May 30, 2007

Technical Document 1

attached to the European XFEL Convention

Executive Summary of the Technical Design Report (Part A)
and
Scenario for the Rapid Start-up of the European XFEL Facility (Part B)

Introduction

The XFEL Technical Design Report (TDR), adopted by the XFEL Steering Committee in July 2006, foresees a facility comprising an accelerator complex for an electron energy of up to 20 GeV (17.5 GeV in the standard operation mode), five undulator branches with ten experimental stations, and various office, laboratory and general utility buildings distributed over three different sites. An executive summary of the TDR is given in **part A** of this Annex to the "Convention concerning the construction and operation of a European X-ray Free-Electron Laser Facility" (XFEL Convention).

The total project cost of the XFEL Facility as set out in the Technical Design Report (TDR) and in Annex 3 to the XFEL Convention amounts to 1081.6 M€, out of which 38.8 M€ for the preparation, 986.4 M€ for construction and 56.4 M€ for commissioning (all in 2005 prices).

In order to begin the construction as early as possible, the Contracting Parties agreed that the facility be realised in steps, with initial commitments covering only the costs of the first step. The construction costs for the first step were set at approximately 850 M€ (instead of 986.4 M€).

In **part B** of this Annex the characteristics of the rapid start-up scenario of the XFEL project are briefly outlined. A reference configuration, corresponding to a construction cost of 850 M€ is described; this configuration is not unique and alternative ones, all of which have construction costs not exceeding 850 M€, are also exemplified. A timeline for the final decision on the adoption of a specific configuration is also indicated. All alternatives are upgradeable to the full facility as described in the TDR.

Part A of
Technical Document 1

EXECUTIVE SUMMARY
of the
TECHNICAL DESIGN REPORT

Executive Summary

1 Basic Objectives

This report contains a full technical description of the European X-ray Free-Electron Laser Facility, a new international scientific infrastructure to be built in the north west of Hamburg. The purpose of the facility is to generate *extremely brilliant* (peak brilliance ~ 10^{33} photons/s/mm^2/mrad^2/0.1%BW), *ultra-short* (~ 100 fs) pulses of *spatially coherent* x-rays with wavelengths down to 0.1 nm, and to exploit them for revolutionary scientific experiments in a variety of disciplines spanning physics, chemistry, materials science and biology. The design contains a baseline facility and provisions to facilitate future extensions and improvements, in preparation of further progress in the relevant technologies. The basic process adopted to generate the x-ray pulses is SASE (Self-Amplified Spontaneous Emission), whereby electron bunches are generated in a high-brightness gun, brought to high energy (up to 20 GeV) through a superconducting linear accelerator, and conveyed to long (up to ~200 m) undulators where the x-rays are generated. Five photon beamlines deliver the x-ray pulses to ten experimental stations, where state-of-the-art equipment is available for the experiments.

From this new user facility, novel results of fundamental importance can be expected in materials physics, plasma physics, planet science and astrophysics, chemistry, structural biology and biochemistry, with significant possible impact on technologies such as nuclear fusion, catalysis, combustion (and their environmental aspects), as well as on biomedical and pharmaceutical technologies. Thanks to its superconducting accelerator technology, in spite of competing American and Japanese projects, the European X-ray Free-Electron Laser Facility will allow Europe to keep its leadership in basic and applied science with accelerator-based light sources, a leadership it acquired in the early 90's with the construction and operation of the European Synchrotron Radiation Facility (ESRF) in Grenoble.

2 History of the Project

The basic technology underlying the European X-ray Free-Electron Laser Facility is the superconducting linear accelerator technology, developed by an international collaboration coordinated by the DESY laboratory in Hamburg, with the initial objective to create TESLA (Tera-Electronvolt Superconducting Linear Accelerator), an electron-positron linear collider with TeV energy, for particle physics studies, hence the name TESLA technology. It was soon realized that this type of innovative linear accelerator had ideal characteristics for an x-ray free-electron laser. Proposals to build a free-electron laser, first as a side branch of the linear collider, and later as a self-standing facility were put forward by DESY to the German government. The construction of a test facility (TESLA Test Facility 1, or TTF1) was undertaken, and lasing down to ~90 nm wavelengths was successfully demonstrated in 2000. TTF2 had the more ambitious goal to push lasing to 6 nm wavelengths, with a 1 GeV linear accelerator. This should be achieved in 2007; in the meantime, acceleration of electrons up to 0.75 GeV has obtained lasing at 32 nm (Jan. 2005) and at 13 nm (April 2006), and a vigorous user program was started in August 2005 in the experiments hall downstream from the free-electron laser, forming what is now called the FLASH facility. In 2003, the German government decided to launch the proposal to constitute a European Facility for the construction and operation of an x-ray free-electron laser in Hamburg, undertaking the commitment to finance the new facility by providing up to 60% of its construction costs, and up to 40% of the operation costs. The choice of the location in Hamburg is motivated by the possibility to take advantage of the unique experience and know-how of the DESY Machine Division in the area of superconducting linacs, and of the possibility to gain first-hand experience on the operation of an FEL through the FLASH facility.

3 The Scientific Case and the X-ray FEL International Context

All natural sciences benefit from the use of photons (light waves) of different wavelengths to probe the phenomena of nature. The use of infrared, visible and near ultraviolet light has been revolutionized by the invention of gas lasers and of solid-state lasers, with their properties of high brilliance, spatial coherence and, in more recent decades, ultrashort pulses, with duration down to a few femtoseconds or less (1 femtosecond, or 1 fs, equals a billionth of a millionth of a second; light travels a distance of 0.3 μm in 1 fs). This time scale is of particular importance because atoms in molecules and solids oscillate around their equilibrium positions with typical periods of a few hundreds of fs, and in general, movements of atoms during the rearrangement of their positions in chemical reactions, or phase transformations also occur on such a time scale.

In the range of the ultraviolet, soft x-ray and hard x-ray wavelengths, great progress was achieved by the exploitation of synchrotron radiation, the brilliant emission by electrons or positrons orbiting in a circular accelerator. Synchrotron radiation, however, is far less brilliant than a powerful laser, has a very limited degree of spatial coherence, and it comes typically in pulses of ~ 30 ps = 30,000 fs duration. The objective of the modern projects for the realization of x-ray free-electron lasers is the extension of the scientific and technological revolution, ushered by lasers in the visible light range, to the x-ray range, providing spatially coherent pulses of < 100 fs duration, with peak powers of many GW.

As discussed in four international workshops organized between October 2005 and March 2006 in Hamburg, Paris, Copenhagen, and near Oxford, the outstanding properties of the European XFEL beams (coherence, ultra-high brilliance and time structure) and the development of appropriate detectors and instrumentation will allow completely new experiments. A few examples are listed below.

Coherence can be used for holographic and lensless imaging in materials science and in biology. Spectacular possibilities open up, as detailed theoretical studies and simulations predict that, with a single very short and intense coherent x-ray pulse from the XFEL, a diffraction pattern may be recorded from a large macromolecule, a virus, or a cell, without the need for crystalline periodicity. This would eliminate a formidable bottleneck for many systems of high interest, e.g. membrane proteins, viruses and viral genomes. Measurement of the over-sampled x-ray diffraction pattern permits phase retrieval and hence structure determination. Although individual samples would eventually be destroyed by the very intense x-ray pulse, a three-dimensional data set could be assembled, when copies of a reproducible sample are exposed to the beam one by one.

The high intensity can also be used to produce highly ionized states of atoms, generating in the laboratory conditions and processes occurring in interstellar gases. In conjunction with the ultra short pulse duration, it can be exploited in pump-and-probe experiments, where conventional laser pulses (pump) are used to trigger a chemical reaction or a phase transition, and the XFEL pulses (probe), each following the pump pulse with a well determined delay (from ~50 fs up to ns or even μs), provide a "movie" of the atomic displacements and rearrangement of chemical bonds. In this way, catalytic mechanisms in chemical and biochemical reactions can be elucidated, fast reactions (e.g. combustion) can be subject to detailed investigation, nucleation of ordered phases at phase transitions can be imaged, and hitherto inaccessible states of matter can be brought to experimental investigation: if the pump pulse is sufficiently powerful to produce a plasma, the x-ray pulse can still penetrate the highly ionized medium (opaque to visible light) and provide information on the propagation of the shock front, on the time evolution of temperature and pressure distributions, on the equation of state.

As already emphasized, the potential relevance of scientific breakthroughs of this caliber extends beyond basic science, to technologies of essential importance for Europe. It would not be wise to leave a competitive advantage in this field to United States, where the LCLS (Linac Coherent Light Source) project is well under way at Stanford, and to Japan, where the SCSS (Spring-8 Compact SASE Source) has obtained financial green light for start-up already in 2006. Although these projects started already, and are probably going to be completed earlier, the European XFEL adoption of the superconducting accelerator technology allows producing 30,000 x-ray pulses per second (and possibly even more in the future), to be compared to the 120 of the LCLS and 60 of the SCSS. In addition to this decisive technical advantage, reducing the time necessary to complete some experiments by two orders of magnitude, the useful experience acquired with FLASH could considerably benefit the rapid establishment of a successful scientific exploitation. If the European XFEL Facility keeps a schedule comparable to that of the competing projects, it can occupy the leading position in this field.

A European laboratory in Hamburg, pursuing excellence in the physics and applications of hard x-ray free-electron laser radiation would be complementary to other projects in Europe emphasizing the soft x-ray part of the spectrum, and benefit all of them through the development and sharing of common technologies.

4 Layout and Performance Goals of the Facility

The main components of the Facility are (see Figure 4.1):

- the injector
- the linear accelerator
- the beam distribution system
- the undulators
- the photon beamlines
- the instruments in the Experiments Hall.

These components are disposed along an essentially linear geometry, 3.4 km long, starting on the DESY campus in the northwest part of the city of Hamburg, and ending in the neighboring Federal State of Schleswig-Holstein, south of the city of Schenefeld, where the Experimental Hall is located.

The basic functions of the main components are schematically described in the following. In the injector, electron bunches are extracted from a solid cathode by a laser beam, accelerated

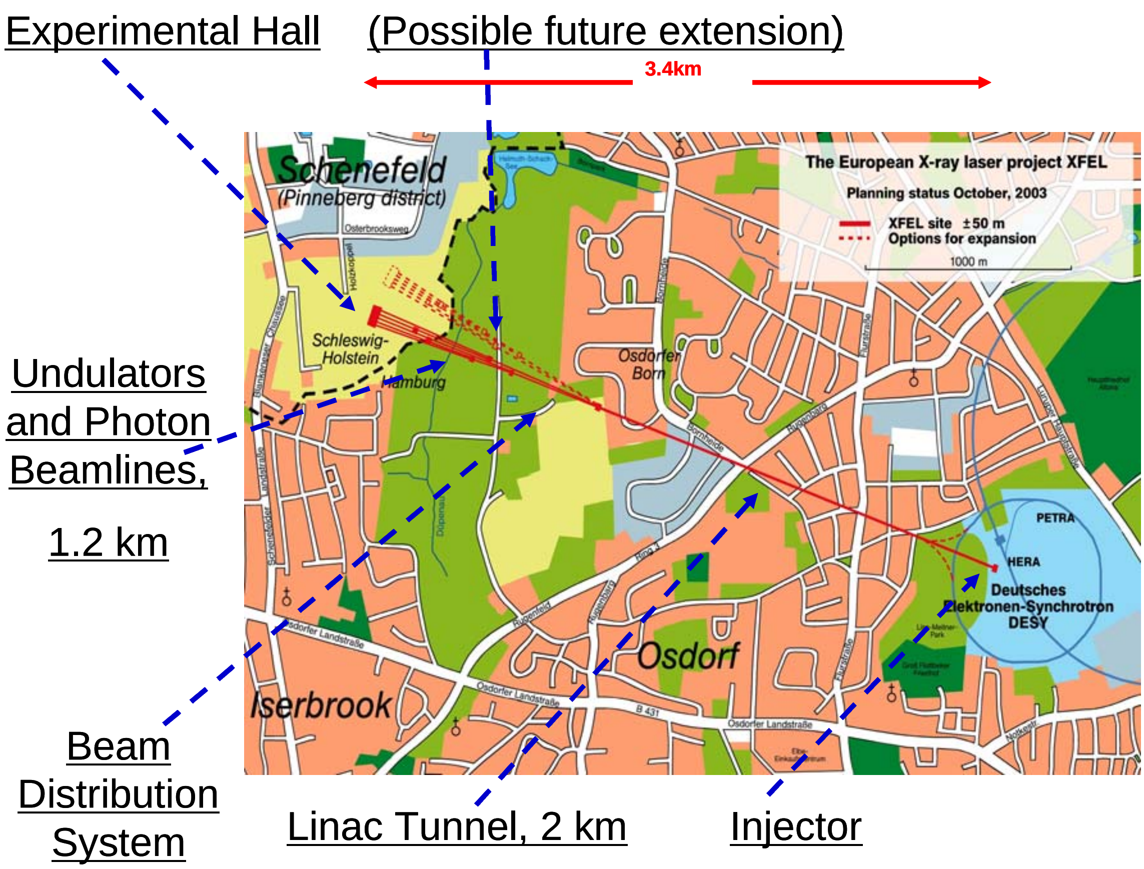

Figure 4.1: *Schematic layout of the main components of the European XFEL Facility.*

by an electron RF gun and directed towards the linear accelerator (linac) with an exit energy of 120 MeV. In the linear accelerator, consisting of a 1.6 km long sequence of superconducting accelerating modules, magnets for beam steering and focusing, and diagnostic equipment, the electrons are accelerated to energies of up to 20 GeV (17.5 GeV is the energy foreseen for the standard mode of operation of the XFEL facility). Along the accelerator, two stages of bunch compression are located, to produce the short and very dense electron bunches required to trigger the SASE process. At the end of the linac, the individual electron bunches are channeled down one or the other of two electron beamlines by the beam distribution system (Figure 4.2). Electron bunches channeled down the electron beamline 1 pass through the undulators SASE1 and SASE3, producing respectively hard x-ray photons with 0.1 nm wavelength (SASE1) and softer x-ray photons with 0.4 -1.6 nm wavelength (SASE3), by the SASE free electron laser process. After going through SASE3, electrons are deviated towards a beam dump. Electron bunches channeled through the electron beamline 2 are led through the undulator SASE2, where hard x-ray photons with wavelengths 0.1-0.4 nm are produced by the SASE process; and then through the undulators U1 and U2, before ending in the second beam dump. In U1 and U2, very hard x-ray photons (wavelengths down to 0.014 and 0.06 nm, respectively) are generated by the spontaneous emission process. The photons generated by the five undulators are transported through the respective photon beam line to the Experimental Hall, where they are fed into ten experimental stations. Reducing the electron energy at the end of the accelerator would generate longer wavelengths, in case they are required by some experiments; for example an electron energy of 10 GeV would correspond to x-rays of 4.9 nm wavelength from the SASE3 undulator.

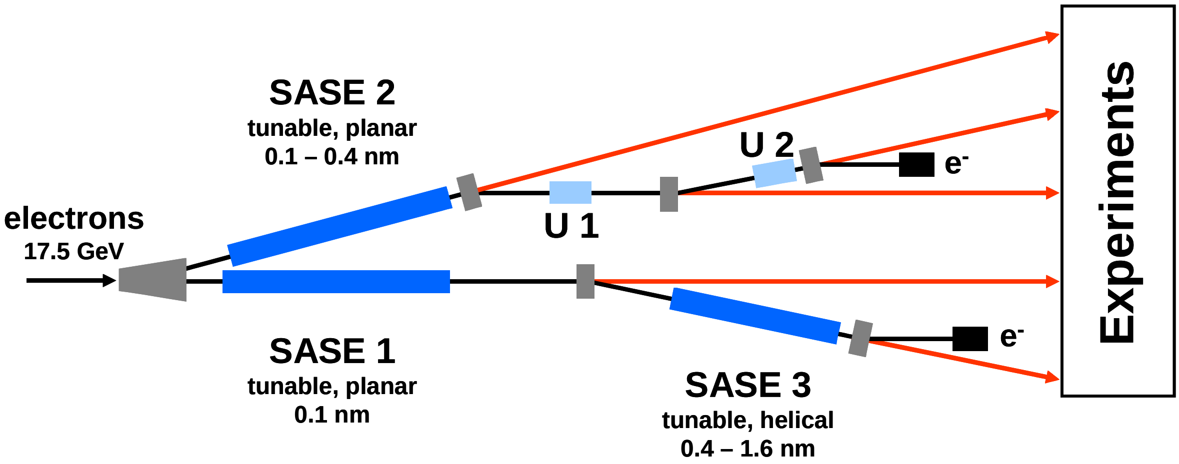

Figure 4.2: *Schematic view of the branching of electron (black) and photon (red) beamlines through the different SASE and spontaneous emission undulators. Electron beamlines terminate into the two beam dumps, photon beamlines into the Experimental Hall.*

The installation and commissioning of the accelerator, the undulators, beamlines and experimental stations will take place gradually, according to a strategy for the achievement of intermediate and final goals of the Facility which was established with the advice of the Scientific and Technical Issues (STI) Working Group.

The first electron beamline and the SASE1 undulator are going to be installed first. Commissioning of the accelerator and of the SASE1 undulator, beamline and first station is pursued, in parallel with installation of the other electron branch, until the first set of intermediate goals (see Table 4.1) is reached.

As recommended by the STI Working Group, the following criteria for the start of operation of the accelerator complex and the SASE radiators and beamlines were adopted:

- The accelerator complex and SASE1 start operation when on SASE1 a photon beam is obtained with the intermediate values of Table 4.1, and sufficient equipment is installed and commissioned to perform first scientific experiments.
- SASE2 starts operation when the same criteria as above are fulfilled, for wavelengths between 0.2 and 0.4 nm.
- SASE3 starts operation when the same criteria as above are fulfilled, for wavelengths between 2 and 6 nm.

Following the positive experience of the FLASH facility, developments towards the final project goals on all beamlines will proceed in parallel with early user operation, as soon as the criteria stated above are fulfilled.

Parameter	SASE1 Intermediate Values	SASE1 Final Project Values	Units
Wavelength	< 0.2	0.1	nm
Peak Brilliance	10^{30}	5×10^{33}	Photons/s/mm^2/ mrad^2/0.1%BW
Dimension at sample (no optics)	< 1.0	~ 0.6	mm^2, FWHM
Positional Stability	50	10	% of beam size, rms
Photon Energy Stability	~ 0.1	~ 0.1	%
Shot-to-Shot Intensity Fluctuations	Up to a factor 10	0.3 – 0.5	Dimensionless, Peak-to-Peak

Table 4.1: *Intermediate and final project values for the accelerator and SASE1 undulator and corresponding photon beamline.*

5 Cost, Schedule and Personnel

5.1 Cost of the Project

All costs from the project preparation to the commissioning phase (i.e. prior to the start of operation) have to be summed up in order to determine the total project construction cost (TPCC). There will be a period of about 2.5 years during which an overlap of construction, commissioning and operation will occur (see also the discussion of time schedule and budget profile below). The contributions to the TPCC, summarized in table 5.1, are:

- The project preparation costs. These are the expenses since the XFEL Memorandum of Understanding came into effect (end of 2004) by DESY and by those institutes which have concluded collaboration contracts with DESY under the XFEL MoU.
- The construction costs in the proper sense, of the accelerator, the undulators, the photon beamlines, scientific instruments, civil engineering and technical infrastructure of the European XFEL Facility, including capital investment and manpower.
- The cost for commissioning the facility with beam.
- An addition to the personnel cost, in order to take into account allowances for personnel moving from their home country to work at the XFEL company.
- An additional personnel cost overhead, taking account of the XFEL company's management & support costs.

Recurrent costs during the construction in the proper sense (electricity, water, helium) are not included in the TPCC, since they will be covered by the DESY operation budget free of charge to the XFEL project. Costs related to land acquisition are also not included in the TPCC, since Germany offered to provide the ground free of charge to the project.

Project preparation		38.8 M€
Project construction, capital investment	*736.3 M€*	
Project construction, personnel	*250.1 M€*	
Total construction cost		**986.4 M€**
Beam commissioning		56.4 M€
Total Project Cost		**1,081.6 M€**

Table 5.1: *Total project construction cost, including preparation – commissioning phases. All cost figures are on the price basis of the year 2005. . - The original Table 5.1 of the TDR has been slightly re-arranged: the additional personnel cost (allowances) and the additional management overhead of the XFEL GmbH, initially shown in separate lines of the table, are now included in the cost for construction and commissioning.*

As described in detail in chapter 10, the breakdown of this cost between the major components of the facility, is displayed in Figure 5.1.

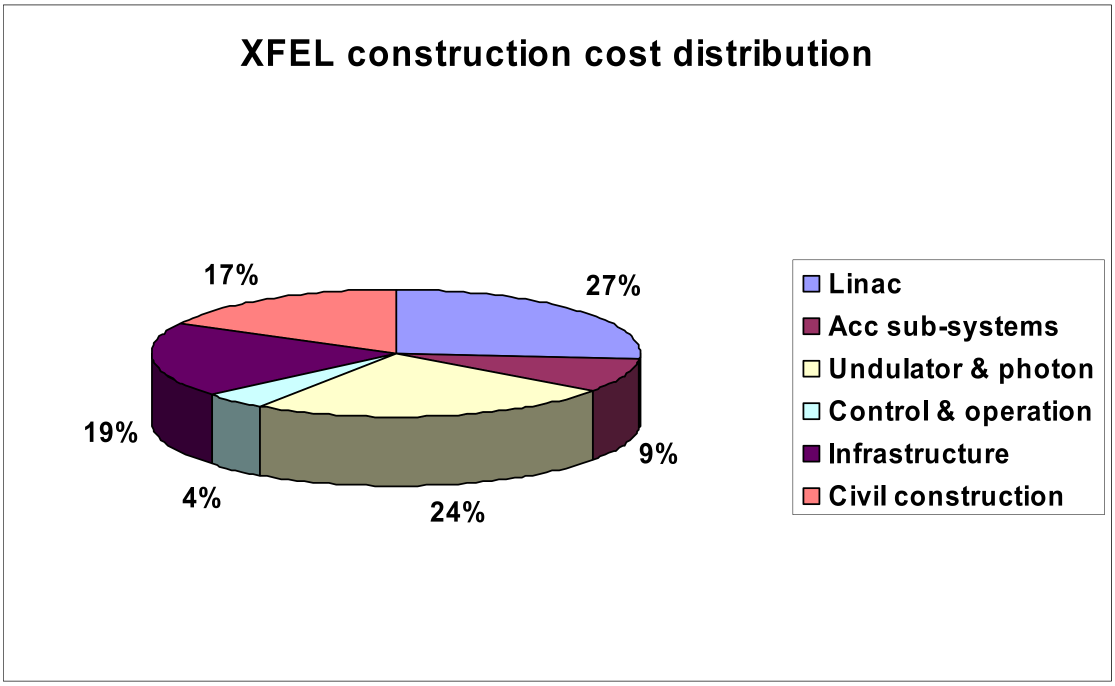

Figure 5.1: *Breakdown of the proper construction costs (sum of capital investment and personnel cost) into the work package groups corresponding to the main components of the facility.*

An analysis of the risk of overspend was performed according to guidelines specified by the Full Costing Issues (FCI) subgroup of the Administration and Financial Issues (AFI) Working Group. The resulting risk budget (8% of the proper construction costs) amounts to 78 M€, and is the additional figure required to bring the probability of successful completion of the Facility within budget to 98%.

The estimated yearly operation costs of the Facility, after the end of all construction, are 83.6 M€, including all recurrent costs for operation, maintenance and refurbishing, and support of the international user activities, plus a PhD student and a visiting scientists program.

5.2 Project Time Schedule

The time schedule for the project is presented in Figure 5.2, which assumes that the official start of the project construction is January 2007. For each of the major parts of the facility, phases during construction (which can partially overlap in time) can be defined as:

- Design, prototyping and industrialization
- Fabrication (including pre-series)
- Installation
- Commissioning (technical and with beam)

In summary, the construction schedule provides for the milestone of first beam into the linac to be met 6.5 years after the start of construction. At this point in time, the first branch of beam lines with the SASE1 undulator will also have been installed. Beam commissioning will then progress until the intermediate performance milestones of SASE1 radiation are reached, 7.5 years after the start of construction. This beamline will then become operational for first experiments. Commissioning of the other beamlines follows.

5.3 Budget Profile

With the different contributions to the TPCC as summarized above, the construction time schedule and the operation costs as described in chapter 8, a complete budget profile for all phases from preparation to operation can be constructed. The result is displayed in figure 5.3 showing the yearly budget from 2005 – 2016 on the price basis of the year 2005 (i.e. without applying an escalation to take inflation into account).

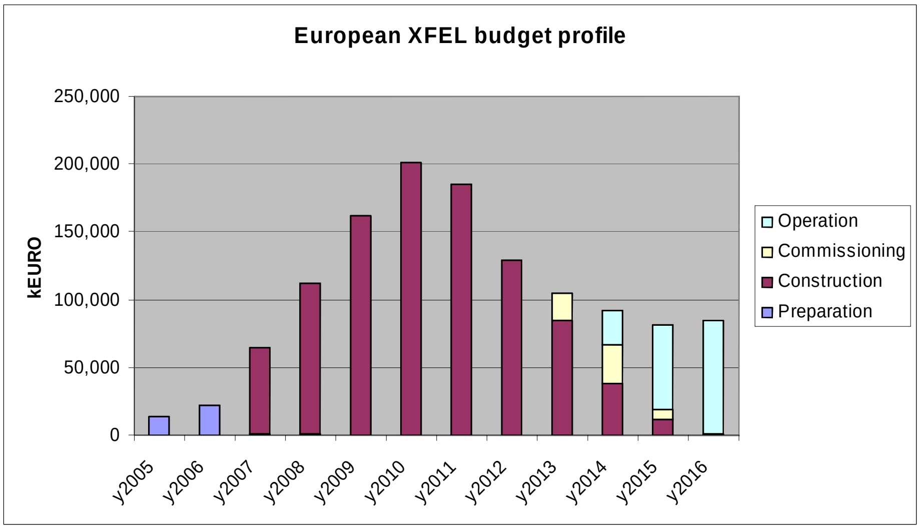

Figure 5.3: *Budget profile (sum of capital investment and personnel cost on year 2005 price basis) from preparation to operation phase of the project.*

Personnel costs, as given explicitly in Table 5.1 and implicitly in Figure 5.3 correspond to the cost of the personnel hired by the Facility, plus the personnel costs for those work packages of the project, which are provided as an in-kind contribution by laboratories of the participating countries.

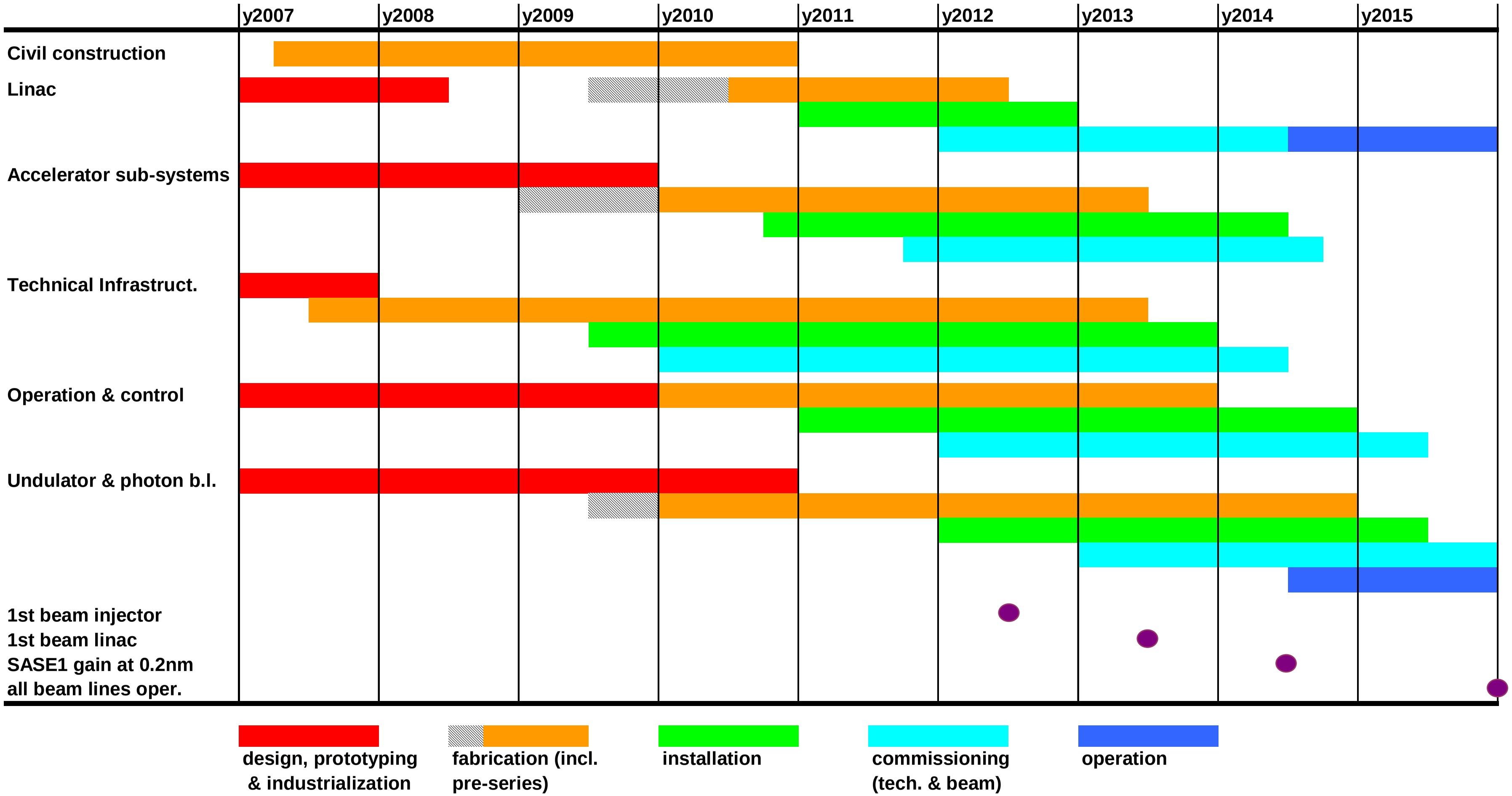

Figure 5.2: *Sketch of the schedule for the main components of the Facility from start of construction to beginning of operation.*

[Schedule taken from XFEL Technical Design Report, July 2006]

Part B of
Technical Document 1

SCENARIO FOR THE RAPID START-UP
of the
EUROPEAN XFEL FACILITY

Scenario for the rapid start-up of the European XFEL Facility

Basic Features of the Start-up Reference Configuration

The entire photon spectrum specified in the TDR will be made available, however the start-up configuration will comprise only three photon beamlines (instead of five) and six experimental stations (instead of ten). The performances of the accelerator as specified in the TDR are maintained, so that the facility can reach the reference parameters for operation at 0.1 nm photon wavelength. However, the energy surplus of the accelerator with respect to the standard mode (17.5 GeV) will be removed. Cost reductions are planned to be made in such a way that the start-up configuration remains expandable to the Facility specified in the TDR. All suppressed or reduced items can be inserted back, during the construction period or later, depending on whether and when the required funding will become available. However, in order to avoid additional effort and cost, the decision to reinstall a certain item has to be taken within a certain time frame. *These critical points in time are indicated below for the main reduction items.*

Details on cost reductions and their impact

Accelerator complex

Four units (four accelerator modules and one radio frequency station per unit) in the main section of the linac (after the 2^{nd} bunch compression stage) will not be installed. This reduces the linac design energy from 20 to 17.5 GeV and the number of reserve units from two to one in this part of the accelerator (another reserve unit remains in the section between the bunch compressors). Operation at the reference energy of 17.5 GeV with the TDR reference parameters is guaranteed. However, the possibility of increasing the beam energy and repetition rate is severely restricted. *The decision to install the initially suppressed units would have to be taken by the time the tender process for linac components is launched (mid-2008).*

The complete system of electron beamlines up to the beam dumps will be built as part of start-up configuration, whereas the installation of some special beam diagnostics will be postponed.

Undulators and Experiments

A reduction in the number of undulators from five to three is considered. The number of experimental stations with their infrastructure is correspondingly reduced (six instead of ten). Further cuts in experimental facilities affect optical laser installations, sample environment R&D, sample preparation laboratories, specific instrumentation (all reduced by 50%) and generic detector R&D (40%). One out of three full developments for area detectors and particle detectors will be delayed until the upgrade to the full project. Later extension towards the initial design remains possible. The following figure illustrates one possibility of coping with this change. It aims at having the same spectral interval of photon energies covered as foreseen in the TDR, although with reduced possibility of parallel exploitation of instruments. In the figure, the option to move SASE 3 from its original position to the position of U 1 is indicated.

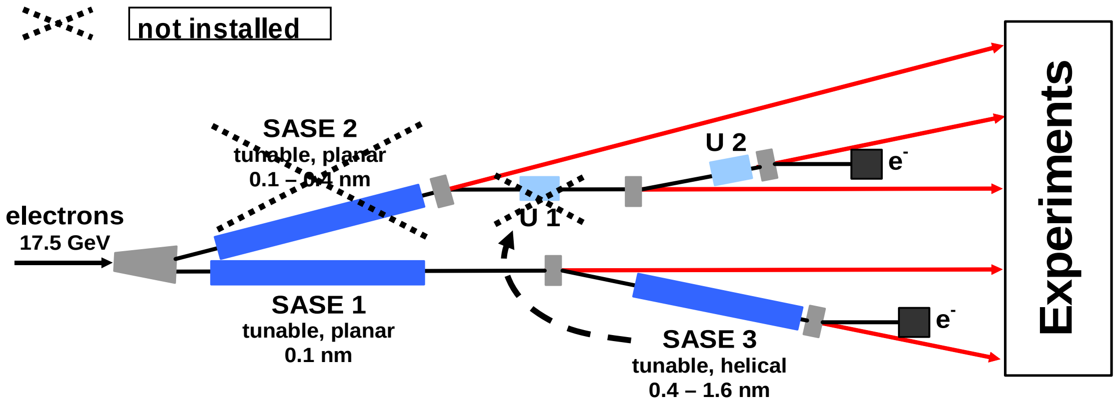

Fig. 1: Option for undulator layout in Step 1 of the XFEL

This could be advantageous in case the recovery of the SASE 2 beam line has to be postponed for a longer time, because the two initially installed SASE beam lines could be operated in the two separate electron beam lines, providing more operational flexibility. Further below in this document, four possible variations of the above reference scenario are outlined, showing that there is still great flexibility in the choice of photon beam lines and stations within the first step of the project. *The time line for deciding the undulator number and configuration is determined by the time of the first order to be placed. This order is currently scheduled for the second half of 2009. Earlier impacts are however expected for the development of area detectors, where a decision is due during the first half of 2007.*

Technical Infrastructure

Instead of constructing a new liquid helium plant, the existing HERA plant shall be refurbished and upgraded. Two out of three liquefier units will be used for XFEL, the other one for FLASH. This will lead to a reduced redundancy in case of failures, but one of the two units is still sufficient to keep the linac cold and even to operate it with restricted parameters. DESY looses the option to use part of the plant for other purposes.

The module test facility will be reduced by merging the (originally separate) horizontal cavity test stand with one of the three module test stations. Thus only two module test stands are available during the time when single cavity tests take place in the horizontal cryostat. Since this is expected to happen only during the initial phase of module production at low rate, it is not expected to cause delays in the series production and testing of accelerator modules.

The possible decision to restore these reduction items is urgent (mid – end 2007).

Buildings

The layout of the underground buildings is preserved completely, in order to be able to expand the start-up configuration to the Facility specified in the TDR. The size of the Office Building and of the canteen at the Schenefeld Campus can be reduced, but later extensions of these buildings remain possible. The hall for a new cryogenic plant is removed.

A decision to implement the originally planned full-size Campus buildings would have to be taken at the time of the calls for tender (in 2008), or at the latest in mid 2009, if a call for tender in tranches is envisaged.

Cost estimation

The start-up configuration, based on these assumptions, allows a cost reduction of approximately 137 M€ with respect to the 986 M€ for the full facility set out in the TDR and in Annex 3 to the Convention. The cost reduction refers to 106.9 M€ under investments and 30.1 M€ under Personnel, which leaves construction costs of 849.3 M€ **(in 2005 prices)** still to be covered. A breakdown of the cost reductions is given in the table below.

Work package group	**Cost reduction**[1] with respect to Technical Design Report		**Reduced construction cost**[1] (Investment + Personnel)
	under Investment	**under Personnel**	**of XFEL Facility in start-up configuration**
WPG1 Linac	24,9	4,0	231,2
WPG2 Accelerator sub-systems	1,6	1,1	83,6
WPG3 Undulators & photon beam lines	57,9	18,5	149,5
WPG4 Control & operation	0,2	0,8	38,4
WPG5 Infrastructure	15,2	2,4	171,7
WPG6 Site & Buildings	7,1	0	161,6
GmbH personnel additional overhead		3,3	13,3
Total:	**106,9**	**30,1**	**849,3**

[1] (in M€, year 2005 price basis)

Alternative scenarios for the Start-up Facility

In the following paragraphs, alternative scenarios for the realisation of a start-up configuration of the European XFEL are discussed. These alternatives show that the budget for the start-up configuration of the European XFEL, and in particular the reduced budget for the photon beam systems, still offers the flexibility required to respond to the requests of the scientific community. Since the final decision for one of these options is not immediately required (if necessary at all), it will be thoroughly discussed with representatives of the scientific communities involved.

The cost figures given are relative to the numbers quoted above for the reference scenario.

Alternative Scenario A

In this scenario only a moderate modification is applied, in that, instead of SASE 1, the gap-tuneable device SASE 2 is initially installed. This would allow operating the accelerator at constant energy, while tuning the photon energy by gap variation of the undulator. To cope with the higher cost of SASE 2 with respect to SASE 1, the soft X-ray FEL undulator SASE 3 is not built in helical technology, but as a more conventional planar device. Reduced R&D and construction costs for the planar devices allow substantial savings. A later extension to a helical FEL providing circular polarized radiation could be implemented by replacing only the undulator segments in the final gain lengths.

The cost for this scenario is 2.7 M€ lower than the reference one. *The time line to decide in favour of this scenario depends on the number of undulator segments to be ordered (mid 2009) and the R&D phase for the helical undulators (latest start end 2008).*

Alternative Scenario B

In this scenario emphasis is given to the supply of hard X-ray FEL radiation, by keeping both hard X-ray FELs SASE 1 and SASE 2. To compensate for the higher cost of these devices, no other undulators will be built during the first step of the project. However, since the experimental hall provides sufficient space, it is still possible to build six instruments around these two undulators. Considerable resources for undulator and beamline could be used in this scenario to increase the budget for sample environment and detector R&D.

This cost for this scenario is 1.1 M€ lower than the reference one. *This scenario can be upgraded to full scale at any moment without specific cost increase. However, for the SASE 3 helical undulator, it is to be kept in mind that an R&D phase must start 2.5 years prior to installation date.*

Alternative Scenario C

In this scenario all three FEL undulators SASE 1, SASE 2 and SASE 3 are kept in the first step of the full project. The soft X-ray FEL undulator is considered to have planar magnetic field configuration (see Scenario A.). In order to cover the increased cost for undulators, it is proposed that the number of instruments be reduced from six to four. One could envisage to install these four instruments at the hard X-ray FEL beamlines of SASE 1 and SASE 2, and to provide an open port at the soft X-ray beamline, where experiment groups could assemble their own apparatuses (FLASH concept). Alternatively, scientific instruments on SASE 3 could be built with funds provided by consortia of experimentalists.

The cost for this scenario is 0.9 M€ lower than the reference one. *This scenario can be upgraded to full scale at any moment without specific cost increase. For the helical configuration of SASE 3 it is valid what is written under scenario A.*

Conclusion

Construction costs of 850 M€ allow the facility to be built in a start-up configuration with the following features:

1. It can later be expanded to recover the full facility as specified in the TDR, with no additional costs if the corresponding decisions are taken early enough.

2. It offers a variety of possibilities in the choice of the radiators in the first step, and therefore in the corresponding experimental program, with more or less priority given to hard vs. soft X-rays, coherence vs. spontaneous emission, etc.