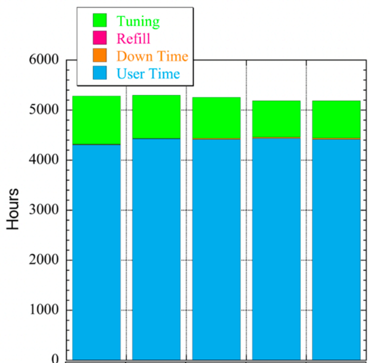
2. Operation Status

1. SPring-8

Figure 1 highlights the operation statistics for the last five fiscal years. In FY2024, the total operation time for the storage ring was 5,187 hours with 4,440 hours allocated for user operations. The downtime due to machine trouble was 21.6 hours in addition to the planned downtime of 1.6 hours for switching the user operation modes with different patterns. The considerably short downtime led to an excellent user availability of 99.5%. As we emphasize the importance of the mean time between failures (MTBF) for user experiments, we have continuously achieved MTBFs higher than 200 hours in recent years by suppressing the frequency of machine failures. In FY2024, we obtained the MTBF of 316 hours.



	FY2020	FY2021	FY2022	FY2023	FY2024
Acc. Operation Time	5284.6	5300.2	5259.3	5187.9	5187.1
SR Operation Time	5274.8	5300.2	5259.3	5187.9	5187.1
Tuning&Study (Acc.&BL)	964.6	860.2	819.3	723.9	747.1
Refill	3.6	3.1	4.3	4.1	1.6
Down Time	7.4	10.0	19.7	24.2	21.6
Mean Time between Failures	718.2	553.4	232.4	403.2	315.5
Achieved User Time	4309.0	4426.9	4416.0	4435.7	4416.9
Planning User Time	4464.0	4440.0	4440.0	4464.0	4440.0
Availability (%)	99.7	99.7	99.5	99.4	99.5

Fig. 1. SPring-8 operation statistics for the past five years.

Since the user time operation of SPring-8 with full-energy direct beam injection from the 8 GeV linear accelerator (linac) of SACLA started in 2020, the new injector has provided a stable and reliable beam injection to the storage ring. In FY2024, 99.7% of the achieved user time (4416.9 hours) was operated in the top-up mode with the stored beam current of 100 mA. The top-up operation availability is kept at the same or even higher level than that of the original beam injection setup by the 1 GeV linac and 8 GeV booster synchrotron, as indicated in Fig. 2. The new injection setup from the SACLA linac is being continuously improved and sophisticated in detail each year so that extremely stable and reliable top-up operations with the current stability of about 0.03% and the availability of 99.7% are provided to user experiments. In addition, the new injection setup is also beneficial to the current accelerator operations, because we can save much power without running the conventional 1 GeV linac and the 8 GeV booster synchrotron.

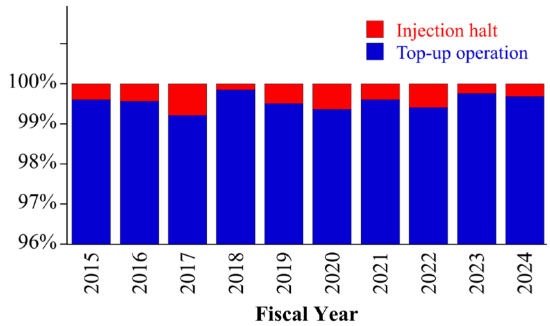


Fig. 2. SPring-8 top-up operation statistics for the past ten years.

After almost 30 years of operation, the high operation statistics such as the operation availability, MTBF, and top-up operation availability could all of a sudden become worse. Some accelerator components are extensively showing signs of aging, which could cause machine trouble anytime. In particular, electric devices, including power supplies, have deteriorated in recent years, but many inner electric circuits and devices are outdated and new parts are not readily available from vendors unless the parts are to be newly designed and re-manufactured. Therefore, we have developed and implemented maintenance strategies based on thorough investigations of potential problems, and have carefully maintained the old devices by utilizing existing or alternative parts until the major upgrade of SPring-8. So far, our strategy and the maintenance procedures are working as desired, and high reliability and long MTBFs are being obtained. Obviously, it is necessary to completely renew most of the components before a major machine failure occurs.

2. SACLA

In fiscal year 2024, SACLA operated as scheduled without major troubles, providing X-ray laser to users. Table 1 summarizes the total operation time, user's experimental time, downtime in user's experimental time, and laser availability. These values, such as operation time and laser availability, remained at high levels consistent with previous years.

We summarize the major components replaced during fiscal year 2024. The SACLA electron gun was replaced twice in July and March due to reduced cathode emission. The details of the emergency replacement in July are described in the previous section. The klystron, a high-power radio-frequency (RF) source, was not replaced this fiscal year. A total of 42 replacements were performed for the thyratron, the high-voltage switching device used in the klystron pulse power supply. Of these, new thyratrons were used in 18 cases; the others involved reusing thyratrons previously used in upstream sections for downstream sections. Four of the replacements using new thyratrons were performed at the L-band accelerator; the reasons for these replacements will be reported later.

Since SACLA began operation in 2011, 14 years have passed, and failures due to aging components have gradually become more noticeable. In particular, failures have increased in C-band driver amplifiers using GaAs-FET, PLC modules (especially analog measurement modules), and air-cooled fans for high-voltage chargers. We are systematically proceeding with the planned replacement of these components to reduce unexpected operation interruptions due to sudden breakdowns. For other major components, we regularly monitor their condition and replace any showing signs of deterioration during shutdown periods to ensure that stable operation continues.

The L-band accelerator in the upstream section of SACLA accelerates an electron beam with approximately 1 MeV remaining from velocity bunch compression to 35 MeV. It also provides the energy gradient for the bunch compression section BC1. Consequently, it is a critical piece of equipment where even a slight change in the RF field affects SASE generation [1]. The klystron is driven by a pulsed power supply using a thyratron as a high-voltage switch. It has been revealed that tiny changes in the conduction state of this thyratron affect the SASE output. Figure 3 shows an example of the values measured during a fluctuation. The conduction voltage between the thyratron's G1 grid and cathode (C) fluctuated periodically with a full amplitude of about 5 V (corresponding to a conduction resistance of 2 mΩ). This caused the klystron cathode voltage (~270 kV) to change by approximately 0.025%, shifting the phase of the output RF pulse shown in Fig. 3(b) by about 0.1 degrees. This change caused the SASE pulse energy shown in Fig. 3(a) to temporarily decrease from 700 to 400 μJ. This fluctuation is considered to occur due to the aging degradation of the thyratron after operation, and the pattern of fluctuation varies significantly between individual units. Therefore, when fluctuations occur, operation is continued while avoiding them by replacing the thyratron with a new one or by changing operating conditions such as the deuterium gas pressure. Additionally, we pre-test the thyratron's operation on a test stand and select spheres with stable conduction voltage for future replacements. Such fluctuations likely existed previously but went unnoticed either because measurements lacked this level of precision or because they were masked by other variations, such as those from the klystron. The recent improvements in SASE pulse energy and the optimization of bunch compression have made the system highly sensitive to fluctuations in the L-band radio frequency, which is likely another cause of the current issues. Efforts to suppress and stabilize these fluctuations will continue to ensure that the system can handle more advanced operations.

Table 1. Operation statistics of SACLA for FY 2024.

Total operation time	5790 h
User experimental time	BL2+BL3: 4768 h BL1: 1428 h
Downtime in user exp.	BL2+BL3: 122 h BL1: 24 h
Laser availability	BL2+BL3: 97.4% BL1: 98.3%

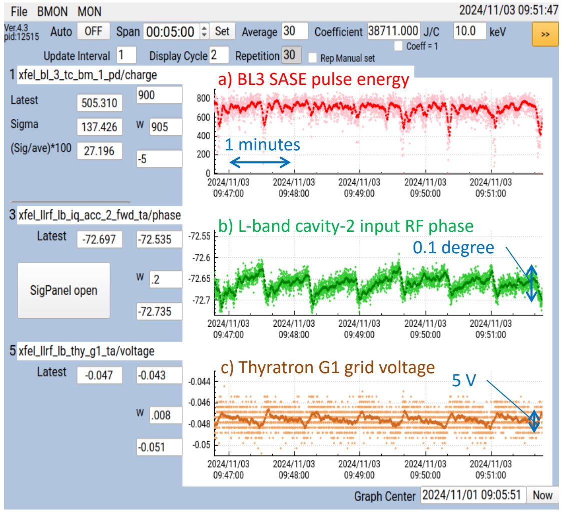


Fig. 3. Example of SASE fluctuations caused by fluctuations in the L-band thyratron.

WATANABE Takahiro[*1,2], TAKANO Shiro[*1,2], and INAGAKI Takahiro[*2]

[*1]Accelerator Division, JASRI

[*2]Innovative Synchrotron Radiation Facility Division, RIKEN SPring-8 Center

References:

[1] Asaka, T. *et al.* (2017). *Phys. Rev. Accel. Beams*. **20**. 080702.