

8 Commissioning and operation

In the following, general aspects of commissioning and operation are discussed, the transition from construction to operation is outlined and the resources required during this transition, as well as for full operation of the facility, are summarised.

8.1 General considerations

A detailed plan for beam commissioning of the European X-ray Free-Electron Laser (XFEL) Facility with a week-to-week or even day-to-day schedule will be worked out in due course when construction work has progressed and first beam operation is in sight. Nevertheless, several essential aspects of the commissioning process can already be assessed:

- A careful and thorough check of all technical components is an indispensable prerequisite for an efficient and successful start-up of beam operation. For example, reliable operation of all radio frequency (RF) stations has to be verified, RF coupling and phasing of the cavities have to be pre-adjusted, polarities and excitation currents of all magnets have to be checked, etc. The functionality of diagnostics devices should be checked as far as possible without a beam in the machine (e.g. using test signals). The control system has to be setup well in advance and software has to be de-bugged, including, for example, using simulated data to test data acquisition and higher level application programmes. In the undulator sections, a precise determination of the magnetic field quality and a pre-alignment of the magnets and diagnostics elements with best possible accuracy is mandatory to facilitate and speed up the later process of electron and photon beam-based alignment.
- A crew, well trained and experienced in accelerator and photon beamline operation, has to be available from the start. The experience already gained at the Free-electron LASer in Hamburg (FLASH) (vacuum ultraviolet (VUV)-FEL) facility and still to be gained in years to come is an extremely valuable asset in this context. Training of XFEL personnel by participation in the operation of FLASH will help to guarantee having a well prepared team available when the XFEL becomes ready for beam commissioning. Furthermore, the experience from the Linac Coherent Light Source (LCLS) commissioning will be particularly invaluable when setting up the Self-Amplified Spontaneous Emission (SASE) FEL process in the challenging x-ray wavelength regime.
- The availability of an already commissioned injector, delivering a good quality, stable beam, will be particularly helpful for an efficient commissioning of the accelerator complex. The layout of the facility with the injector in an enclosure separate from the linac tunnel permits an early start of injector operation, while the linac is still under construction.

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- As a general rule, early commissioning of **all** sections of the facility, from beginning of the linac to photon diagnostics, with relaxed beam parameters (energy, number of bunches, emittance, etc.) should be given priority in comparison to pushing **parts of the machine** to the design specifications. This will not only help to discover unexpected technical problems in all sub-systems as quickly as possible, but will also allow the SASE process to be set up with less stringent requirements on beam stability and steering accuracy. Once a SASE signal has been established and stabilised at longer wavelength, a stepwise optimisation towards the performance goals can take place.

In the later phase of routine operation for users, high reliability and availability of the machine are of particular importance. All sub-systems are laid out with a considerable margin when operated at the baseline design parameters. This de-rated way of operating the components will reduce failure rates. In addition, a linac energy overhead of 10% is built-in to be able to handle RF system failures without the need for frequent tunnel access for repair. Failures of single magnet power supplies in the linac do not make access necessary, since the beam-optics can be re-matched. A flexible control system with well-prepared failure handling procedures is essential for being able to resume beam operation quickly in such cases. Another example of technical detail in the reliability context is the cold water cooling system for all electronics racks in the tunnel, which is expected to reduce the failure rate and improve the lifetime of these systems.

Efficient usage and optimum performance of the XFEL Facility will require a close relationship between operating the machine and the photon beamlines/experiments. This does not necessarily require a common control room, but continuous good cooperation and information exchange between the accelerator operation crew, the photon beamline and instruments operation crew and the user teams is vital and must be established. The layout of the control systems has to take into account the need for fast and well organised data exchange (e.g. concerning photon and electron beam diagnostics, timing, etc.), as well as common standards for parts of the hardware and software.

8.2 Transition phase

When, after installation and technical commissioning have been completed, beam commissioning of the linac begins, there will still be installation work ongoing in other sections (second branch of electron beamline, photon beamlines and scientific instruments). Likewise, when the first photon beamline (SASE 1) starts operation, others are still being commissioned. During this transition phase, construction, commissioning and operation will take place in parallel. This phase will last about 2.5 years, until all five photon beamlines can be expected to be operational. The situation is sketched in Figure 8.2.1, using a relative timescale (on an absolute scale, this phase starts with the third quarter of 2013, under the assumption that construction on the project will start in January 2007, see Chapter 10).

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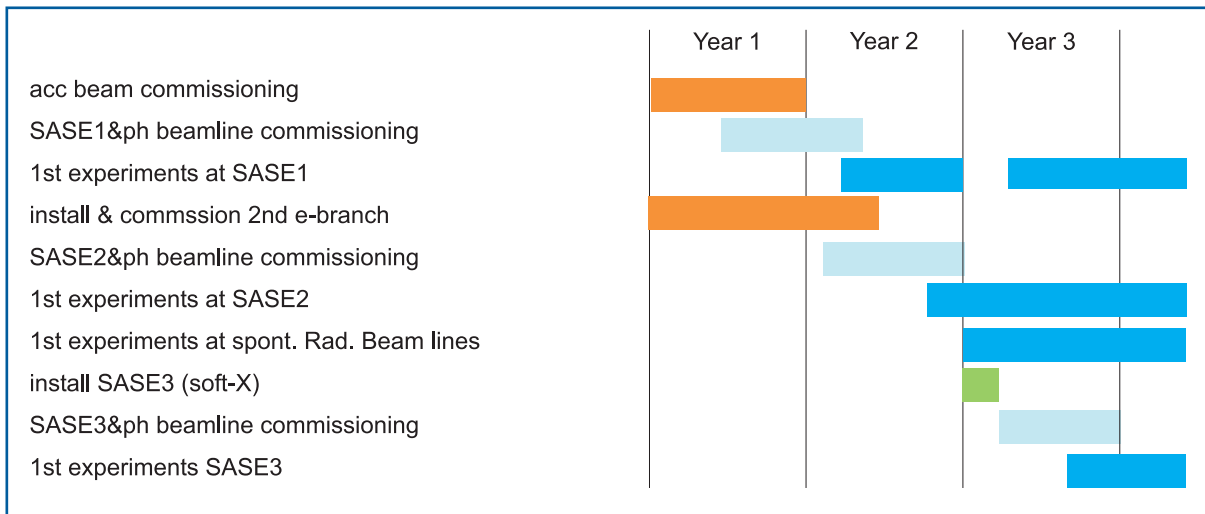


Figure 8.2.1 Sketch of the transition phase, indicating the sequence in which the different parts of the facility will be brought into operation.

The definition for the start of the operation phase of the accelerator and the first beamline (SASE 1) has been chosen so that an intermediate performance goal (relaxed with respect to the design specification, but already with a FEL beam quality sufficient to start first experiments) is reached. This performance goal is shown in Table 8.2.1. It is assumed that this goal will be reached approximately one year after the first beam has been injected into the linac. Likewise, the other FEL beamlines will then enter the operation phase once similar performance goals are reached (at wavelengths of 0.2 - 0.4 nm and 2 - 6 nm for SASE 2 and 3, respectively).

Wavelength [nm]	0.2
Peak Brilliance [photons/s/mm ² /mrad ² /0.1% BW]	> 10 ³⁰
Photon beam size at sample [mm ² FWHM] (no optics)	< 1
Photon beam position stability [% of rms size]	50
Electron beam energy stability [% rms]	0.1
Photon pulse intensity fluctuation [peak-to-peak]	Factor 10

Table 8.2.1 Initial performance goal for the SASE 1 radiator. Reaching this milestone defines the start of operation phase for the accelerator complex and for the SASE 1 beamline.

8.3 User operation

The European XFEL is conceived as a multi-user facility. External user groups will come to the facility for a short period of time to carry out experiments at the various beamlines and experimental stations, suited to their specific project. As is practice at synchrotron radiation facilities, the XFEL will regularly (probably twice a year) invite proposals for research projects. Beam time will be allocated by the XFEL management according to scientific excellence. Priorities will be decided by peer review committees composed of highly qualified scientists, mainly from the contracting party countries. Sufficient flexibility

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will be incorporated into the beam time allocation scheme to allow rapid access to beamlines for promising urgent work or to guarantee long term access to scientifically excellent projects which require beam time over a longer period. Up to a certain number of users (affiliated to universities or publicly funded laboratories of contracting party countries) per selected experiment will be reimbursed or funded by the XFEL for travel and subsistence expenses directly related to the execution of the approved experiment. Many proposals are likely to come from larger collaborations. If more scientists than those supported from the XFEL budget (see Section 8.4) participate in the selected experiment, they will have to be funded from their home institutes. The described procedure refers to the allocation of beam time for non-proprietary research where the results are open for publication. Non-refereed access to beam time, e.g. for proprietary research, will be possible but will have to be paid for.

Scheduling the experiments will be an important task since the time structure, energy range and, to some extent, quality of the photon beams in the various beamlines are not totally independent from each other, i.e. attention will have to be paid as to which experiments are best suited to run in parallel. A seven-days per week, round-the-clock beamline support for the users will be provided to help them make the most efficient use of the beam time allocated.

The total amount of scheduled user beam time per year is expected to be 4,800 hours. This includes the time necessary to set up and re-tune the machine to accommodate changing user requirements (e.g. variation of electron beam energy or bunch train time structure). Using the operation of the FLASH facility as a guideline, it is assumed that one day per week is needed for maintenance. In total, two months per year are foreseen for machine studies and improvements of the FEL performance. The remaining time per year will be allocated to a longer (approximately two months, plus appropriate time for re-start) shutdown, where more time consuming maintenance, refurbishment and additional installations can take place.

The complexity of the installation and of the proposed experiments requires an active and cutting-edge research and development programme to continuously improve the performance of the European XFEL Facility. A strong and highly visible in-house research programme is, therefore, considered important for the overall success of this installation. Topics of in-house research could range from FEL techniques over x-ray optics to scientific applications of FEL radiation. The in-house research programme will further enable staff scientists to promote their scientific careers and will, therefore, render positions at the European XFEL attractive.

8.4 Operation budget

The budget required to operate the XFEL Facility (not escalated, i.e. in year 2005 Euros) is summarised in Table 8.4.1 and its different components are briefly described in the following sections. Note that this will be the yearly budget for the XFEL from when all beamlines have come into operation. During the transition phase, the budget has three components: construction, commissioning (accounted as construction) and operation

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(see Chapter 10). The ramp-up of the operation part of the budget during this phase has been determined according to the sequence of commissioning the different parts of the facility described in the previous sections.

Consumables	11.5 M€
Maintenance and refurbishment	22 M€
Research and development	11 M€
Personnel accelerator and technical infrastructure	19.8 M€
Personnel photon beamlines and experiments	13.8 M€
User support (including overhead)	1.8 M€
Visitor and student programme	1.7 M€
Total yearly operation cost	81.1 M€

Table 8.4.1 Overview of operations costs (in year 2005 Euros).

Consumables include the cost for electricity, fluids (Helium, water) and the exchange/repair of klystrons. For electricity cost, a power consumption of 18 MW (approximately 80% for accelerator/infrastructure and 20% for the experimental facility) has been assumed (corresponding to operation at 17.5 GeV energy and baseline design parameters for the duty cycle), except for the maintenance/shutdown breaks where the power will be significantly reduced. In the transition phase, an initial, somewhat lower, power consumption has been assumed, reflecting the expectation that one would start with reduced electron beam energy and that downtime periods will be longer than later during routine user operation. The cost for fluids has been estimated on the basis of experience at HERA and FLASH. The repair/exchange rate for klystrons has been deduced from the assumption of an average lifetime of 40,000 hours.

Maintenance and refurbishment costs correspond to approximately 4% of the initial capital investment for all technical components, which is a reasonable assumption based on the experience from other large accelerator and synchrotron radiation facilities.

The **Research and development (R&D) budget** is appropriate since it can be expected that for this new type of facility a continuous development of new ideas, concepts and improvements and extensions of the experimental possibilities will take place.

The **personnel** requirement for the **accelerator complex and technical infrastructure** has been estimated from the Deutsches Elektronen-Synchrotron (DESY) Laboratory experience of operating large accelerator facilities. About 30% of the estimated total 251 full-time equivalents (FTEs) are needed for the round-the-clock shift crew (including safety and technical emergency services). The distribution of FTEs over the different technical sub-systems and tasks is shown in Table 8.4.2. The costs per FTE (different for the different categories in Table 8.4.2) were, similarly as for the construction phase, derived from the

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salary structure in the technical groups of the DESY-M division, including an overhead also determined at DESY.

Subsystem/task	FTE
Coordination	3
Linear Accelerator	50
Cryogenics	20
Utilities	35
Vacuum system	23
Beam diagnostics	25
Injector	6
Control system	25
Beam Physics	20
Installation/survey	10
Radiation safety/Personnel interlock	9
General safety	25
Total FTEs per operation year	251

Table 8.4.2 *Distribution of personnel for accelerator and infrastructure in the operation phase.*

The **personnel** requirement for the **photon beamlines and experiments** has been estimated by starting from experience at synchrotron radiation facilities, but taking into account the substantially higher complexity and technical challenges of the XFEL Facility. About one quarter of the estimated total 172 FTEs are needed for the round-the-clock shift crew. The permanent presence of experts from the beamline group will guarantee optimum support for the user groups, enabling them to conduct their experiments in the most efficient and successful fashion. The distribution of FTEs over the different technical sub-systems and tasks is shown in Table 8.4.3 (see also Chapter 9). The costs per FTE

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were, similarly as for the construction phase, derived from the salary structure in the DESY-HASYLAB division, including an overhead also determined at DESY.

Sub-system/task	FTE
Undulators	13
Operation of scientific instruments/In-house research	45
Photon diagnostics and photon transport/x-ray optics	23
Detectors	12
Laser systems	8
Computing	16
Preparation laboratories	10
Beamline/instrument design	5
Vacuum system	11
Mechanics and electronics	23
User administration	4
Public relations	2
Total FTEs per operation year	172

Table 8.4.3 *Distribution of personnel for photon beamlines and experiments in the operation phase.*

The budget for **User support** covers direct funding of user group expenses (travel, accommodation and meals) as well as an additional overhead related to administrative and logistics expenses. It is assumed that on average eight (out of 10) experiments are operated in parallel, in total 200 experiments per year are performed, and typically a user group of six scientists spends 10 days at the facility per visit. With 360€ per travel and 60€ per user day on site, a total amount of direct user support of 1,080 k€ results. Based on the DESY model of FTE-related overhead, another 670 k€ have to be added to this.

The **visitor and student programme** is included in the operation budget to enhance the scientific exploitation of the XFEL Facility. It is directly related to the in-house research programme. The proposed budget provides the salaries for 10 longer-term visiting scientists and 20 PhD students.

The budget summarised in Table 8.4.1 corresponds to the “steady state” situation when the facility is fully operational. During the transition phase, different parts of the operation budget are assumed to ramp-up in a reasonable fashion. For example, the electricity consumption will initially be somewhat lower, because operation will probably start at reduced electron beam energy and the yearly time integral of operation hours will be lower than in the later phase of routine operation. The R&D programme, the funding required for user support and the visitor/student programme will start at a lower level and increase in steps towards the “steady state”. This has been included when putting together the yearly budget and its operation component to derive the budget profile for the transition phase (see Chapter 10). It should also be noted that the personnel in the operation phase will, to a large extent, be the same as in the late part of the construction phase – meaning

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that what changes during the transition phase is essentially how the personnel costs are accounted for.

It should be noted that in the definition of the staff required for operation, the same approach was followed as for the construction phase, i.e. applying the DESY-model with an overhead, covering expenses for management and support and workplace-related