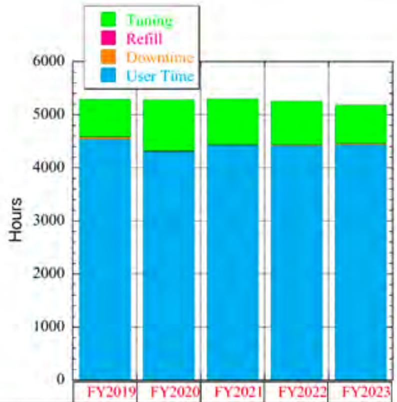
2. Operation Status

1. SPring-8

Figure 1 highlights the operation statistics for the last five fiscal years. In FY2023, the total operation time for the storage ring was 5,188 hours, 4,464 hours of which was allocated for user operations. The downtime due to machine troubles was 24.2 hours in addition to the planned downtime of 4.1 hours for switching among with the different patterns of user operation modes. The considerably short downtime led to an excellent user availability of 99.4%. In recent years, we emphasize the importance of the mean time between failures (MTBF) for user experiments. As the result, we achieved the MTBFs higher than 200 hours these years by suppressing the frequency of machine failures. In FY2023, we obtained the MTBF of 403 hours.



	FY2019	FY2020	FY2021	FY2022	FY2023
Acc. Operation Time	5285.7	5284.6	5300.2	5259.3	5187.9
SR Operation Time	5271.2	5274.8	5300.2	5259.3	5187.9
Tuning&Study (Acc.&BL)	701.7	964.6	860.2	819.3	723.9
Refill	5.6	3.6	3.1	4.3	4.1
Downtime	40.5	7.4	10.0	19.7	24.2
Mean Time between Failures	206.3	718.2	553.4	232.4	403.2
Achieved User Time	4537.9	4309.0	4426.9	4416.0	4435.7
Planning User Time	4584.0	4464.0	4440.0	4440.0	4464.0
Availability (%)	99.0	99.7	99.7	99.5	99.4

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

Since 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 proved a stable and reliable beam injection to the storage ring. In FY2023, 99.8% of the achieved user time (4435.7 hours) was operated in the top-up mode with the stored beam current of 100 mA. The top-up operation availability is kept in the same or even better level compared with the original beam injection setup by the 1 GeV linac and 8 GeV booster synchrotron as indicated in Fig.2. An extremely stable top-up operation with the current stability of better than 0.1% was provided to user experiments. In addition,

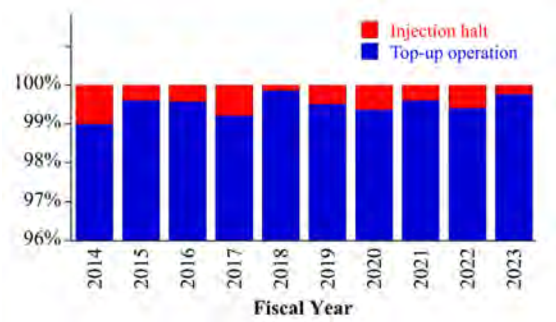


Fig. 2. SPring-8 top-up operation statistics for the past ten years.

the new injection setup is also beneficial to the current accelerator operations, because we can save much power consumption without running the conventional 1 GeV linac and the 8 GeV booster synchrotron.

The high operation statistics such as the operation availability, MTBF, and the top-up operation availability could worsen anytime. Especially signs of aging of the accelerator components have extensively been observed in recent years. In FY2023, the downtime of 24.2 hours included machine failures of long-used magnet power supplies and RF components. Therefore, we have developed and implemented maintenance strategies based on thorough investigations of potential problems. Although these treatments have so far worked well, it is obviously necessary to completely renew most of components before a big machine failure occurs.

2. SACLA

SACLA was operated smoothly for user experiments as scheduled in FY2023 without any major problems. Table 1 shows the statistics of operation times for X-ray beamlines BL2 and BL3 and soft X-ray beamline BL1. The total operation time of the entire facility was 5770 hours. The total user experimental time for BL2 and BL3 was 5112 hours, of which 105 hours was downtime, resulting in a laser availability rate of 97.9%. User experimental time for BL1 was 1308 hours, of which 29 hours was downtime, resulting in a laser availability rate of 97.8%. These operating times and availability rates are similar to those of previous years. About half of the downtime was temporary shutdowns due to, for example, accelerator cavity discharges, thyratron self-fires, and electron gun discharges. The rest was due to accelerator tuning for wavelength switching, special tuning to meet user requests, and temporary interruptions due to injections into the SPring-8 storage ring. The downtime does not include the time for the replacement of experimental setups or adjustment of accelerators and beamlines due to user switching. As can be seen from the high availability rate, there were no serious troubles that required long recovery time in this fiscal year's operation, and the operation was relatively stable.

As for the electron gun, a cathode was replaced during the shutdown period at the end of last year and during the summer shutdown period. As reported last year, the electron gun was replaced with a system in which the entire high-voltage tank was replaced, so the replacement, start-up, and subsequent adjustments went smoothly. In this replacement, a collimator to remove backward electrons from the L-band accelerator was installed immediately in front of the cathode with the aim of improving the cathode life. A method and accelerator tuning tools to reproduce datasets of the accelerator parameters were established using machine learning [1], which enabled a smooth startup of the XFEL operation.

SACLA introduced various beam-based feedback systems to compensate for parameter drifts during long-term operation. In addition to the beam energy and peak current at each stage of bunch compression sections, the bunch charge after a gun chopper collimator and the arrival time before the first bunch compressor were added to the feedback [2]. These additional feedback target parameters cancel the effects of long-term deformation of the electron gun cathode and allow for more stable operation.

Table 1. Operation statistics of SACLA for FY 2023.

Total operation time	5770 h
User experimental time	BL2+BL3: 5112 h BL1: 1308 h
Downtime in user exp.	BL2+BL3: 105 h BL1: 29 h
Laser availability	BL2+BL3: 97.9% BL1: 97.8%

In the C-band main accelerator of SACLA, high voltage application to the klystrons occasionally interlocked and stopped due to cavity or klystron discharges or thyratron self-fires. These interlock events occur about once every two days per RF unit, but since there are 70 RF units, the beam operation of SACLA is interrupted about once every 30 minutes to one hour. When interrupting beam operation due to an interlock, the operator checks the status, and if there is no problem, the operation is reset and restarted, which takes about one minute of downtime. Therefore, we modified the control software of the PLC to have a sequence that automatically resets and restarts operation after a certain period of time in the case of a known interlock such as the one described above. This has reduced the time required to resume operation after the occurrence of an interlock to about 15 seconds, thus reducing the downtime during user experiments.

As an upgrade for accelerator operation, pulse-by-pulse control of the focusing quadrupole magnets was introduced. These pulsed quadrupole magnets enable the optimization of the transverse profiles of the electron beams by changing the focusing magnetic field to each beam destination, BL2, BL3, and ring injection. The pulsed quadrupole magnets allow the FEL output to be stable even when the electron beam energies are different between the beam destinations. For beam injection into the low-emittance storage ring of SPring-8-II [3], these pulsed quadrupole magnets can be used to elongate the bunch to reduce the effect of CSR and improve the injection efficiency in the future.

Seven pulsed quadrupole magnets were installed downstream of the C-band main accelerator section in March 2022, eight magnets in the matching section in the summer of 2023, and two magnets upstream of the C-band accelerator section in March 2024. In addition, four new quadrupole magnets were also added downstream of BC2 and BC3 in March 2024. A power supply capable of changing current in a wider range was also developed and installed [4]. Figure 3 shows photographs of the new quadrupole magnets and power supplies.

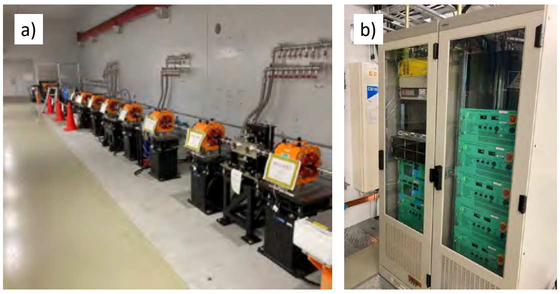


Fig. 3. (a) Pulsed quadrupole magnets installed in the matching section. (b) Power supplies for the pulsed magnets.

To improve reliability, SACLA has been upgrading its accelerator components. As the 476 MHz RF source, instead of the conventional inductive output tube (IOT), we developed a 90 kW solid-state amplifier that combines the outputs from 108 MOSFETs using a TE011 mode cavity combiner [5]. Figure 4(a) shows a photograph of the solid-state amplifier. After several operation tests, this amplifier has been used for regular operation since April 2023 [6]. So far, there have been no problems, and sufficiently stable operation has been achieved. For the BL1 accelerator, a new type of solid-state amplifier [Fig. 4(b)] was fabricated [6, 7]. This amplifier will replace IOT during the summer shutdown period of 2024.

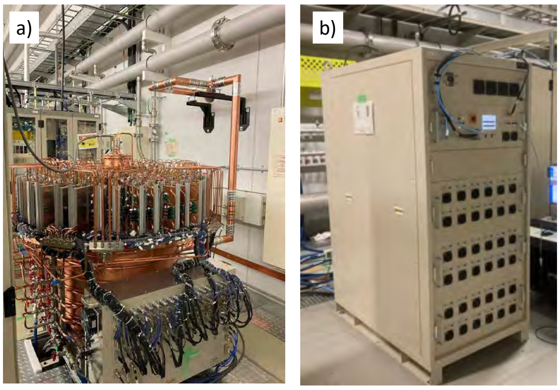


Fig. 4. (a) 476 MHz 90 kW solid-state amplifier for SACLA. (b) 476 MHz 110 kW solid-state amplifier for BL1.

In the upstream section of SACLA, ceramic windows were installed in the waveguide between the klystron and the pulse compressor in order to shorten the time necessary for klystron replacement. Figure 5 shows the ceramic window. By introducing such equipment, we aim to achieve more stable and reliable XFEL operation.

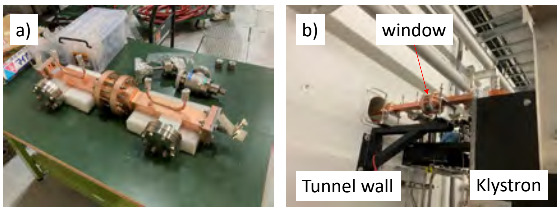


Fig. 5. (a) Waveguide ceramic window. (b) Photograph after installation on CB01-1.

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