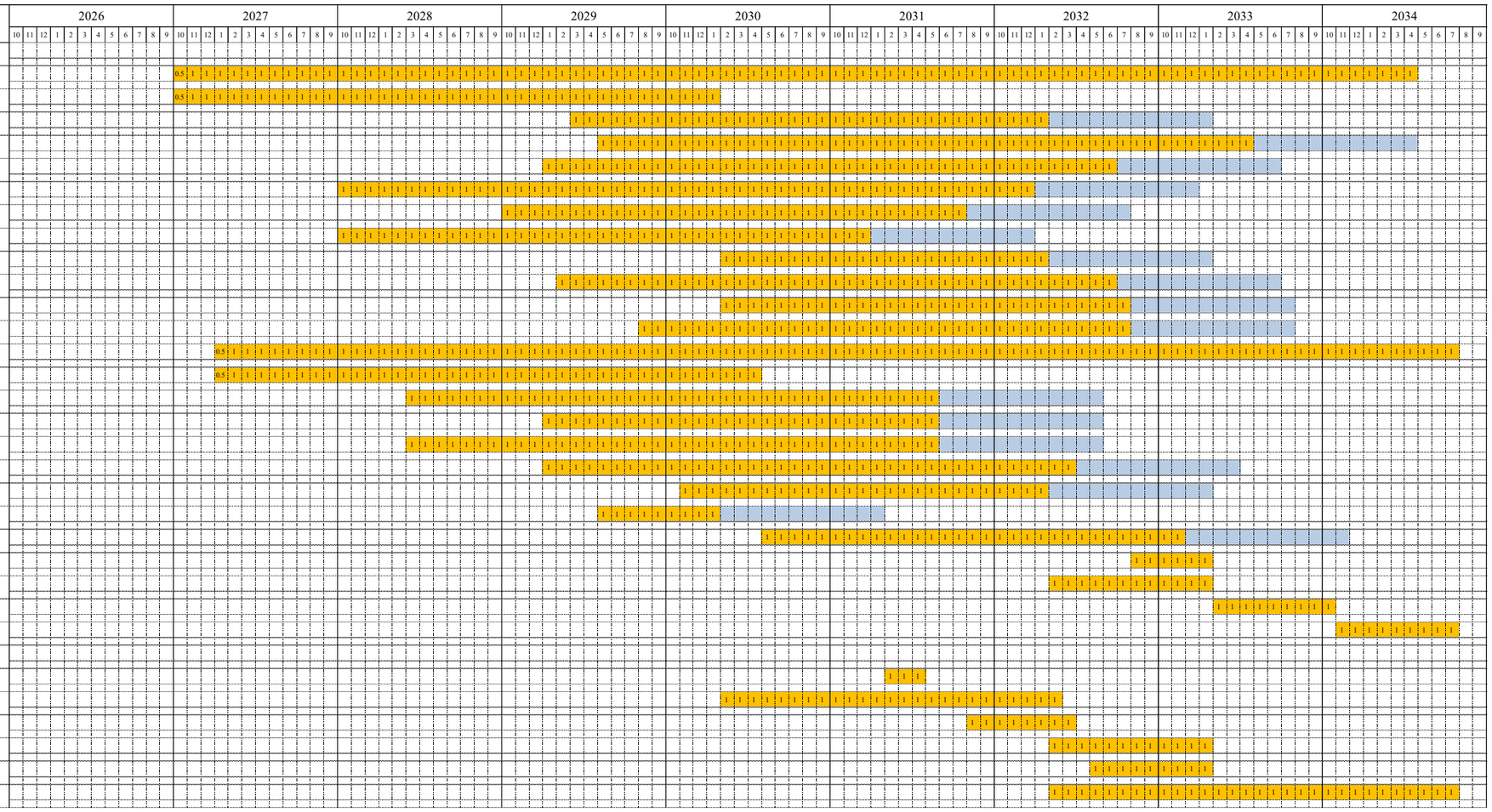
	Month
Appraisal	1
Pledge	1
Signing of Loan Agreement	1
	0
Procurement of Consultant (PMC)	0
- Preparation of RFP	1
- No Objection by JICA	1
- Advertising	2
- Technical Bid Evaluation	1
- No Objection by JICA	0.5
- Price Bid Evaluation	1
- No Objection by JICA	0.5
- Contract Negotiation	1
- No Objection by JICA	0.5
	0
Consulting Services (PMC)	0
Bidding Assistance	0
- Preparation of PQ Documents	1
- No Objection by JICA	0.75
- PQ Advertising	1.5
- PQ Evaluation	1
- No Objection by JICA	0.75
- Preparation of Bid Documents	3
- No Objection by JICA	1.5
- Advertising	3
- Technical Bid Evaluation	1.5
- No Objection by JICA	1
- Price Bid Evaluation	1
- No Objection by JICA	0.5
- Contract Negotiation, Preparation for Contract/Commencement of works	2
- No Objection by JICA	0.5
Project Management	93
	0
Building Construction	0
Construction (Package-1)	50
Survey and layout (Including primary monuments establishment)	8
Cut & fill	12
Infrastructure construction work	22
Road, Walkway and Hard landscape construction work	14
Soft landscape and Irrigation work	8
3GeV Synchrotron building (S Building)	36
Utilities building for synchrotron light source (U Building)	19
Magnet and vacuum laboratories (L Building)	11
User Office and library building (A Building)	15
Guest house and office building (G Building)	11
DI Water Building (D Building)	13
Reception and security (RS Building)	6
Electrical substation 115 kV / 22 kV (ES)	16
Install underground high voltage for electrical substation	18
Defect Notification Period (DNP)	12



(Continued to next page)

Implementation Schedule

	Month
Equipment Procurement	0
Procurement of Equipment (Package-2, Accelerator)	90.5
Bidding	39.5
Instrumentation	35
Control	48
Radiation Safety	42
Magnet	51
Vacuum	34
Mechanical Positioning	39
Magnet Power Supplies	24
RF	41
Machine integration and utilities installation	30
Linac	36
Procurement of Equipment (Package-3, Beamline)	90.5
Bidding	39.5
Insertion Devices	39
Front Ends	29
SWAXS, HRXRD/MX, GIXRD/TRXRF beamlines	39
TXAS, HXAS, XMCT beamlines	39
HRSXS beamline	27
Detectors	9
Hutch, PSS, and Beamline Utilities	31
IDs and front-end installation	6
Beamline assembly & testing	12
Beamline installation	9
Final commissioning	9
	0
Pre-work (Survey and fiducials for control points)	3
Pre-installation in the LAB	25
Accelerator utility installation and testing	8
Machine installation	12
Machine integration and testing	9
Machine and beamline commissioning	30



Source: JST

Figure 6-4 Project Implementation Schedule

6.5.2 Construction Permit Procedure

The procedure and provisional schedule for the design and construction permission for the construction work are as follows.

Table 6-7 Procedure of Construction Permit by Thai Side

Activities	Schedule
1. Preliminary design + approved by SLRI and Project consultant for building design (InterPAC*)	April – June 2021
2. Fixed idea + approved by SLRI and Project consultant for building design (InterPAC*)	June – July 2021
3. Preliminary construction drawing with BOQ + approval process SLRI and Project consultant for building design (InterPAC*)	July – September 2022
4. Construction drawing + approved by SLRI and Project consultant for building design (InterPAC*)	September 2022 – April 2023
5. Building design revision** (new site) + approval process by SLRI, Building design service provider (DKW Consortium)	June 2024 – May 2025
6. Building design revision** (new site) + approval process by SLRI, Project consultant for building design (InterPAC*)	October 2024 – October 2025
7. Send a letter of notification to regional authority under the Building Control Act. B.E. 2522 (prepared by the Design Consultant and submitted by SLRI)	Before construction bidding
8. Send a letter of notification of intention for building construction to PTT and VISTEC (by SLRI)	Before construction bidding
9. Send a letter of notification of intention for building construction to regional authority under section 39 bis of the Building Control Act, B.E. 2522*** (prepared by the Contractor and submitted by SLRI)	After construction bidding/ Before commencement of construction works

*InterPAC is Thailand's project management consultant company that gave SLRI advices (incl. TOR preparation) during building design process

**Construction drawing is included

*** Acknowledgements will be received

Source: SLRI

After completion of construction works/ before the start of use, SLRI needs to send a notification letter for building works completion and request a completion final inspection of the building before start of use to regional authority under the Building Control Act, B.E. 2522, upon which an Acknowledgements will be received after Final Inspection by authority.

6.5.3 PMC Consulting Service Implementation Plan (Non-Disclosure)

(This section is concealed for a certain period.)

6.5.4 Preliminary Project Cost (Non-Disclosure)

(This section is concealed for a certain period.)

6.5.5 Fast Track of ODA Loan Projects and Cost Reduction Measures (Non-Disclosure)

(This section is concealed for a certain period.)

6.6 Scope of GOT's Portion (Non-Disclosure)

(This section is concealed for a certain period.)

7 Utilization System

7.1 Beamline Service Plan

From the viewpoint of utilization system, beamlines at synchrotron radiation facilities are broadly classified into public beamlines, contract beamlines, and beamlines owned by research institutes. Public beamlines are for researchers in universities, industry, and overseas users, while private beamlines are installed by specific research institutes or private companies for their own research projects. In the case of SPring-8, the composition of beamlines including RIKEN beamline, used for RIKEN's own research, is shown in the table below:

Table 7-1 Composition of Beamline of Spring-8 (as of August 2022)

	Public	Contract	RIKEN	Total
Operation	26	15	13	54
Under construction	0	2	1	3
Total (%)	26 (45.6%)	17 (29.8%)	14 (24.6%)	57 (100.0%)

Source: SPring-8

Even though public beamlines generally charge usage fees, some facilities charge no fee (free), intended for trial users as an incentive to increase the number of users. In the case of paid use (with fees), a range of usage fees according to the use conditions, such as disclosure of results and use by local companies, are set by many facilities. Table 7-2 summarizes the usage system of representative SRFs in Japan.

7.1.1 Beamline Service of SPS-I

All SPS-I beamlines are categorized as public beamlines, and although some beamlines allow priority use by specific research institutes and companies with extras charges, there are no particular beamline contracts dedicated to a specific research institute or private company. Table 7-3 summarizes the usage fees of SPS-I by beamline type.

Table 7-2 Summary of Utilization System of Major Facilities in Japan

Facility	Free of charge Publication of results	Charge (Discount) Publication of results	Charge (Discount) Exclusive use Undisclosed results	Charge Exclusive use Undisclosed results
SPring-8 Charge: 1 shift per 8 hours	JPY10,720 (Consumables actual fixed cost burden) • Non-proprietary general proposal • Long-term proposal • Urgent proposal	JPY141,720 • Non-proprietary grant-aided proposal		JPY490,720 • Proprietary general proposal JPY730,720 • Proprietary measurement service • Time-designated proposal
Photon Factory (PF) Charge: Per hour Normal Line or *High Performance Line*	• Joint use (Experimental tasks for academic purposes only)	JPY15,400 or *JPY30,800* • Priority use (National project)	JPY15,400 or *JPY30,800* • Trial use	JPY28,600 or *JPY57,200* • General use
Aichi SR Charge: 1 shift for 4 hours Measurement service charge: per hour	• Non-proprietary grant-aided proposal		JPY103,600 (JPY51,800 for trial use) • Public use (university etc.) • SME user JPY51,800/hour for measurement service	JPY207,200 (JPY103,600 for trial use) • General use JPY77,700/hour for measurement service
SAGA-LS Charge: One day	• Trial use	JPY12,100 Industrial use within the prefecture (industry, academia, and government) JPY24,200 Use of priority fields outside the prefecture (industry, academia, and government)	JPY48,400 (half day) General use by companies in Saga Prefecture	JPY122,100 General use within Saga prefecture JPY244,200 General use outside Saga prefecture

Source: https://photonbeam.jp/prices/

Table 7-3 Rate for SPS-I by Beamline

	Beamline	Rate per hour (THB)
1	BL1.1W: MXT	7,200.00
2	BL1.2W: X-ray Imaging & XTM	6,000.00
3	BL1.3W: SAXS	7,200.00
4	BL2.2: TR-XAS	5,100.00
5	BL3.2Ua: PES	12,000.00
6	BL3.2Ub: PEEM	12,000.00
7	BL6a: DXL	6,200.00
8	BL6b: Micro-XRF	6,200.00
9	BL7.2W: MX	7,100.00
10	BL8: XAS	7,200.00

Source: SLRI

SLRI is considering introducing a trial use system for new customers, but it has not yet been implemented. Nevertheless, technical seminars to promote the use of SRF for new customers have been regularly held, and as a result, in several cases the participants of these seminars have become new users.

During COVID-19, a different measurement service was introduced in which users sent samples via post-mail and researchers of SLRI conducted the experiments instead of users. However, as this was not a systematic official service but a result of collaboration between researchers in universities / research institutes and SLRI, this was kept free of charge. Consequently, SLRI is currently considering starting a measurement service (mail-in-service).

7.1.2 User's Satisfaction and Comments of SPS-I

SLRI conducts an annual customer satisfaction survey targeting SPS-I users. The results of this survey should be used as reference when considering the future usage system of SPS-II and the services to be provided. Therefore, the overview of the survey conducted from 2019 to 2022 and the users' comments are summarized below.

This survey divided the users of SLRI's services into three groups and conducted a sampling survey for a certain number of users in each group. The table below summarizes the population and sample numbers by group for each year.

Table 7-4 Survey Sample Number by Group

Group		2019	2020	2021	2022
Group 1 Users of the synchrotron light and related instrument services from educational institutions and government agencies	Population	350	350	350	400
	Sample	250	200	200	254
Group 2 Users of the synchrotron light and related instrument services from private entities	Population	200	200	200	100
	Sample	100	50	100	50
Group 3 Participants of the synchrotron technology workshops	Population	500	0	500	300
	Sample	250	0	125	150

Source: SLRI, prepared by JST

The survey asked for the respondents' level of satisfaction in each service item on a scale from one to five. The table below summarizes the overall level of satisfaction with the services provided by SLRI.

Table 7-5 Overall Satisfaction by Group

Group	2019	2020	2021	2022	2023
Group 1	4.82	4.84	4.68	4.62	4.65
Group 2	4.69	4.73	4.48	4.52	4.66
Group 3	4.74	n/a	4.48	4.50	4.65

In 2023, only the overall satisfaction results have been released.

Source: SLRI, prepared by JST

It can be seen that all groups are generally very satisfied. Additionally, the table below summarizes the responses to the question about how likely they are to use the service again.

Table 7-6 Intention for Reuse by Group

Group	2019	2020	2021	2022
Group 1	4.56	4.78	4.80	4.71
Group 2		4.53	4.52	4.59
Group 3		n/a	4.59	4.68

Source: SLRI, prepared by JST

Each group is satisfied with the service provided by SLRI to some extent, which leads to their intention for reuse in the future.

As for Group 1 and Group 2, the sampled users are also classified according to whether they are new users or existing (repeating) users, and the results are summarized in Table 7-7. Both groups include a certain number of new users every year, except for Group 2 in 2020; particularly Group 2 has a relatively higher percentage. It is attributed that this is possibly due to users that participated in technical seminars classified as Group 3 later became synchrotron users.

Table 7-7 Type of User of Group 1 and 2

Group	User Type	2019		2020		2021		2022	
		Number	%	Number	%	Number	%	Number	%
Group 1	Repeat User	157	62.8%	159	79.5%	167	83.5%	186	73.2%
	New User	93	37.2%	41	20.5%	33	16.5%	68	26.8%
	Total	250	100.0%	200	100.0%	200	100.0%	254	100.0%
Group 2	Repeat User	50	47.2%	50	100.0%	68	68.0%	28	56.0%
	New User	56	52.8%	0	0.0%	32	32.0%	22	44.0%
	Total	106	100.0%	50	100.0%	100	100.0%	50	100.0%

Source: SLRI, prepared by JST

From these survey results, although it can be inferred that users are generally very satisfied with the services provided by SLRI and the usage system of SPS-I, they also provided opinions for potential improvement, listed below. It is recommended that SLRI refers to them when considering future services and usage systems.

- User scheduling should be prioritized based on the research topics.
- Additional sample preparation and processing equipment should be provided, such as metal etching and dielectric film deposition.
- There is a need for advanced, in-depth training sessions on specialized techniques like IR and XAS.
- The time taken for maintenance is too long.
- A policy to compensate users for lost beamtime caused by technical failures or beamline issues should be considered.
- Outreach efforts should be strengthened to attract more users.
- The website should be more transparent; specifically, the SPS-I Operation Schedule should be easily accessible, and workshop advertisements should be more detailed.
- A technical manual should be created specifically for first-time users.
- The user registration and proposal submission processes should be simplified.
- Users must receive advance notification before any scheduled Beam Dump.
- Guest rooms should be equipped with high-performance computers dedicated to data analysis and processing.
- A shuttle bus service should be provided within Suranaree Campus.
- Available technologies should be diversified to include Grazing-Incidence Wide-Angle X-ray Scattering (GIWAXS).

7.1.3 Beamline Service for SPS-II

Seven beamlines are planned to be installed in the first phase of SPS-II, and are intended to be public beamlines. SPS-II plans to provide academic and SME users with cheaper services fees. The current assumed beamline usage fees are summarized in the table below.

Table 7-8 Rate for SPS-II

User Group	Percentage Compared to Industrial User	Baht/Hour
Industrial group		34,000
SME	33%	11,333
Academia	10%	3,400
Feasibility study and training	100%	34,000
Foreign users	100%	34,000

Source: SLRI

SLRI will develop usage systems henceforth. In order to greatly promote industry-academia collaboration and industrial usage, it is necessary to build updated usage systems and support systems that meet those needs, which are currently and mainly provided by the Business Development Section.

(1) Expansion of Services for Industrial Users

- To deploy concierges and coordinators with specialized knowledge under the Organization Strategy Division; so that companies engaged in product development can receive appropriate advice and consultation regarding the selection of beamlines and measurement methods, and new approaches to problem solving.
- To provide matching support service to introduce research partners such as universities in response to requests from individual companies.
- To provide a measurement service (mail-in-service).

(2) Development of New Users such as SMEs and Startup Companies

As mentioned above, the introduction of a reduced usage fee for SMEs is being considered. In addition, it is recommended to:

- consider a trial use system for SMEs and startup companies with promising research themes such as drug discovery and new materials.
- to consider creating a system to systematically attract new customers in collaboration with the support for startup companies that universities and NESTDA are working on.

(3) Establishment of a Usage System in Collaboration with the Regional Community

It is recommended to discuss with EEC (or EECi) to establish regional collaboration to provide a priority quota of beamtime usage for local companies in EEC, following the study case of collaboration between Sendai City and NanoTerasu in Japan.

(4) Development of Intellectual Property Management and Environment for using Databases, Networks

In order to ensure that companies can conduct research with peace of mind, it is recommended to thoroughly manage intellectual property and confidential information, and deploy analysis equipment and databases that can handle high-throughput data. With these developments, an increase in industrial users is expected; particularly international ones.

7.1.4 Beamline Service for SRFs in Japan

As reference, the following information regarding beamline service of SRFs in Japan has been collected by JST. In addition to the information in the table below, it has been identified that the beamline usage fee is generally composed of electricity cost, labor cost, equipment cost and consumable fee. All users will be charged the user fees such as consumables.

Table 7-9 Summary of the Terms of Uses of Beamlines in SRFs in Japan

		SPring-8 (RIKEN+JASRI)	NanoTerasu (QST+Registration Agency)	NanoTerasu (PhoSIC)
User Qualification				• Members that have paid the joining fee • Membership types vary according the number of investment units, etc. • (Platinum, Gold, General)
Beforehand Consultation		• Prior consultation from the user to the registration agency • Conducting on-site and online training sessions • Establishment of a web contact window for first-time users • Counseling for industrial use by consultants who specialize in the field • Response to light requests such as measurement agency • Examination	▪ Under Review (※Details to be discussed with the registration Agency)	• Mechanism of use and Procedure consultation • Professional research consultation (partner matching) • BL usage consultation
System Usage	**Non-proprietary results**	• Regular Use • Emergency/special use • Use by graduate students • Priority use (paid option)	• General tasks	
	Proprietary Results (Payment)	• Regular Use • Time-specified use/measurement proxy use	• Outcome Proprietary task	• Basic use (with free support) • Advanced use (additional charge) • Mail-in and proxy measurement (additional charge) ※ Details under consideration
Usage Fee		• Non-exclusive ownership results: only the actual cost of consumables goods • Proprietary Results: 480,000 yen/8 hours • Non-proprietary results (priority use): 131,000 yen/8 hours ※ Separately, there is a charge for consumables goods	• General task: Only the actual burden consumables actual cost • Proprietary Results: actual cost of consumables + beam usage fee	• Enrollment fee 50 million yen (per unit) • Usage fee: 35,000 yen/hour (2022 subscription) • Considering other options
Task application		• Based on user needs, call for proposals will be increased from 2 times a year to 6 times a year. • All assignments are submitted online	• Twice a year (Examination /addition while monitoring the conditions)	• BL reservation method is as follows (interim report) • Monthly application is possible • Reservations for all members are confirmed up to one month in advance • (Primary selection) • Platinum members and special gold members can reserve up to 7 days in advance (secondary selection) • All members can make reservations up to 2 days in advance if there are vacancies (tertiary selection)
Task Examination		• Task examination will be conducted 5 months before the start of use, and then the selection committee will decide. • Notification of acceptance/rejection from the registration agency 1.5 months before the start of use • ※Average period for twice-yearly public offerings	• Under review (※Details to be discussed with the registration agency)	
Conducting experiments		• User support by registration agencies • Technical guidance support when using facilities • Conduct user satisfaction surveys to reflect user needs • Strengthening technical and research capabilities of staff by focusing on securing and training human resources	• User support by registration agencies	• PhoSIC staff provides basic guidance on measurement as user support • Strategic collaboration with academic partners • Mail-in and measurement agency services are charged (details under review)
Data analysis and interpretation of results		• Performed independently by users, but respond appropriately to consultations	• Implemented independently by users	• Basic guidance on data processing and analysis is provided as user support. • Advanced offers fee-based services such as analysis (under review)
Method of publication of results (non-proprietary results)		• User submits experiment report within 2 months after experiment • The user publishes the paper within 36 months after the experiment (※extension possible)	• Under review • (※Details to be discussed with the registration agency)	
Usage fee payment (Proprietary Results)		• Payment to registration authority within 2 months after receipt of invoice	• Under review • (※Details to be discussed with the registration agency)	• Billing to members after use (details under review)
Revision schedule		• Based on user needs, there is a plan to improve the complex usage system by reviewing the long-term usage system	• Discuss with the registration agency based on the issues that emerged from common experiments	• In order to secure incentives for securing early construction costs and to ensure sustainability during the operation period, usage fees in are planned to be revised from now on
Information provision to users		• Introduction of case studies in user information magazines such as booklets • Facility tour • Website • Dissemination and public awareness events including online ones (WS, workshops, study groups, training courses, etc.) • School (summer school, autumn school) • SPring-8 symposium, industrial use	• Website • QST International Symposium • Japanese Society of Synchrotron Radiation Annual Meeting of Japan Synchrotron Radiation Society and Synchrotron Radiation Science • Nano Terrace General Tour • Scheduled to be serialized in a newspaper series • QST press conference • Etc.	• Coalition conference (twice a year) • End station usage technology briefing session • Meeting at the Society of Synchrotron Radiation • Trial use in Miyagi Prefecture, Sendai City, etc. • International Synchrotron Radiation Facility Forum • Other outreach (dissemination through newspapers, television, YouTube, pamphlets, facility visits, websites, various meetings, citizen lectures, etc.), etc.

Source: Japan's Ministry of Education, Culture, Sports, Science and Technology

7.2 Utilization System for Promoting Industrial Use and Industry-Academia Collaboration

7.2.1 Current Situation

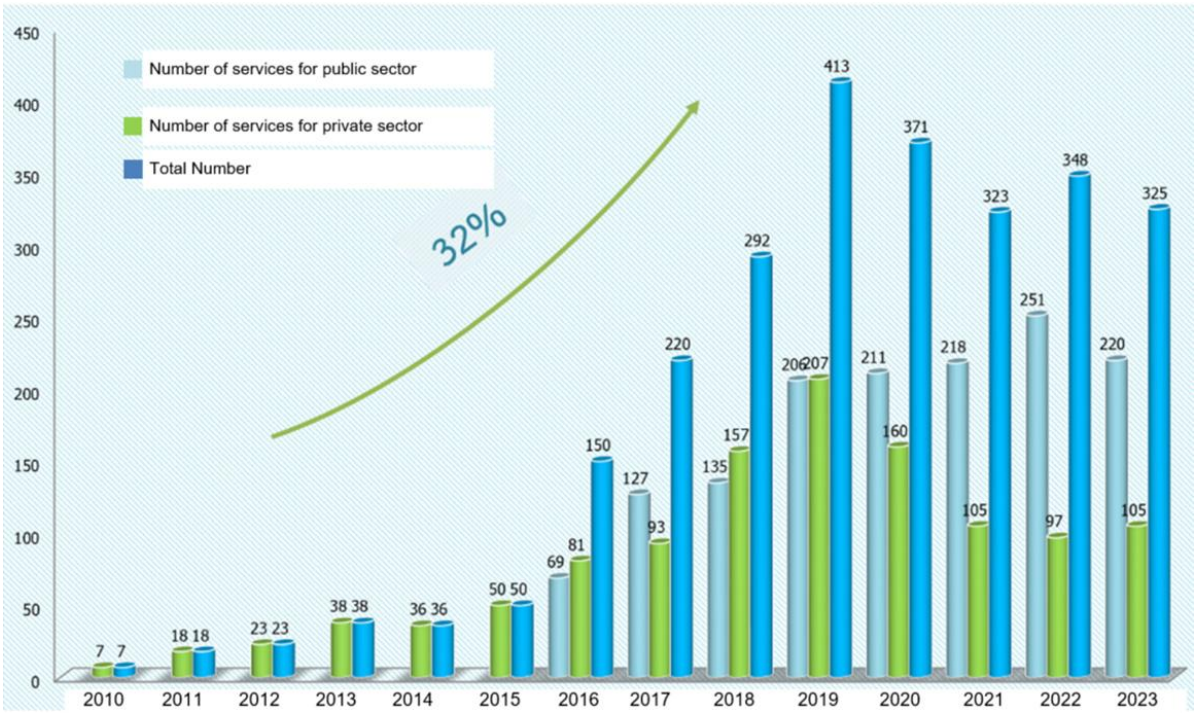
(1) SLRI: Synchrotron Light and Related Technology Services

Synchrotron Light Research Institute (Public Organization) began providing services to external agencies, both government and private sectors since 2010. The institute provides a total of 6 services, namely (1) Synchrotron Light Technique Service, (2) Technical and Engineering Service, (3) Research Service, (4) Consulting Service, (5) Basic Scientific Instrument Service and (6) Other services such as technology transfer, renting space, sale of souvenirs, etc. These outstanding and diverse properties of synchrotron light can be applied in research studies, problem solving, and product development, and as a result, more agencies from the government (including the education sector) and private sectors have come to use the service, reflected on a compounding annual growth rate (CAGR) of 32 percent of the number of projects that are receiving services from the institute.



Source: SLRI

Figure 7-1 SLRI Service Platforms



Source: SLRI

Figure 7-2 Synchrotron Light Service Statistics and Related Technologies (Fiscal Year 2010-2023)

The number of services provided was low from 2010 to 2015, but increased rapidly after 2016, peaking in 2019 with 413 cases. However, it has been declining since 2020, possibly due to the COVID-19 pandemic. The number of services for private sector increased from 2016, reaching 207 cases in 2019, but declined after 2020, halving to 97 cases in 2022.

In Figure 7-2, the total number of services provided to the private sector from 2012 to 2022 is 1,047, of which 1,024 are shown in the table below by industry and service type.

Table 7-10 Summary of SLRI Services for Private Sector: By Industry and Service (2012 to 2022)

Industry	Scientific Instrument Services	Technical and Engineering Services	Synchrotron Light Services	Research Solutions Services	Total
Food & Agriculture	161	2	60	26	249
Rubber & Polymer	134	12	52	1	199
Automotive	137	0	3	0	140
Pharmaceuticals & Cosmetics	84	0	15	4	103
Metals & Ceramics	50	4	25	0	79
Electronics & Micro components	52	6	21	0	79
Petroleum & Chemicals	14	1	28	2	45
Textiles	0	0	3	0	3
Others	74	19	34	0	127
Total	**706**	**44**	**241**	**33**	**1024**
%	**68.9**	**4.3**	**23.5**	**3.2**	**100.0**

Source: SLRI

SLRI provided 241 synchrotron light services from 2012 to 2022, which is 23.5% of the total services. The industries in which it was most used were "food and agriculture (60 cases)," "rubber and polymer (52 cases)," "metals and ceramics (25 cases)," "electronics and micro components (21 cases)," and "petroleum and chemicals (28 cases)." The main applications of synchrotron light services in the food and agriculture industry are to analyze the ingredients and quality of food, and in the rubber and polymer industry to analyze the structure of materials. In the metals and ceramics, as well as the electronics and micro components industries, it is used for precise material evaluation and improvement of manufacturing processes. On the other hand, it is less used in automotive (3 cases) and textiles (3 cases) industries. From the data, it is understood that synchrotron light services are used mainly in certain fields. Further industrial applications are expected in the future.

(2) Analysis of Potential Customers

SLRI conducted an industry analysis to identify potential Thai industrial customers for a next-generation SRF. SLRI's analysis included companies listed on the Stock Exchange of Thailand (SET) as well as unlisted but well-known companies. The evaluation was based on the following criteria:

1. Enterprise Value (EV)
    - A company’s market value is compared to the industry average to calculate a score.
    - If the EV is higher than the industry average, a score of 100 is awarded.
2. Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA)
    - A company's profits (EBITDA) are compared to the industry average and rated.
    - If EBITDA is above the industry average, it gets a score of 100; if it is below the industry average, it gets a score of 0.
3. Research, Development and Innovation
    - Analyze the company's business operations and evaluate how much synchrotron light technology can contribute to problem solving, as well as research and development.
4. Company Image
    - Evaluate the company's interest and potential in industrial research and technological development.

Each evaluation item was scored out of 100, and the overall score was calculated using a comprehensive evaluation methodology. If any item scored 0, the overall score was also 0. This is used as an indicator by SLRI to identify promising companies and conduct more effective marketing activities. The evaluation criteria and calculation method are summarized in the table below.

Table 7-11 Evaluation Standards and Calculation Method

Evaluation Item	Evaluation Standards and Calculation Method
EV Score	Enterprise Value (EV) is an indicator of a company's management strength as viewed by the market. If a company's EV exceeds the industry average EV, it is awarded 100 points. $\text{EV Score} = \frac{Concerned\ Enterprise'\ s\ EV\ Score}{EV\ Average\ Score} x100$
EBITDA Score	A company's profitability reflects its management capabilities, production processes, product and service development, marketing and public relations activities, and R&D capabilities in the field of science and technology. If a company's EBITDA exceeds the industry average EBITDA, it will be given a score of 100. If the EBITDA is negative, it will be given a score of 0. $\text{EBITDA Score} = \frac{Concerned\ Enterprise's\ EBITDA\ Score}{EBITDA\ Average\ Score} x100$ If EBITDA > average EBITDA, EBITDA score will be 100 If EBITDA < 0, EBITDA score will be 0
Research Score	Evaluated items are (1) the company's image, (2) the details of the business (including areas where scientific research and development can be conducted) - for example, in the agricultural related industry, this would include agricultural production processes, nutritional value, food processing processes, etc. - and (3) the opportunities to utilize scientific research and development to solve or develop business problems.
Total Score	$\text{Total Score} = \sqrt{\sqrt{EV\ Score\ x\ EBITDA\ Score}\ x\ Research\ Score}$

Source: SLRI

Based on the final score calculated using the above method, the companies are classified as follows:

- Score 50-100: Companies with the potential to build R&D business partnerships
- Score 25-49: Companies with the opportunity to build ongoing relationships or develop new collaborations to promote scientific and technological innovation
- Score 1-24: Companies that could become targets for SLRI to approach in the future

Table 7-12 Evaluation Standards and Calculation Method

Industry	Number of companies with final score:			Companies with final score of 25 or more (score)	Companies with experience of using synchrotron services*
	50-100	25-49	1-24		
Agriculture	1	3	4	Mitr Phol Sugar Corp. Ltd. & Group (82) Sri Trang Group (42) Thai Wah (37) Univanich Palm Oil (31)	1
Food	7	7	23	Charoen Pokphand Foods (CPF) (100) Thai President Foods (100) CP RAM (100) Thai Union Group (97) Betagro (80) GFP-T (72) Eastern Polymer Group (63) Thai Vegetable Oil (49) NR Instant Produce (37) Asian Sea Corporation (36) Malee Group (36) Thai Coconuts (35) Sappe (34) Thai Foods Group (32)	2
Biotechnology	14	8	11	PTT Global Chemical (100) Bangchak Corporation (100) Demco (100) PTT (Thailand's oil and gas) (100) SCG Packaging (97) Banpu (95) IRPC (95) Mitr Phol Sugar Corp. Ltd. & Group (82) Khon Kaen Sugar Industry (78) Singha Estate (78) Thai Agricultural International Sugar Company Limited (75) Gulf Energy Development (71) Eastern Polymer Group (63) Kraburi Sugar Group (55) Buriram Sugar (47) NR Instant Produce (37) Malee Group (36) Global Green Chemicals (35) BBGI (35) North East Rubber (32) Thai Eastern Group (32) Toray Textiles (Thailand) (27)	4
Plastics and polymer	3	2	4	Siam Cement Group (SCG) (100) TPI Polene (100) Eastern Polymer Group (63) Apico Hitech (32) Toray Textiles (Thailand) (27)	1

Industry	Number of companies with final score:			Companies with final score of 25 or more (score)	Companies with experience of using synchrotron services*
	50-100	25-49	1-24		
Steel and metals	3	1	25	Sahaviriya Steel Industries (100) PTT Exploration and Production (PTTEP) (100) Eastern Polymer Group (63) Apico Hitech (32)	2
Advanced materials and packaging	13	7	15	Siam Cement Group (SCG) (100) PTT (Thailand's oil and gas) (100) CP RAM (100) TOA Paint (Thailand) (98) SCG Packaging (97) Supalai (95) IRPC (95) Tipco Asphalt (91) Saraburi Cement (97) SCG Decor (84) SC Asset Corporation (80) Pruksa Holding (59) Wanachai Group (54) Polyplex (Thailand) (44) TMT Steel (34) BG Container Glass (33) Land and Houses (32) S. Kijchai Expertise (28) Toray Textiles (Thailand) (27)	1
Rubber and tires	1	5	8	Sri Trang Agro-Industry (50) Sri Trang Gloves (Thailand) (42) North East Rubber (32) Univentures (28) Innova Rubber (Thailand) (27) Goodyear (Thailand) (26)	0
Solar power and clean energy	14	0	8	BCPG (100) B.Grimm Power (100) Energy Absolute (100) Global Power Synergy (100) PTT (Thailand's oil and gas) (100) Banpu (95) Electricity Generating Authority of Thailand (EGAT) (87) Rojana Industrial Park (86) Singha Estate (78) CK Power (71) Gulf Energy Development (71) Bangkok Aviation Fuel Services (65) WHA Corporation (50) Banpu Power (50)	0

Industry	Number of companies with final score:			Companies with final score of 25 or more (score)	Companies with experience of using synchrotron services*
	50-100	25-49	1-24		
Battery	4	0	0	Energy Absolute (100) Global Power Synergy (100) Next Point (100) Thai Energy Storage (TES) (100)	0
Medical care, public health, pharmaceuticals, health, cosmetics	7	11	9	PTT (Thailand's oil and gas) (100) CP RAM (100) TOA Paint (Thailand) (98) Bangkok Dusit Medical Services (BDMS) (89) Mega Lifesciences (73) Pruksa Holding (59) Big C Retail Corporation (50) HomePro Center (50) S&J International Enterprise (39) NR Instant Produce (37) Thai Wah (37) RS (36) BBGI (35) Bumrungrad International Hospital (32) Univentures (28) Chiangmai Ram Medical (27) Namwiwat Medical (25) Karmarts (25)	0
Semiconductor	3	2	4	BCPG (100) Banpu (95) Cal-Comp Electronics (Thailand) (50) Hana Microelectronics (47) KCE Electronics (45)	0
Environment	7	1	6	TPI Polene Power (89) Saraburi Cement (87) Singha Estate (78) CK Power (71) Eastern Water Resources Development and Management (EASTW) (59) WHA Corporation (50) Banpu Power (50) Polyplex (Thailand) (44)	0
Total	77	47	117	(Some companies are counted twice)	11

* Number of companies that have past experience of using synchrotron services, among the companies with final score of 25 or more.

Source: JST, based on data from SLRI

Through this analysis, SLRI was able to clarify the main customer base for the next-generation SRF. In particular, SLRI selected companies listed on the SET that are active in research and development as targets. Going forward, SLRI plans to utilize the results of this analysis to strengthen collaboration with target companies and promote the industrial use of synchrotron radiation technology.

(3) Various Technical Seminars

SLRI has been proactive in transferring knowledge and technologies to private sectors in the past 4 years from 2019-2022 (119 times) in which the synchrotron light utilization and technology related has been presented to the companies either directly or online (COVID-19 from 2020 - 2021) as shown respectively in Figure 7-3 and Figure 7-4. In addition, the institute has welcomed public and private entities whom have come to discuss / visit a total of 73 times, along a total of 731 visitors. Most of the industry groups that have come for visit and discussions were from the food industry, agriculture, medicine, cosmetics and materials science fields. The details of some activities are shown in Figure 7-5. The purpose of these events was to build confidence and demonstrate the readiness of the synchrotron laboratory and basic science laboratory of the institute.



PTT Exploration and
Production Public Company Limited



Federation of Thai Industries

Source: SLRI

Figure 7-3 Examples of Technology Transfer/ Meeting with the Private Sector and Related Agencies (Fiscal Year 2019-2020)



MMP Corporation Company Limited



Beautiful Mom Company Limited

Source: SLRI

Figure 7-4 Examples of Technology Transfer/ Meeting with the Private Sector and Related Agencies (Fiscal Year 2021)



Saha Group Industrial Park and
Lion Corporation (Thailand) Limited



Baramizi Company Limited

Source: SLRI

Figure 7-5 Examples of Technology Transfer/ Meeting with the Private Sector and Related Agencies (Fiscal Year 2022)

(4) MHESI

The Higher Education Sandbox is a higher education policy which MHESI is implementing to provide innovative higher education programs with industry-academia collaboration. The Higher Education Sandbox is a higher education system launched by MHESI based on Article 69 of the Higher Education Law B.E.2562 with the aim of innovatively improving the conventional higher education curriculum and program to meet the human resource development needs of the industry. Higher education programs under this system are required to develop a curriculum in collaboration with the industry. It is possible to develop a curriculum without being bound by the conventional school period (4 years of bachelor's degree) or curriculum and syllabus requirement, which enables to develop more practical and innovative curriculums that meet the needs from the private sectors.

Whether MHESI will come up with a policy or specific program to support industry-academia collaboration in SPS-II is an issue for future consideration, but it is recommended to consider developing a new curriculum for raising synchrotron engineers and researchers using the Higher Education Sandbox system in collaboration with Thai universities and companies.

(5) EECi

EECi is a special economic zone project in charge of NSTDA under the jurisdiction of MHESI. As mentioned, NSTDA has already established BIOPLIS, ARPOLIS, and SPACE POLIS in EECi as research institutes to promote industry-academia collaboration and has begun providing industry-academia collaboration services such as pilot plants and R&D consulting services.

According to the hearing held during the field survey in February 2023, NSTDA had not planned any programs aiming development of an industry-academia collaboration for SPS-II at that time. Coordination with NSTDA for promotion of industrial collaboration with SPS-II is an issue for future consideration.

7.2.2 Future Plan

There is no future plan for a utilization system that promotes industrial use and industry-academia collaboration in SLRI, MHESI and EECi so far, as they are expected to be developed after the demand survey for SPS-II has conducted.

7.3 Utilization System to Prevent Military Use

Under the Japan's Official Development Assistance Charter (March 2003), the principles of Japan's ODA are as follows.

(1) Environmental conservation and development should be pursued in tandem.
(2) Any use of ODA for military purpose or for aggravation of international conflicts should be avoided.
(3) Full attention should be paid to trends in recipient countries' military expenditures, their development and production of mass destruction weapons and missiles, their export and import of arms, etc.
(4) Full attention should be paid to efforts that promote democratization, the introduction of a market-oriented economy, and situations that secure basic human rights and freedoms in the recipient country.

Based on the above-mentioned (2) and (3) principles of Japan's ODA , both SLRI and JST confirmed that SPS-I had not been used for any military purpose and SPS-II also shall not be used for any military purpose nor to aggravate international conflicts in the future.

8 Operation and Maintenance (O&M) Plan

As mentioned in Chapter 2, SLRI does not outsource any O&M works of SPS-I, so SLRI is entirely responsible for all O&M works. Similarly, for SPS-II, SLRI has not planned to outsource any O&M work as it will be done in-house.

The detailed O&M plan for SPS-II is still under consideration. It will follow the O&M mechanism and method used in SPS-I, but upgraded and updated following the design of SPS-II. This O&M mechanism can be referred to in Section 2.3.4.

When designing the O&M plan for SPS-II, it is recommended for trainees to be dispatched to overseas SRFs for OJT (described in Chapter 9), to be given verification of O&M plans at designated facilities as task and expected to give feedback to build the O&M plan of SPS-II. The organization structure after 2033, which was planned in consideration of SPS-II O&M, is described in the next section.

8.1 O&M Management and Related Organizations

SLRI plans to reorganize its structure twice, once in February 2023 (done already) and then in 2033, having the O&M of SPS-II in mind. The details of these two reorganizations can be referred to in Chapter 9 and the organization chart after the second organizational restructuring (2033) can be seen in Figure 8-1.

After 2033, 4 Divisions and 12 Sections, under the jurisdiction of the SPS-II Deputy Director, will be in charge of O&M of SPS-II. The total number of staff in SLRI will become 352, from which 166 people will be assigned to these 4 Divisions and 12 Sections, as summarized in the following table.

Table 8-1 Staffing Plan of 4 Divisions and 12 Sections

Division / ***Section***	**2033**
Light Source Division (SPS-II)	37
SPS-II Operation & Maintenance Section	*15*
Accelerator Research & Development Section	*22*
Beamline Division (SPS-II)	56
SPS-II Beamline Operation Section	*31*
Applications R&D Section	*25*
Instrumentation Development Division (SPS-II)	20
Instrumentation Development Section	*20*
Engineering & Utility Division (SPS-II)	53
Mechanical Section	*11*
Fabrication Section	*8*
Building Section	*8*
Electrical Engineering Section	*9*
Control System Section	*8*
IT Section	*7*
Automation AI Section	*2*
Total	166

Source: SLRI

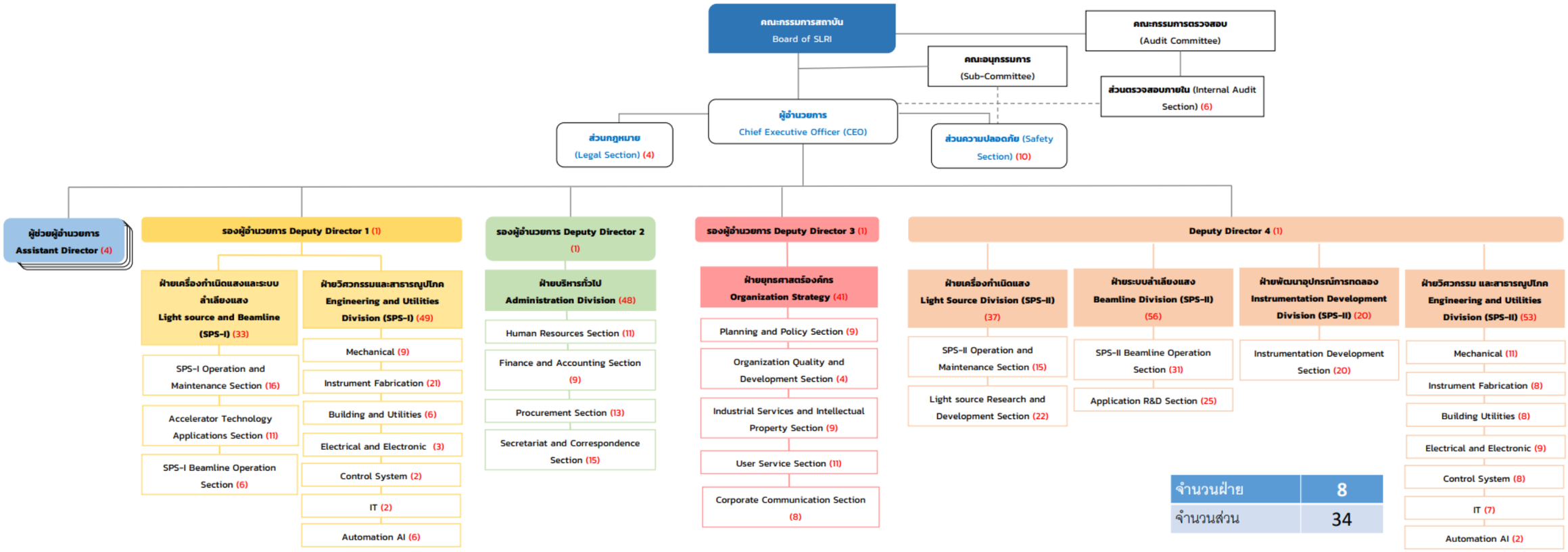
These 166 staff are to engage in the following duties related to the O&M of SPS-II:

1) Accelerator operation and maintenance work
2) Beamline maintenance and R&D support
3) Operation monitoring, maintenance, and inspection of utility facilities
4) Safety management work

User services, academic support, industrial and public linkages, corporation communications, strategic planning, procurement and finance, human resource management and development are under the Organization Strategy Division and the Administration Division, which will be responsible for the institute as a whole by working remotely for both SPS-I and SPS-II facilities.

Regarding the O&M system in the SPS-II, compared to SPring-8, 166 staff will work for 7 beamlines, which is considered to be sufficient in terms of number of personnel compared to SPring-8, while about 390 staff works for 40 beamlines[29] in SPring-8. Regarding the technical capabilities of personnel, considering that many of the 166 staff will be newly hired and the existing staff lacks experience in working at the next-generation synchrotron radiation facility, sufficient human resource development through human resource programs referred in the Section 9.4 is absolutely important. Expenses related to O&M are summarized in エラー! 参照元が見つかりません。.

[29] 14 RIKEN beamline and 26 public beamlines as of October 2022



Source: SLRI

Figure 8-1 Organization Structure after 2033

9 Human Resource Development (HRD)

This chapter aims to examine the human resource development (HRD) plan for the SPS-II project. Prior to describing the plan details, the organizational restructuring plan, the project team formation, and the academic degree status and recruitment plan will first be discussed, followed by the HRD plan.

9.1 Organizational Restructuring of SLRI

SLRI is planning to have two organizational restructurings, the first in 2023 and a second one in 2033, in preparation for the implementation of the SPS-II project. Accordingly, the first reorganization was carried out in February of 2023.

Before this first reorganization, SLRI consisted of 6 Departments and 26 Divisions under 1 Director and 2 Deputy Directors, which was reorganized into 10 Divisions and 43 Sections under 1 Director and 4 Deputy Directors. In the second reorganization planned for 2033, SLRI will be reorganized into 8 Divisions and 38 Sections under 1 Director and 4 Deputy Directors.

As of February 2025, SLRI employs a total of 231 staff, in which 21 staff are working under the SPS-II Development, which is divided into 2 divisions, which are the SPS-II Project Management Division and the SPS-II Technology Development Division. SPS-II Development under SLRI is responsible for formulating the master plan of the Project, getting the cabinet approval and completing all the relevant governmental processes, as well as designing the machine and developing necessary prototypes. The SPS-II Project Management Division is responsible for planning, project formulation, governmental processes, budgeting, human resources, legals, as well as building design. On the other hand, the SPS-II Technology Development Division is responsible for technical issues, including accelerator and beamline design, accelerator physics, beamline optics, experimental station design, and prototype development.

The number of SLRI staff is planned to increase to 352 in 2033 when the second reorganization is completed, by recruiting 121 new staff. The recruitment and allocation plan for these 140 people is summarized in the table below.

Table 9-1 Staffing Plan of SLRI

Position/divisions	Feb 2023	Sept 2024	Feb 2025	Before Procurement (2027)	Before Construction/ Manufacturing (2028)	Before Assembly/ Installation (2030)	Before Project Completion (2033)
Deputy Directors	4	4	4	4	4	4	4
Assistant Directors	4	3	3	3	3	3	3
Administration Division	36	36	38	44	47	51	52
Organization Strategy Division	24	23	24	27	33	37	39
SPS-I Operation Division	18	18	19	22	24	24	24
Accelerator Research and Development Division	7	8	10	11	11	11	11
Beamline Division	28	30	33	33	35	38	43
Synchrotron Research and Applications Division	15	16	16	16	17	19	20
Mechanical System Development and Utilities Division	31	33	33	40	52	53	53
Technical and Engineering Development Division	22	22	23	23	27	35	37
SPS-II Project Management Division	8	8	10	17	20	21	21
SPS-II Technology Development Division	6	9	11	24	31	32	32
Safety Section	5	5	5	6	7	9	9
Internal Audit Section	3	2	2	2	3	4	4
Total	211	217	231	272	314	341	352

Source: SLRI

In the second reorganization (implemented from 2030), for the operation and maintenance of SPS-II, 4 Divisions will be established under the jurisdiction of the Deputy Director in charge of SPS-II, and 166 staff will be allocated under these 4 Divisions as shown in the table below.

Table 9-2 Personnel Composition of Departments Related to the SPS-II Project

Division / ***Section***	**2030**
Light Source Division (SPS-II)	37
SPS-II Operation & Maintenance Section	*15*
Accelerator Research & Development Section	*22*
Beamline Division (SPS-II)	56
SPS-II Beamline Operation Section	*31*
Applications R&D Section	*25*
Instrumentation Development Division (SPS-II)	20
Instrumentation Development Section	*20*
Engineering & Utility Division (SPS-II)	53
Mechanical Section	*11*
Fabrication Section	*8*
Building Section	*8*
Electrical Engineering Section	*9*
Control System Section	*8*
IT Section	*7*
Automation AI Section	*2*
Total	166

Source: SLRI

9.2 SPS-II Project Team

Apart from the organizational staffing plan mentioned above, SLRI has already started the selection of members for the SPS-II Project Team, for which 55 existing staff and 9 external contract staff have been selected, but yet to be finalized. The following table summarizes the draft of the SPS-II Project Team by component / task.

Table 9-3 Staffing Plan for SPS-II Project Team

Component / Task	As of 2025			Before the start of procurement (2027)			Before the start of construction works (2028)		
	Full-time Staff	Concurrent	Temporary Staff	Full-time Staff	Concurrent	Temporary Staff	Full-time Staff	Concurrent	Temporary Staff
Project Leader and deputy leaders	**1**	**2**		**1**	**2**		**1**	**2**	
SPS Project Management	**3**	**22**	**4**	**8**	**31**	**4**	**9**	**31**	**4**
Project Coordination Office	3		1	8		1	9		1
Procurement		5	1		7	1		7	1
Finance		3	1		4	1		4	1
Others (legal, budgeting, HR, marketing, PR, etc)		14	1		20	1		20	1
Accelerator	**7**	**29**	**10**	**17**	**38**	**10**	**24**	**47**	**10**
linac	1	3		2	4		3	5	
Beam Dynamics		3			3		1	3	
Beam Diagnostics	1	3		2	3		2	3	
Magnet System	3	1	5	4	2	5	6	2	5
Vacuum System	1	4	4	3	7	4	4	10	4
RF System		6	1	2	6	1	2	6	1
Control System		3		1	4		2	5	
Magnet Power Supply System		2		1	3		1	5	
Girder and Magnet Positioning System	1	4		2	6		3	8	
Beamline	**4**	**27**	**5**	**6**	**27**	**5**	**6**	**32**	**5**
Beamline center	4			4			4		
Insertion devices		2	1		2	1		2	1
Front ends + FEA		4			4			4	
Optics, monochromator, beamline diagnostics, integration		5	1	1	5	1	1	6	1
End stations, Detectors, Sample Environment		5	3		5	3		5	3
Control, Automation, Data Acquisition, Equipment Protection		4			4			5	
Hutch		2			2			2	
Beamline Vacuum		2		1	2		1	2	
Scientific Program and Future Beamlines		3			3			6	
Building and Infrastructure	**7**	**15**	**1**	**8**	**17**	**1**	**10**	**24**	**1**
Building and Utility	4	2		5	2		6	8	
Survey and Alignment	2			2	1		3	1	
Radiation Protection and Safety System	1	10		1	11		1	11	
IT Infrastructure		3	1		3	1		4	1
System Integration and Sub-system Compatibility	**-**	**-**	**-**	**1**	**-**	**-**	**1**	**2**	**-**
Coordinator for System Integration									
Assembly, Integration and Test				1			1		
System Engineering Service								2	
Beam Commissioning									
Increase by	**-**	**-**	**-**	**19**	**20**	**0**	**10**	**23**	**0**
Sub-Total	**22**	**95**	**20**	**41**	**115**	**20**	**51**	**138**	**20**
Total	**137**			**176**			**209**		

Source: SLRI

9.3 New Recruitment Plan

SLRI legal entity is defined as a Public Organization, according to the royal decree of the 1999 Act, making its staff regarded as a government institution employee. Even though SLRI has some degree of discretion in setting the salary amount, its staff has no pension at retirement besides the pension set for a civil servant. The table below summarizes the current conditions for new recruitment.

Table 9-4 Condition of New Recruitment in SLRI

Type of employment	Contract base with 5-year period
Basic Monthly Salary (start) (For fresh graduated and without prior experience)	PhD: THB 38,000 for Engineer, Scientist and Physicist THB 26,674 for Administrator Master: THB 23,000 for Engineer and Laboratory Scientist THB20,610 for Administrator Bachelor: THB 18,300 for Engineer THB 15,000 for Administrator Diploma: THB10,623 for Technician
Other benefits	a. Medical treatment fee (200,000 THB / year) b. Medical treatment fee for family (70,000 THB /year) c. Dental treatment fee (5,000 THB / year) d. Dental treatment fee for family (3,000 THB / year) e. Tuition fee for children (4,000 THB /year) f. Bonus is not mandatory. It depends on the income of SLRI on that particular year.

Source: SLRI, prepared by JST

All SLRI staff don't have full (life)-time employment but are 5-year period contract-based. According to SLRI, the turnover ratio is quite low, and most contracts are renewed when requested.

9.4 Human Resource Development (HRD) Plan

SLRI has established the following guidelines for HRD based on the understanding that it is necessary to work under a sustainable HRD method for a smooth construction, operation and maintenance of the next-generation SRF (SPS-II).

Creating a Working Ecosystem involves creating a system that is conducive to mindset growth and working skills development, conducting the following schemes:

I. Developing incorporated Human Resources Management and Human Resources Development Systems
II. Determining the development approaches and methods that encourage learning participation and create learning supporting tools.
III. Creating an Organizational Culture that stimulates continuous self-development.
IV. Cultivating mindsets about working as a team in public services.
V. Creating an atmosphere that promote a good working-life quality.
VI. Networking domestically and internationally in HRD.

Based on the above, the following three programs are to be addressed during the Project implementation period.

1) On-the-Job Training
2) Human Resources Development Scholarship
3) Synchrotron School and Accelerator School

9.4.1 On-the-Job Training

Necessity of On-the-Job Training

SLRI has 231 staff as of February 2025 and among these, 64 have doctoral degrees in the fields of advanced science and technology, which suggests that SLRI is an institute with high research capabilities. However, there are no staff with experience in installation and calibration of the next-generation synchrotron equipment (accelerator and beamline). Thus, JICA advisors pointed out that it is important for this Project's success to reinforce this inexperience somehow. In addition, JICA advisors also suggested that one of the key factors for the future operation is to raise researchers able to master advanced measurement techniques, required by the next-generation synchrotron. Another important issue is the development of the engineers and technicians that are familiar with the operation and maintenance of a next-generation synchrotron.

Therefore, OJT at next-generation synchrotron radiation overseas facilities can be an effective tool to deal with these issues. At the initial stage of this Project, the installation of the next-generation synchrotron equipment (accelerators and beamlines) and the strengthening of the capabilities of the staff engaged in installation and commissioning of the next-generation synchrotron equipment (accelerators and beamlines) is the enhancement priority through OJT, and as this Project progresses, the target of OJT should be expanded to the acquisition of advanced beamline measurement technology and strengthening the capabilities of the staff engaged in research and development and operation management.

OJT Terms

SLRI plans two different schemes for OJT:

- Short-term OJT: up to 6 months
- Long-term OJT: up to 12 months

The short-term OJT is for the current SLRI staff, as they cannot leave Thailand for a long time due to their current tasks, whereas the long-term OJT is for the new staff to train the core manpower for O&M and R&D of SPS-II.

Candidates for Training Institutes

SLRI lists the following 10 institutes for acceptance of OJT:

- Photon Factory, KEK, Japan
- SPring-8, Japan
- NanoTerasu, Japan
- National Synchrotron Radiation Research Center (NSRRC), Taiwan
- Deutsches Electronen-Synchrotron (DESY), Germany
- Swiss Light Source (SLS), Swiss Confederation

- Advanced Light Source (ALS-U), Lawrence Berkeley National Laboratory, USA
- National Synchrotron Light Source II (NSLS-II), Brookhaven National Laboratory, USA
- ANSTO, Australia
- Diamond, UK
- ALBA, Spain
- SIRIUS, Brazil

SLRI has dispatched staff to international partner institutes for OJT and the following table summarizes its past record.

Table 9-5 Past Record of OJT

Institute	Year	Number of Participant
National Synchrotron Light Source II (NSLS-II) USA	2018	2
Shanghai Synchrotron Radiation Facility (SSRF) China	2017	9
Shanghai Synchrotron Radiation Facility (SSRF) China	2019	4
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2013	4
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2014	5
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2016	9
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2017	4
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2018	20
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2019	1
National Synchrotron Radiation Research Center (NSRRC) Taiwan	2020	7
	Total	65

Source: SLRI, prepared by JST

A total of 65 staff have been involved in OJT activities, but some participants did multiple trainings, making the actual number of participants 45. Also, SLRI dispatched 19 staff for OJT at SPring-8 in March 2023.

Implementation Plan of OJT

SLRI has planned the following OJT implementation (refer to **Attachment 5: Outline of OJT** for detail).

Table 9-6 Number, Annual Dispatch and Cost Estimation of OJT

Type		2025	2026	2027	2028	2029	2030	2031	total
Short-Term	No. of Trainees*	0(0)	0(0)	51 (51)	62 (62)	15 (15)	30 (30)	19 (19)	177 (177)
	Budget** (THB)	0	0	7,930,500	9,686,160	2,487,100	5,034,500	5,276,200	30,414,460
Long-Term	No. of Trainees*	2(0)	0(0)	1 (1)	2 (2)	3 (3)	0(0)	0 (0)	8 (6)
	Budget** (THB)	0	0	330,800	661,600	1,318,000	0	0	2,310,400
Total	No. of Trainees*	2(0)	0(0)	52 (52)	64 (64)	18 (18)	30(30)	19 (19)	185 (183)
	Budget** (THB)	0	0	8,261,300	10,347,760	3,805,100	5,034,500	0	32,724,860

* X (Y); X = number of trainees from all sources of funding; Y = number of trainees under OJT-PMC Program

** Budget only calculated from OJT-PMC Program (THB)

Source: SLRI

9.4.2 Human Resources Development Scholarships

SLRI positions the scholarship programs as an important tool for talent acquisition and development. Developing human resources to acquire specialized knowledge and advanced technology in fields such as particle accelerator physics, materials physics, system control engineering, electrical engineering, mechanical engineering, and biomedicine through master's and doctoral degrees at overseas graduate schools, raises the core human resources for the operation and maintenance, and research and development of the next-generation synchrotron. These scholarships benefit both the SLRI and each individual personnel's future career path.

SLRI has been using the scholarship programs for HRD and plans to actively use them for the SPS-II project. The following table summarizes representative scholarship programs in Thailand and the acquired number of scholarships by SLRI's staff in 2022.

Table 9-7 Available Scholarship Programs and Number in 2022

Scholarship Program	Number 2022
Scholarships from the Office of the Civil Service Commission (OCSC)	1
Scholarships to study in China through OCSC	
Scholarships in the field of science and technology from the Ministry of Higher Education, Science, Research and Innovation (MHESI)	2
Scholarships in the field of science and technology for supporting EECi (Eastern Economic Corridor of Innovation)	3
Scholarship from Thailand Academy of Science (TAS)	2
Total	8

Source: SLRI, prepared by JST

In total, 8 scholarships were awarded in 2022. If SLRI can sustain the same annual number of scholarships during the SPS-II Project period, it could greatly contribute to SLRI's recruitment plan. However, these scholarships are not allocated for SLRI, as they are approved based on proposals. Therefore, GOT or other agency should consider a stable provision of scholarships to SLRI for successful recruitment and HRD plans.

As previously mentioned, SLRI has actively utilized scholarships for its HRD and 58 of its current staff have PhDs, 40 of which were obtained in overseas universities. The following table shows the breakdown of PhDs by country.

Table 9-8 PhD by Country

Country	Number	%
Australia	1	1.7%
China	1	1.7%
Denmark	1	1.7%
France	1	1.7%
Germany	1	1.7%
Japan	5	8.6%
Switzerland	1	1.7%
Thailand	18	31.0%
United Kingdom	21	36.2%
United States	8	13.8%
Total	58	100.0%

Source: SLRI, prepared by JST

It is expected that the number of PhD holders from Japanese universities will increase as the SPS-II project will be implemented in cooperation with Japanese researchers.

9.4.3 Synchrotron School and Accelerator School

SLRI has been dispatching staff to international training in synchrotron application, beamline design and development, particle accelerator design and development. The representative international training schools are listed below.

- Hercules European School is a five-week course coordinated by the Université Grenoble Alpes (UGA). This school provides training for students, postdoctoral and senior scientists from European and non-European universities and laboratories, in the field of Neutrons, X-ray Synchrotron Radiation, and Free Electron Laser for condensed matter studies (Biology, Chemistry, Physics, Materials Science, Geosciences, and Industrial applications). Neutron and X-ray science is integrated with complementary techniques like (but not limited to) optical and electron microscopy, NMR, optical and THz spectroscopy. https://hercules-school.eu/
- CERN Accelerator School, which provides training for physicists and engineers in particle accelerator physics. CERN Accelerator School was established in 1983 with the main purpose of preserving and transmitting the accumulated knowledge at CERN and elsewhere, particularly on particle accelerators and colliders of all kinds. This provided a framework for a series of courses, either on general accelerator physics or on a specialized topic. https://cas.web.cern.ch/
- U.S. Particle Accelerator School (USPAS), which provides knowledge on high energy particle accelerator, particle accelerator and related fields, in their training curriculum. USPAS is a national graduate-level program that provides training and workforce development in the science and technology regarding charged particle accelerators and associated systems.
  https://uspas.fnal.gov/index.shtml

- The Asia-Oceania Forum for Synchrotron Radiation School (AOFSRR School), which is aimed at science and engineering graduate students, postdoctoral fellows, and early career researchers from across the Asia-Oceania region who are interested in pursuing a career in synchrotron radiation related fields. This school will present a range of lectures and practical sessions related to the theory and applications of synchrotron radiation to a wide range of science and technology researchers.

These schools provide the necessary knowledge required for the development and operation of SRF and related research works. It is recommended to use these schools, especially for young human resources.

The following table summarizes past records of participation at these schools.

Table 9-9 Participation Record to Synchrotron and Accelerator Schools

School	Record
Hercules European School	2015: 2 2016: 1 2018: 1
CERN Accelerator School	2014: 2 2018: 2
U.S. Particle Accelerator School (USPAS)	2015: 4 2016: 2
AOFSRR School (after 2017) Cheiron School managed by SPring 8 (2011 to 2015)	2011: 2 2012: 3 2013: 2 2014: 2 2015: 3 2017: 2 2018: 2 2019: 2

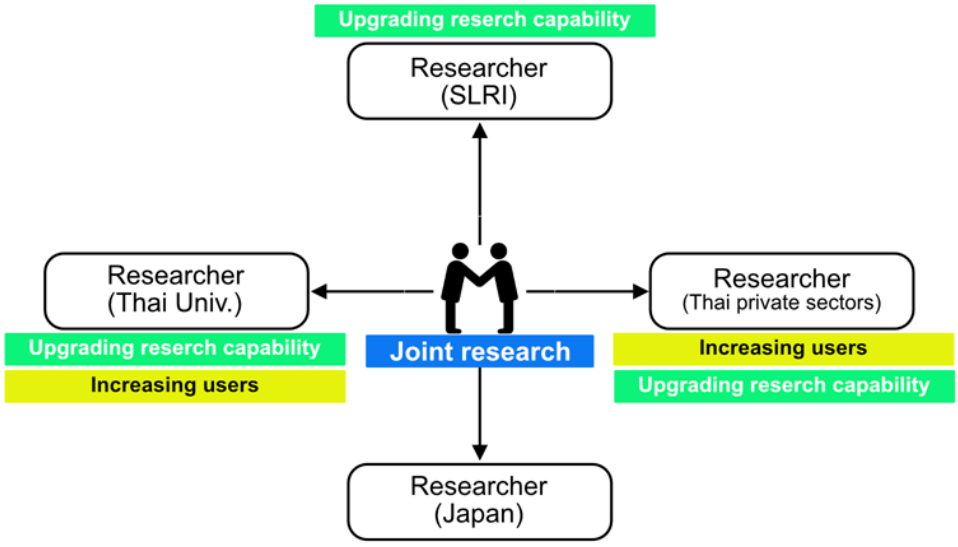
Source: SLRI, prepared by JST

9.4.4 Training by Invited Experts

As previously mentioned, there is a plan to invite multiple experts from overseas during the engineering designs and the installation & commissioning of equipment. When taking this opportunity, on-site trainings from these invited experts, grouped to their specialized training contents with selected trainees, is recommended. It was verbally confirmed that the cost estimation for this Training by Invited Expert was THB 200,000 per one-month stay.

9.4.5 Joint Research Program

Various HRD programs are planned for the SPS-II project, on the premise this HRD is exclusive to SLRI staff. However, the joint research program introduced in this section, is a program that not only improves and updates the researchers' capabilities but also allows training to researchers at research institutes other than SLRI by conducting joint research. Joint research has been carried out between SLRI and research institutes or universities, so by systematically implementing the joint research program, different types of research institutes especially in the private sector can be involved.



Source: JST

Figure 9-1 Joint Research Program

Figure 9-1 shows a schematic diagram of the joint research program based on the formation of research teams by universities, research institutes, and private companies in and outside of Thailand. SLRI researchers are expected to participate in the joint research team as members and along with the development of advanced beamline technology in the future, they will be able to collaborate with other research institutes and companies to develop innovative beamlines and measurement methods. In addition, diverse measurement methods can be learned by conducting appropriate procedures of the targets from the counterparts.

Joint research will not only improve the capabilities of SLRI researchers, but also will raise needs and issues regarding the SPS-II beamline from other research institutes and private companies through the joint research activities, which shall be used as feedback to future SLRI beamline installation plans. As a result, an increase in the number of SPS-II beamline users can be expected, other researchers can improve their research capabilities related to synchrotron radiation technology.

MHESI or other research funding agency in Thailand should consider setting up the necessary research funds to implement this joint research program and using existing programs such as the Science and Technology Research Partnership for Sustainable Development Program (SATREPS).

9.4.6 Establishment of Academic Program in Synchrotron Technology

Although it overlaps with the purpose of the previous section, nurturing a wide range of human resources in the field of synchrotron radiation science and technology whom can work not only in SLRI but also other research institutes, especially in R&D at the private sector, is significantly important to increase the number of future users for the SPS-II, improving the effectiveness of this Project. Therefore, academic programs specializing in synchrotron radiation technology research should be set up to expand HRD. Suranaree University of Technology and Khon Kaen University, the main users of SPS-I, and VISTEC are possible candidates. It is also suggested to develop a program in collaboration with industries by utilizing the Higher Education Sandbox promoted by MHESI, as described in Section 7.2.1.

10 Japan Study Trip (J-Trip)

Japan Study Trip (hereinafter referred to as "J-Trip") is a study trip program titled "Learning from Similar SRFs in Japan," as the human resource development part of the Preparatory Survey. The 10 participants sponsored with JICA budget are officials belonging to SLRI and the Ministry of Finance (PDMO). The other 20 participants from SLRI Executive Board, SLRI Sub-committee, Budget Bureau, DKW Consortium, and InterPAC joined with their respective budget.

10.1 Objective

The objective of J-Trip is as follows.

- To share technology utilized in Japan's next generation SRF
- To share facility management and examples of industrial use and industry-academia collaboration
- To promote understanding of the synchrotron radiation research field in Thailand and HRD

10.2 Schedule

Upon thorough coordination with SLRI, the J-Trip was conducted from 26 March 2023 to 1 April including travel days. RIKEN helped the JST to coordinate the site visit to their SRF, which are the NanoTerasu in Miyagi Prefecture, and SPring-8 in Hyogo Prefecture. The schedule is shown below.

Table 10-1 Program Schedule of J-Trip 2023

Date		Activity	Program	Contents
Sat, 25 March	22:50-	Travel	Departure from Bangkok (NH850)	
Sun, 26 March	-06:30	Travel	Arrival in Tokyo (NH850) Travel from Tokyo to Miyagi	
Mon, 27 March	10:00-12:00	Site Visit	Visit to NanoTerasu (next generation SRF)	Introduction and explanation of characteristics of NanoTerasu, and the collaboration concept from the perspective of next-generation SRF
	14:00-16:00	Lecture	Industry-Academia Collaboration Using Synchrotron Radiation (by Photon Science Innovation Center (PhoSIC))	Introduction of NanoTerasu, which promotes the concept of an Innovation Ecosystem, from the perspective of PhoSIC, which started the collaboration concept.
Tue, 28 March	10:00-12:00	Site Visit	Visit to Research Center for Electron Photon Science (ELPH), Tohoku University	Visit to the university's unique research institutes, including a large electron accelerator, nuclear physics, radioisotope production, and terahertz light science. This can be applied to the current operation of SPS-I, which is also related to electron accelerators at SLRI, and potential future initiatives.
	13:30-14:30	Discussion	Online discussion with JICA and JST	
	15:00-16:00	Lecture	Introduction to Research Complex's Initiatives (by Sendai City Hall)	Explanation of efforts to form a research complex in collaboration with NanoTerasu from the perspective of Sendai City Hall.

Date		Activity	Program	Contents
Wed, 29 March	10:00-12:00	Lecture	Initiatives Promoting Industrial Collaboration with Next-Generation SRF (by NTT Urban Development as an SRF user)	Learning on how to promote industrial use of the NanoTerasu next-generation SRF, utilizing the Urbannet Sendai Central Building, from NTT Urban Development, with which we have a collaboration agreement.
	PM	Travel	Travel from Miyagi to Hyogo	
Thu, 30 March	09:00-12:00	Discussion	Discussion with RIKEN regarding SPring-8	Introduction to SPring-8 and learning about energy-saving technologies for accelerators and beamlines in the SPring 8-II project, examples of calculations of economic ripple effects, and alignment with the ultimate objectives of the project.
	13:00-16:00	Site Visit	Visit to SPring-8, SACLA and NewSUBARU	
	16:00-18:00	Discussion	Discussion with RIKEN, JICA and JST	
Fri, 31 March	09:00-12:00	Discussion	Discussion with RIKEN, JICA and JST (core participants only)	Discussion regarding the maintenance system (particularly the system, roles and number of personnel for assembling and integrating the accelerator) and operation, that has been learned from case studies.
Sat, 1 April	10:50-15:30	Travel	Flight from Tokyo to Bangkok (NH847)	

Source: JST

10.3 Participants

Below is the list of participants sponsored by the JICA budget.

Table 10-2 Participants Sponsored by JICA

No	Name	Affiliation	Position
1	Dr. Prapong Klysubun	SLRI	Deputy Director for SPS-II Development
2	Dr. Supat Klinkhieo	SLRI	Deputy Director for SPS-I Operation
	Dr. Supagorn Rugmai	SLRI	Deputy Director for Operation and Beamline Utilization
4	Ms. Raweewan Lertsuksombut	SLRI	Assistant Director for Strategy and Organization Quality
5	Ms. Umaratchani Keawbutta	SLRI	Chief Administration Division
6	Ms. Porntip Sudmuang	SLRI	Chief SPS-II Technology Development Division
7	Ms. Malee Attaphibal	SLRI	Chief SPS-II Project Management Division
8	Dr. Wasupol Rungtanapirom	SLRI	Scientist – International Coordinator, SPS-II Project Management Division
9	Ms. Nuchjira Suksai	PDMO	Economist, Public Infrastructure Project Financing Bureau
10	Ms. Metawadee Puangmalai	PDMO	Economist, Planning and Policy Bureau

Source: JST

10.4 Results

This J-Trip program provided an excellent opportunity for SLRI and PDMO officials to learn through lectures about the maintenance and operation of Japan's SRF, the philosophy behind human resource development and research, industry-academia collaboration efforts, the “collaboration” concept, and government initiatives in research complexes. In addition, facility tours were provided following the lectures, allowing participants to see for themselves the current state of Japan's SRF, the users' experiences, and the content they had learned in advance in lectures, further deepening their understanding. The participants actively asked questions, exchanged opinions, and discussed ideas during each lecture and tour, demonstrating their willingness to apply what they learned to future SPS-II projects.

11 Economical and Financial Planning (Non-Disclosure)

(This section is concealed for a certain period.)

12 Environmental and Social Considerations

12.1 Procedures on Environmental Protection

The Enhancement and Conservation of the National Environmental Quality Act **(NEQA), B.E. 2518 (1975)** was enacted in 1975 including the Environmental Impact Assessment (EIA), which was originally imposed in this law. In B.E. 2527 (1984), the second Ministerial Regulation was enacted, prescribing the registration of the EIA consultant licensing.

The EIA system had been continuously developed until the **NEQA, B.E. 2535 (1992)** was enacted in 1992. This act made an important contribution to introducing and implementing the EIA report review system by a committee of experts to study the report.

Later, the concept of EIA system reformation was more concrete when the Constitution of the Kingdom of Thailand B.E. 2550 (2007) was in effect. The Constitution prompted the improvement of the EIA system, such as the prescription on types and sizes of project with serious impact to natural resources, environmental quality, and health, are required to have the Environmental Health Impact Assessment (EHIA), a strict public participation guideline and the driving force for Strategic Environmental Assessment (SEA) as the tool of policy-plan-program making both sectoral-based and area-based for the executive's decision making.

After the Constitution of the Kingdom of Thailand B.E. 2560 (2017) went into effect, the EIA system was revised by the amendment of EIA regulation on NEQA B.E. 2535 (1992), which is **the NEQA (No.2) B.E. 2561 (2018)** and the secondary legislation under the amendment act such as the rule and guidance of measures implementation report and the assignment of state agency to act on the behalf of the Office of Natural Resources and Environmental Policy and Planning (ONEP).

For JICA Environmental Checklist, see **Attachment 6: JICA Environmental Checklist**.

12.1.1 The Enhancement and Conservation of the National Environmental Quality Act (No.2) B.E.2561 (2018)

The main law on environmental protection and pollution control was published in the Government Gazette Volume 135, Part 27a, dated 19 April 2018, which shall come into force 90 days from the date of its publication: 19 July 2018. In summary, it was to change the name "EIA Report" and "Part 4 Preparation of EIA Report" to be entirely re-established as can be summarized below.

Table 12-1 Repealed and Replaced Parts of the NEQA (No.2) B.E. 2561

Chapter III	Description
Section 46 (Definition)	• Definition of "EIA", "permit/permission" and "operator" (unless stated otherwise)
Section 47 (SEA)	• In case where there is a strategic environmental assessment in accordance with any other regulation or law, the EIA shall take into consideration the findings of such strategic environmental assessment.
Section 48 (Reporting)	• The Minister, with the National Environmental Board' s approval, shall have the power to issue a notification specifying that any project, undertaking, or operation of the State or which the State will give any person permission to operate, is a project, undertaking, or operation that impacts the environment or may seriously impact natural resources, environmental quality, health, sanitary, life quality, or other important interests of people, communities, or environment, which an operator or person asking for permission must provide an EIA report." (Section 48, paragraph one) • Rules, procedure, and conditions on providing an EIA report under paragraph one, shall be prescribed in the Minister's notification with the National Environmental Board's approval. Those rules, procedure, and conditions may be different due to categories or sizes of projects and shall at least consist of the subject matter of detail of the project, current environmental situation, assessment of alternatives that can be operated, assessment of environmental impact which may directly and indirectly occur due to implementing the project, public participation in the EIA, and measures to prevent and rectify impacts and to compensate and remedy injuries and damages.(Section 48, paragraph 2) • "ONEP shall recommend that the National Environmental Board review the notification under paragraph one every five years or, if necessary, within a shorter timeframe." (Section 48, paragraph four)
Section 50 (Examination)	• ONEP or the state agency assigned by the National Environmental Board to act on its behalf, shall examine the EIA report and relevant documents submitted. (Section 50, paragraph 3) • ONEP with the National Environmental Board's approval, may assign another state agency to act on its behalf unless the project, which is required to provide an EIA report under paragraph one, is a project that may seriously impact natural resources, environmental quality, health, sanitary, life quality, or any other important interests of people, communities, or environment, or is a project, undertaking, or operation under Section 49, paragraph four. This shall be in accordance with the rules and procedure prescribed in the National Environmental Board's notification (Section 50, paragraph 5).
Section 51/1 (Approval)	• In case where the expert committee does not give its approval, the operator or person asking for permission shall amend or provide anew the EIA report in accordance with the guidelines, details, issues, or topics as required by the expert committee within 180 days from the date of receipt of the expert committee's notification of its findings. Otherwise, it shall be deemed that the operator or person asking for permission does not intend to submit that EIA report and shall be also deemed that the consideration process of that EIA process is concluded. However, this shall not affect the right of the operator or person asking for permission to submit a new EIA report (Section 51/1, paragraph 2). • In case where the expert committee does not approve the EIA report submitted pursuant to paragraph three, it shall be deemed that the process of considering the EIA process is concluded. However, this shall not affect the right of the operator or person asking for permission to submit a new EIA report (Section 51/1, paragraph 4). • Whether the expert committee gives approval or not, such opinion of the expert committee shall be final (Section 51/1, paragraph 5).
51/2 (Inspection)	• The expert committee or competent officials assigned by the expert committee, shall have the power to inspect the premises of the project, undertaking, or operation for which the EIA report is submitted. Such inspection shall be conducted in front or with consent of the operator or person asking for permission.

Chapter III	Description
51/3 (Permission)	• The official with the legal power to grant permission shall bring the implementation report of measures indicated in paragraph one which the operator or person asking for permission shall provide under Section 51/ 5, to prescribe as conditions in giving permission or renewing a license as well (Section 51/3, paragraph 2).
51/5 (Implementation Report)	• For the benefit of monitoring, inspecting, and developing the system of EIA, the operator or person asking for permission who provides an EIA report and is granted permission to proceed, shall provide an implementation report of measures required in the EIA report and submit it to the official with the legal power to grant permission at least once a year in accordance with the rules and procedure prescribed in the Minister's notification with the National Environmental Board's approval (Section 51/5, paragraph 1).
51/6 (Consideration Process)	• An EIA report with opinions from the National Environmental Board or approved or deemed to be approved by an expert committee, may be used in requesting for the Cabinet's approval or in a permission consideration process as required by law within a period of 5 years from the date the Office of Natural Resources and Environmental Policy and Planning or the state agency assigned by the National Environmental Board to act on its behalf issues a letter notifying opinions of the National Environmental Board or the expert committee's approval, as the case may be (Section 51/6, paragraph 1)
101/2	• Description about the Penalty

Source: Environmental Impact Assessment in Thailand (2021)

12.1.2 Initial Environmental Examination

Initial Environmental Examination (IEE) for this Project has been conducted and the report has been prepared in 2019 (B.E. 2562) by SLRI, to which the Ministry of Natural Resources and Environment (MNRE) has considered and approved this Project. It was additionally informed that the Project mentioned is not the type and size of projects or activities that require an EIA report. The letter mentioned about the above agreement by MNRE was issued to the Secretary-General to the Cabinet on 18 February 2020. After that it was informed by the Secretary-General to the Cabinet on 21 February 2020.



Source: SLRI

Figure 12-1 Official Letter from Cabinet (Left) and from MNRE (Right)

12.1.3 Confirmation of the Necessity of EIA Study

After above 2 letters have been issued, the construction site of Synchrotron Facilities has been changed in EECi area. In accordance with the Environmental Impact Assessment in Thailand (2021), it was deemed that it is not necessary to conduct EIA for the Project as confirmed by Office of Natural Resources and Environmental Policy and Planning (ONEP), the responsible organization of MNRE. Since the land has already been acquired and there will be no relocation of residents, in accordance with the JICA Environmental and Social Considerations Guidelines (2022), the Project is considered as category C.



Source: SLRI

Figure 12-2 Official Letter from ONEP

In the Environmental Impact Assessment in Thailand (2019), 35 types of projects are categorized to be required preparing EIA report. One of the types of those projects is related to building construction. The criteria are shown in Table 12-2.

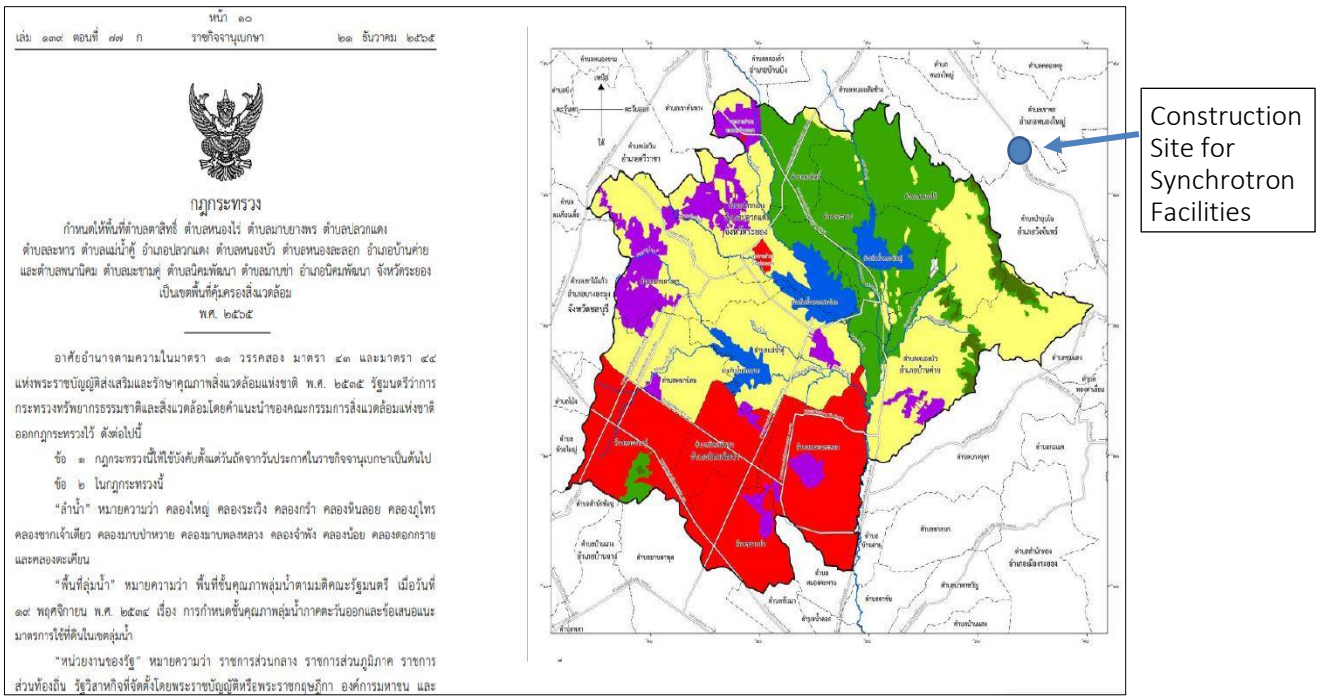
Table 12-2 Criteria in EIA in Thailand (2019)

No	Type of projects, undertakings, or operations	Size	Stage
27.	High-rise or extra-large building under the law on building control with the locations or utilization purposes as follows; 27.1 Located adjacent to a riverbank as indicated in Annex 2, seashore, lake, or beach, or near or in a national park or historical park, which may impact environmental quality; 27.2 Buildings used for retail or wholesale business 27.3 Buildings used as an office or place of business of private sector.	Height of 23.00 meters or more; or total floor area of all floors or each individual floor area in the same building of 10,000 square meters or more	When applying for a construction permit; or when notifying the local competent official, in the case of notifying a local competent official under the law on building control without applying for a permit.

Source: SLRI

According to the Ministry of Natural Resources and Environment (MNRE), this Project doesn't meet conditions of 27.1, 27.2 and 27.3. If so, it is not necessary to consider 'Size' for next step neither 'Stage'.

In addition, MNRE has designated the sensitive area, and the letter has been issued. The letter and location map are show in Figure 12-3. The projects in this sensitive area are required EIA study. The construction site of Synchrotron facilities is out of sensitive area.



Source: SLRI

Figure 12-3 The Letter and Sensitive Area Designated by MNRE

12.2 Waste Management of SLRI

12.2.1 Water Drainage System

Water drainage system of inside and outside building in SLRI is shown in Table 12-3

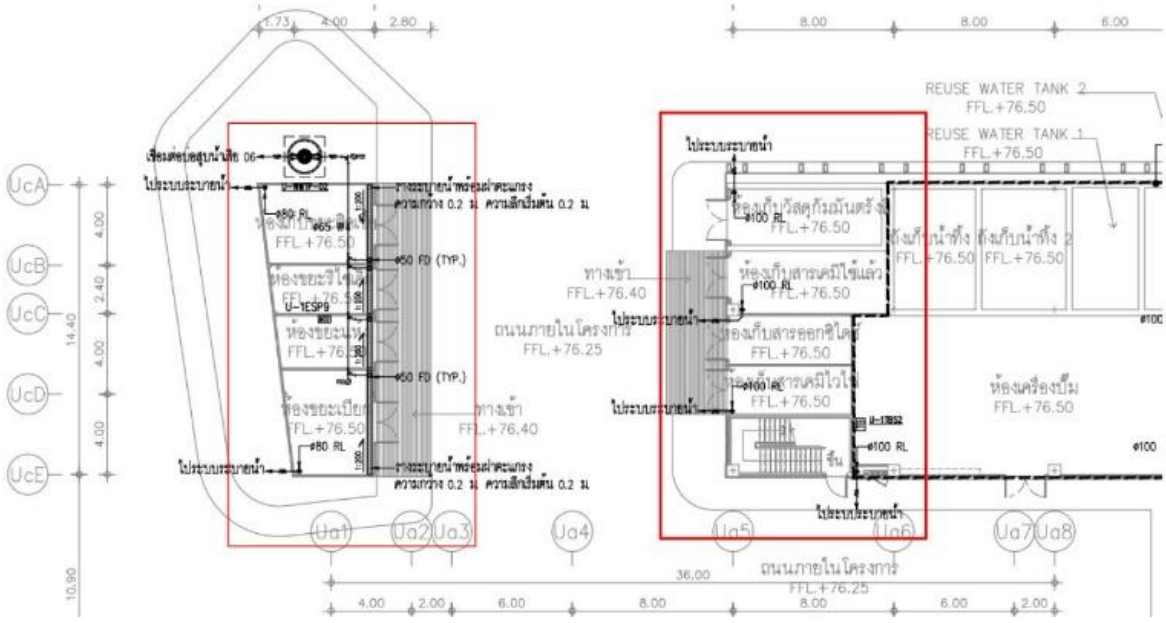
Table 12-3 Water Drainage System

Inside Building	Outside of Building
• To separate the wastewater sump from each building before transfer to central wastewater sump. • Wastewater from cooling water of accelerator machine will be separated the sump from the wastewater of synchrotron building and must be checked the contaminated radionuclides in wastewater to prevent the environmental impact. • The parameters of contaminated radionuclides in cooling water i.e., tritium production, gross alpha and gross beta.	• Wastewater from each building will be treat by the aerobic treatment system before transfer to the central wastewater sump. • The effluent of total wastewater from the center must be checked the wastewater controlling parameters before drainage to the public canal in EECi i.e, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Total Dissolved Solids (TDS), pH, etc.

Source: SLRI

12.2.2 Solid Waste Management

Generated solid waste is around 3L/person/day in SLRI, and the total estimation of generated solid waste in SPS-II is around 1.96m^3/day. Generated solid waste from SPS-II will be expected to consist of general waste, hazardous waste and recycle waste. For general waste, it will be store in gathering point and eliminate by local office. There are 2 waste storerooms in SLRI. The drawing and pictures are shown in Figure 12-4. The solid waste is separated depend on the humidity in the left room in the drawing. And the solid waste is separated by the type of waste, i.e., general waste, chemical waste in right room in drawing.



Source: SLRI

Figure 12-4 Waste Storeroom in SLRI



Source: SLRI

Figure 12-5 Chemical Waste Room

12.2.3 Hazardous Waste Management

Chemical waste, which is generated from lab, will be collected in the gathering point, and sent to disposal by the licensed industrial company (have the authorization from the government to eliminate the hazard

waste). The containers of chemical waste must be labeled with the name of chemical and risk hazard. Biological waste will be disinfected by an autoclave machine before transport to the local office. The company uses technology from Germany to improve domestic waste management methods to European standards that significantly minimize environmental impact and become a prototype project that is systematically managed according to ISO 9001 (Quality Management Systems) and ISO 14001 (Environmental Management Systems). For the treatment of the gas emissions (e.g.,handling of volatile chemicals), draft chamber will be installed to exhaust it to the outside.



Source: SLRI

Figure 12-6 Waste Collection by a Licensed Company

12.2.4 Radioactive Waste Management

Radioactive waste will be sent to TINT (Thailand Institute of Nuclear Technology) which is authorized from OAP (Office of Atoms for Peace, under MHESI) to eliminate the radioactive waste in Thailand.

The cost for waste management (for send to licensed company and OAP, including monitoring cost) is paid by SLRI.

12.3 Analysis on Project Formulation as a Climate Change Countermeasure Project

12.3.1 Position on JICA Climate-FIT

This Project was initially planned to follow the Mitigation approach of JICA Climate Finance Impact Tool (JICA Climate-FIT), which focuses on the quantitative evaluation of Green House Gas (GHG) emissions reduction/removals, especially on the mitigation effect from research results using SRF.

However, as the survey progresses, it has become clear that:

- The current design stage does not have enough information for a meaningful estimation of GHG emission reduction, as confirmed to the building facility team.
- The mitigation effect stemming from research using SRF dwells on advanced technology, on which qualitative elaboration can be discussed, as opposed to quantitative calculation.
- The outreach effect of research impact from using SRFs is wide on many levels – hence a qualitative discussion on a wider perspective is considered more powerful on the current initial stage.

For these reasons, analysis will be made following JICA Climate-FIT guideline for Adaptation. The sectoral viewpoint of "Infrastructure: Industrial Area" will be chosen as the most appropriate for this Project, while referral to other guideline will be used as necessary to get a full picture of this Project's impact as a special type of architecture.

12.3.2 Adaptation on Thailand's Updated Nationally Determined Contribution 2020

In accordance with Decision 1/CP.21 of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), Office of Natural Resources and Environmental Policy and Planning of Thailand has submitted the updated Nationally Determined Contribution (NDC) in a letter No. 1007.2/13850 dated 20 October 2020.

National Adaptation Plan that GOT has developed has 6 priority sectors, as shown below:

1) Water resource management sector
2) Agriculture and food security sector
3) Tourism sector
4) Public health sector
5) Natural resources management sector
6) Human settlement and security sector

Furthermore, the application of Integrated Water Resources Management (IWRM) and Ecosystem-based Adaptation (EbA) practices, use of technology to improve crop/ livestock varieties and management systems, as well as Tools for Climate Change Vulnerability Assessment in the above-mentioned 6 sectors have been described as the technology development and transfer part of Thailand's updated NDC 2020.

In this Project, the related sectors can be divided into 2: direct impact (water resource management, natural resources management) and indirect impact (agriculture and food security).

12.3.3 Future Climate Risk Analysis

Based on JICA Climate-FIT Adaptation, a Climate Risk Matrix has been prepared as follows.

Table 12-4 Climate Risk Matrix

		Hazard							
		H1: Flood	H2: Torrential Rain	H3: Earthquake	H4: Drought, heatwave				
	Current frequency of hazard	+	–	–	–	Vulnerability *Past & current efforts against the impacts occurred & actions to address them, planned initiatives*	Count	Climate Risk *Selected risk to manage*	Potential Adaptation Options
	Future prospect	→	→	→	→				
Exposure	E1: Site preparation (incl. tree felling)	1 Although the site might not be flooded, delay caused by flood elsewhere is not negligible	1 Might cause delay	0 No impact	0 No impact	• Plan the ground preparation in the dry season	0	There are no significant climate risks for E1 due to flood nor torrential rain. However, pay attention to: • Soil erosion and generation of dust due to mass logging • Sink loss	Plant trees equal to or greater than the number of harvested trees, onsite & off site
	E2: Procurement and transportation of construction materials	1 Although the site might not be flooded, procurement might be delayed	1 Road closures & disruptions may hinder transportation and cause delay	1 Road closures & disruptions may hinder transportation and cause delay	0 No impact	• Source the construction material from nearby area as much as possible	0	There are no significant climate risks for E2 due to flood, torrential rain, nor earthquake	-
	E3: Construction of SPS-II and its related facilities	1 Although the site might not be flooded, delay caused by flood elsewhere is not negligible	1 Might cause delay	0 No impact	0 No impact	• Proper site management, material storage and waste control can help minimize the impact of flood and torrential rain	0	There are no significant climate risks for E3 due to flood, nor torrential rain.	-
	E4: User' s comfort and productivity (incl. research & HRD activity)	0 No impact as the site is not very unlikely to be flooded	0 No impact, although outdoor activity will be limited	3 Although earthquake is unlikely, the vibration will cause disruptions/ malfunctions of machines	1: As the indoor temperature must be kept within a certain range, heatwave will cause energy bill to increase	• Use earthquake design principle for the structure • Apply green building design to reduce energy consumption (hence energy bill) and to increase comfort for the user, which in turn improve productivity	1	• Although earthquake design is not required for the area, it's worth considering the damage cause by earthquake would be costly	• Use of earthquake design • Reduction of ceiling height (reducing the volume of building = cheaper energy bill) • Use of Roof-top solar panels
Count		0	0	1	0				

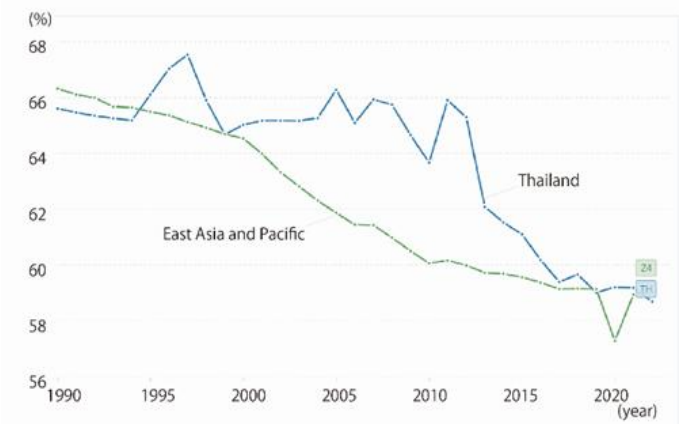
Source: JST

12.4 Gender Mainstreaming Needs

12.4.1 Gender-Related Social Norms and Customs in Thailand

Traditionally, women in Thailand have had relatively free access to economic activities, including compulsory service during the Ayutthaya dynasty (1351-1767)[30], and have been actively involved not only in agriculture but also in commercial activities such as buying and selling of goods. In religious thought, while men are considered to acquire the greatest merit by becoming ordained, women are considered to acquire merit by, for example, offering the products of their commercial activities to priests. This is said to be the reason for the high female labor force participation rate.

On the other hand, in line with the global trend of declining female labor participation since the 1990s, its rate in Thailand has also been on a downward trend. The main reasons for this, it has been pointed out, are the increasing rate of young people entering tertiary education, the ageing of the population and the loss of motivation to work. In recent years, the female labor participation rate[31] in Thailand has been the same as the average for South-East Asia and the Pacific (59% in 2022, ILO, see figure below).



Source: JST based on ILO Modelled Estimates and Projections database (ILOEST), ILOSAT

Figure 12-7 Trends in the Labor Participation Rate of Women (Thailand, Southeast Asia and the Pacific region)

There are many challenges in terms of gender equality, such as difficulties in wage in the labor market and educational opportunities. In national planning, gender issues were addressed for the first time in the Fourth Development Plan of 1975, which included (i) the improvement of education as a basis for employment, (ii) gender equality in employment and vocational training, and (iii) revision of laws that discriminate against women. In 1981, the Convention on the Elimination of Discrimination against Women (CEDAW) was signed and ratified, and in 1989 the National Commission on Women's Issues was established as an independent body within the Government. The local administrative law that stated that “the village head should be a man” was amended in 1982. In the 1990s, with the advent of democratization, some of the

[30] Male peasants were obligated to work for the king or nobles for a certain period of time. When the men were away, women had to do all the work.
[31] Employment rate of the population aged 15 and over

family laws that legalized male-headed families and women's submission to their fathers and husbands within the family, among others, were rectified.

Under Thailand 4.0 the country aims to shift its economy from being industry driven to high-tech driven and value-based. Promoting gender equality and inclusiveness is a key component of Thailand 4.0. The Gender Equality Act (2015) established the Committee to Promote Gender Equality (CPGE) to enact the Act's policies and mechanisms to advance gender equality. The Minister of Social Development and Human Security is in charge of the execution of The Gender Equality Act (2015) and has the power to appoint competent officers and issue regulations or notifications in accordance with this Act. In addition, the Women Development Strategy (2017-2021), developed by the Ministry of Social Development and Human Security, sets out goals, objectives and targets in the area of gender equality which will be steering tools for effective budget allocations.

12.4.2 Gender Gap and Government's Efforts in Advanced Science and Technology Fields

According to UNESCO report titled "Cracking the Code: Girls' Education in STEM" released in 2015, girls face obstacles such as gender stereotypes, lack of female role models in STEM fields, and social anxiety. Nonetheless, it cited Thailand as one of only three countries in the Asia-Pacific region that has an above global average proportion of women researchers working in science, technology and innovation. In Thailand, women make up more than half of these researchers at 53%. In higher education, women are also 53% of students in the sciences, however, they are less than 24% of students in engineering, manufacturing and construction studies.

12.4.3 Activities of Other Donor Agencies

(1) UNESCO

Thailand is the first country in Asia-Pacific to pilot a policy toolkit under UNESCO's global STEM and Gender Advancement (SAGA)[32], project aimed at analyzing the impact of policies on gender disparities in STEM, developing better indicators for evidence-based policy-making and building capacity to collect data on gender in STEM.

Thai educators work with experts from the United Nations Educational, Scientific and Cultural Organization (UNESCO) to improve STEM education for girls and young women as part of the 20-year national strategy Thailand 4.0 that aims to transform the Kingdom into a nation where innovation, creativity, research and development, and green and high-technologies drive the economy.

The policy toolkit includes appropriate funding, data disaggregated by gender, gender responsive career counseling, scholarships, programs for female STEM professionals, gender responsive teaching strategies and learning materials, among other elements.

[32] The SAGA project is a global UNESCO project, supported by the government of Sweden, that aims to improve the situation of women and girls and reduce the gender gap in science, technology, engineering, and mathematics (STEM) fields at all levels of education and research.

(2) ILO

According to the ILO, over the next decade, technological advances including automation and robotics, will significantly change jobs and enterprises in Thailand. The ILO estimates that 44% of employment (over 17 million jobs) face a risk of automation in Thailand. Female are employed predominantly in jobs requiring low STEM skills, which are clearly at risk of automation. Women are 50% more likely than men to losing their job because of automation. To address these issues, and considering the national economic and social development priorities, the ILO identified the electrical and electronics sector as high-growth in Thailand, presenting significant projected STEM-related skills gaps and opportunities for growth for women over the next decade. Under this circumstance, to provide women with critical soft and technical STEM-related skills to help women gain quality employment and support the career advancement of women in the Electrical and Electronics sector in Thailand, "Women in STEM workforce readiness and development programme in Thailand" has been implemented from 2017 to 2020.

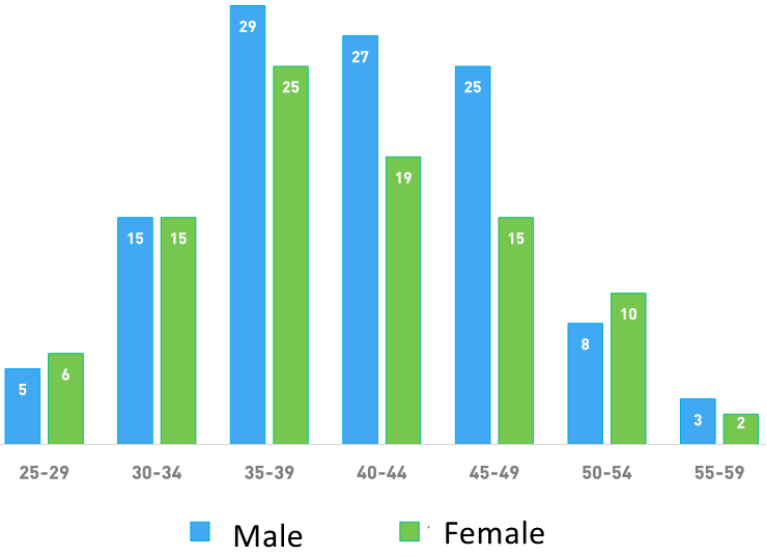
12.4.4 Gender Balance Situation in SLRI

As specified in the Sustainable Development Goals (SDGs) no. 5 "Gender Equality", JICA's Global Agenda aims to build a gender-equal and fair society by promoting empowerment of women and girls. Based on SLRI's Annual Report 2023, while there are no women in the Executive Board as of December 2022, there are 8 women out of 18 people in the Management Team, as shown below. Regarding the gender ratio of employees at SLRI in 2023, almost half (45%) are female, and it can be seen that a gender balance is generally maintained in all age groups. When recruiting new employees, SLRI doesn't specify gender requirements, and during the selection process, SLRI conducts interviews, exam papers, and practical tests without considering genders. SLRI offers 60-day maternity leave, 30-day female parental leave, 15-day male parental leave, and 60-day sick leave which can be taken in cases of miscarriages and menstrual pains.



Source: SLRI

Figure 12-8 Management Team of SLRI in Annual Report 2023



Source: SLRI

Figure 12-9 Gender Balance by Age Group

12.4.5 Proposal for the Project

Thailand is recognized as one of the region's leading countries in terms of gender neutrality and equality. Below are gender-related measures and policies implemented in Thailand. These initiatives demonstrate alignment with gender mainstreaming in JICA projects and could be adopted in the Project, as well as other JICA projects in other countries.

Table 12-5 Gender-Related Measures in Thailand

Category	Measures
Policy Mainstreaming on Gender Equality and Inclusiveness Promoting gender equality and inclusiveness as a key component across national policies and plans.	• **The 13th National Economic Social Development Plan (NESDP) (2023-2027)** - Inclusive growth - Leave no one behind • **SDG** No. 5 "Gender Equality" A requirement for government agencies to incorporate a gender perspective into national budgets, health, education, and employment policies.
Strengthening Legal Systems for Gender Equality and Women's Empowerment Establishing specific gender equality acts and women empowerment strategies to further advance the country's commitments to gender equality.	• **Gender Equality Act (2015)** A law prohibiting discrimination based on sex (including sexual orientation and gender identity). • **National Women's Development Strategy** A government strategy focusing on women's political participation, economic independence, and access to education and vocational training. • **Equal Marriage Law (effective in 2025)** A symbolic example of the legal system's efforts to promote the protection of rights regardless of gender.
Policy Formulation Based on Gender Analysis Basing policy-making decisions on thorough gender analysis to determine and mitigate their potential impacts on gender disparities.	• **Development of Gender-Disaggregated Data (GDD)** The National Statistics Office (NSO) collects gender-disaggregated data on educational enrollment rates, employment rates, wages, health indicators, etc. • **Policy Evaluation in Collaboration with UN Women and UNDP** A Gender Impact Assessment (GIA) was piloted at the local government level. • **Application to Health Policies** Gender and social factors are taken into account in maternal care, HIV prevention, and LGBTQ+ health care.
Structural Equality of Educational and Employment Opportunities Ensuring equal education and employment opportunities for all genders in various fields, particularly prioritizing participation in fields such as STEM, and in various positions including managerial and technical positions.	• **Higher Education and Research** Research grants and leadership development programs for female researchers, and scholarships for female students in STEM fields. • **Universities and Educational Settings** Creating learning environments that take gender identity into consideration and supporting reskilling for women in technical and digital fields. • **Public Sector and Businesses** Guidelines aimed at increasing the proportion of women in managerial positions and supporting reskilling for women in technical and digital fields.

Source: JST