XFEL The European X-Ray Laser Project XFEL

X-Ray Free Electron Laser

Interim Report of the Scientific and Technical Issues (XFEL-STI) Working Group on a European XFEL Facility in Hamburg

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This Interim Report has been prepared by the Scientific and Technical Issues Working Group in a series of five Working Group (XFEL-STI) Meetings held from April 2004 to December 2004 at DESY, Hamburg.

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Contents

Executive Summary

The scientific case for the proposed European XFEL Facility in Hamburg is extremely strong due to its unique features of brilliance, spatial coherence and time structure, for which many orders of magnitude are gained with respect to the best storage ring based synchrotron radiation sources. With this type of source it will be possible for the first time to study directly new states of matter on atomic length and time scales, i.e. with resolutions of 0.1 nm in space and femto-seconds in time. Examples include:

- probing the time evolution of solid-state structures and chemical reactions on the femto-seconds timescale;
- solving the structure of biomolecules without the need for crystallization;
- exploration of the non-linear properties of matter in the X-ray range and the dynamics of fluctuations on interatomic length scales and femto-second time scales;
- production and investigation of matter in portions of its phase diagram inaccessible to other probes.

The core of the proposed European XFEL Facility is a linear accelerator based on superconducting RF technology with an inherently high degree of flexibility with respect to energy reach and time structure of the pulse sequence. Two independent injector sections and a flexible electron and photon beam distribution system will allow for continuous development of the facility. The incorporation of further technological advances, likely to mature during the coming years, will improve the performance of some of the subsystems and will thus further extend the scientific case of the European XFEL Facility.

The proposed site, with the facility starting on the DESY campus and the beam distribution system and the experimental hall located in an area of low environmental noise, is well suited. The overall cost for the construction of the European XFEL Facility including 5 undulators in 5 underground tunnels serving 10 experimental stations is estimated as 908 M€. It is recommended that construction should start in 2006 so that the commissioning with beam could commence in 2012. The cost frame for additional R&D programmes for fast area detectors, optical laser systems, sample environment and handling and X-ray optics is estimated to 50 M€. Operational costs, escalated to the first year of operation (2013), are estimated as 90 M€ per year.

There are at present several national efforts to build VUV and soft X-ray free electron lasers in Europe. However, the scientific promise of a source capable of reaching photon wavelengths of 0.1 nm and below is so great that it calls for a joint European endeavour to turn it into reality. Strong synergies with the optical laser community in Europe are expected during the construction of the facility as well as for the preparation and performance of the experimental programme at the European XFEL Facility. Following the decision of the particle physics community to plan the International Linear Collider based on superconducting TESLA technology, the accelerator programme of the European XFEL Facility will interest many accelerator laboratories world-wide in contributing to the construction of its linear accelerator. As a whole, the European XFEL Facility will play a leading role in the world of science over many years and will attract outstanding scientists, and especially young researchers. The XFEL will have a truly European dimension and deserves strong support from the European countries and the European Community.

The STI working group strongly recommends proceeding as soon as possible towards the foundation of the European XFEL Facility in Hamburg.

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I. Preamble

The Scientific and Technical Issues Working Group (XFEL-STI) was established by the X-ray Free Electron Laser Steering Committee (XFEL-SC). The XFEL-SC is charged with the preparation of the documents necessary for the foundation of a European X-ray Free Electron Laser Facility in Hamburg. The charge letter specifying the functions of the XFEL-STI is attached as Annex 1. The composition of the XFEL-STI is reported on the cover pages of this report. A Memorandum of Understanding (MoU) regulating the preparatory phase for the construction of the European XFEL Facility and signed by the presently participating countries is reported as Annex 2. The MoU summarizes the two main charges of the XFEL-STI, which are:

- Provide the XFEL-SC with an Interim Report by the end of 2004 which:
  1) Assesses the scientific goals and the overall layout of the European XFEL Facility in Hamburg, and 2) Explores the construction and operational costs of the facility.
- Contribute to the preparation of the documents necessary for the contract among Member Countries regulating the construction of the new facility, as specified in the MoU.

II. Introduction

The XFEL-STI met for the first time on 1 and 2 of April 2004, and agreed to the following in generating the present Interim Report (IR).

The XFEL-STI should discuss and define a common basis for implementing a critical review of the already existing European XFEL Facility proposal developed by DESY in the context of the TESLA project. The Interim Report should evaluate and complement this material in the context of the new initiative aiming at the creation of a European X-ray Free Electron Laser Facility (European XFEL Facility).

The XFEL-STI fully supports the general concept that European and Non-European Countries should get together to construct and operate a European XFEL Facility in Hamburg, aiming to deliver an X-ray beam with unprecedented properties. This facility will open new avenues in science and will provide Europe and other participating countries with a unique new tool necessary to keep their Science at the leading edge worldwide, in an area where European large-scale facilities have a long-standing leading tradition. The XFEL-STI acknowledges the fact that a similar project (LCLS) is well under way in the US and activities are also being discussed in Japan and Korea.

The XFEL-STI identified the following four main subjects, which will be separately discussed in this IR. They are respectively:

1) <u>The XFEL Scientific Case</u>

   This section will summarize the scientific areas where the new facility is expected, within today’s knowledge, to have the most significant impacts**.** Breakthroughs in these areas will not be possible without an X-ray free electron laser. The peak brilliance and the transverse coherence of the XFEL are impossible to achieve with storage rings, the X-ray range appears today to be inaccessible for other kinds of lasers, and femto-second pulses can be achieved at existing X-ray sources only at the cost of a dramatic reduction in intensity.

2) The Accelerator Design and Related R&D Programmes

In this section the layout of the accelerator system is discussed. This includes in particular the photocathode RF-gun injector, bunch compressor, superconducting main linac, beam distribution and stabilisation systems. Questions of beam time structure and pulse repetition rates in the baseline design are addressed as well as possible future developments towards high duty cycle, up to continuous wave (CW) operation, and possibilities for reaching shorter wavelengths.

3) The XFEL Process and Related R&D Programmes

Proven and foreseeable XFEL production schemes for the anticipated wavelength range are summarized in this section. Anticipated possible alternative operational schemes for shorter pulses, shorter wavelengths, and seeding options will also be discussed as inputs for the XFEL R&D programme.

4) The Photon Beamlines and Related R&D Programmes

The development of the European XFEL Facility is seen as a staggered process, which must envision a baseline design for a set of phase-I beamlines, followed by a new wave of experimental infrastructures and beamlines in a phase-II programme, which should be thoroughly discussed and streamlined as early as possible. The design of the whole facility must be flexible enough to be able to accommodate a continuous upgrade and refurbishment programme for the phase-I (and phase-II) beamlines reaching far beyond the respective baseline designs. This report addresses only the instrumentation and the infrastructural developments for the phase-I beamlines.

It is not the aim of this IR to deliver a full Technical Design Report (TDR), but to identify the information necessary for the production of such a TDR for the European XFEL Facility. The XFEL-STI recognizes in this respect that a large amount of material is already available, notably in the TESLA XFEL TDR Supplement, published by DESY in October 2002 for the "First Stage of the X-ray Laser Laboratory" (http://tesla.desy.de/new_pages/tdr_update/supplement.html), and in Part II and Part V of the TESLA TDR, March 2001 (http://tesla.desy.de/new_pages/TDR_CD/PartII/accel.html, http:// tesla.desy.de/new_pages/TDR_CD/PartV/xfel.pdf). Furthermore, the ongoing work of the DESY XFEL group (http://xfel.desy.de) provides additional input for the finalisation of the technical layout of the facility. An update of the facility layout including a compilation of the relevant parameters is provided in Annex 3.

The XFEL-STI, in order to meet the challenges and to address the points outlined in II.1-4, has decided to summarize its findings in key statements (section III) and to highlight the main subjects in a series of short statements in sections IV to VII. At an enlarged meeting, organized by the XFEL-STI in Hamburg on the DESY site on June 22-24, experts were invited to present and discuss the topics covered in sections III to VII. The participants and the agenda of the meeting are listed in Annex 4. The presentations given at that meeting are also available under http://xfel.desy.de/content/e761/e830/index_eng.html. The material gathered at this meeting was analysed in detail by the XFEL-STI and, after successive discussions and iterations at the third and fourth meetings, held on September 27/28 and November 10, 2004 in Hamburg, is contained in sections IV-VII. Estimates of the construction and operational costs of the facility are summarized in chapter VIII. The report was finalized during the 5th Meeting on December 20, 2004. A concluding section summarizes the Interim Report and provides the final recommendations of the XFEL-STI.

III. Key Statements of the XFEL-STI Working Group

The working group makes the following key statements:

1) XFEL: A Source of Unprecedented Properties

The Linear Accelerator based European XFEL Facility will provide an X-ray source with unprecedented properties in terms of peak brilliance, average brilliance, coherence, pulse duration and time structure as indicated in Table 3.1. The peak brilliance of the European XFEL Facility will supersede any other conventional X-ray light source by at least 10 orders of magnitude as illustrated in Figure 3.1. This source, which will allow exploitation of X-ray photons with wavelengths resonant with inter-atomic distances, and with pulse durations comparable to times of inter-atomic motion and bonding electron motion, will be uniquely matched to investigations of the structure and dynamics of matter at its most fundamental level. It will offer a completely new perspective for diffraction, imaging and absorption X-ray studies.

	Unit	SR Source	XFEL
Peak Brilliance	ph/s/mm^2/mrad^2/0.1%bw	10^{23}	10^{33}
Average Brilliance	ph/s/mm^2/mrad^2/0.1%bw	10^{20}	10^{24}
Pulse Duration	pico-seconds	100	0.1
Coherent Flux	ph/bunch	100	10^{12}

Table 3.1: Base parameters of the European XFEL Facility compared to the typical characteristics of a 3rd generation Synchrotron Radiation (SR) Source.

2) Scientific Impact for Europe and Beyond

The European XFEL Facility is a must for the future of Science in Europe and abroad. It will be a facility with enormous discovery potential and very high impact in many different disciplines. There will be an initial period of time with bursts of unexpected, revolutionary results accompanying the first fore-front experiments. These will dominate the operation of the European XFEL Facility rather than routine applications as known from existing synchrotron radiation facilities. Its initial operation will focus on specific scientific subjects which will bring together the efforts of leading Academic, Research and Industrial Laboratories for their exploitation, and for the creation of new associated experimental protocols. This facility is therefore highly complementary to existing storage ring based synchrotron radiation facilities.

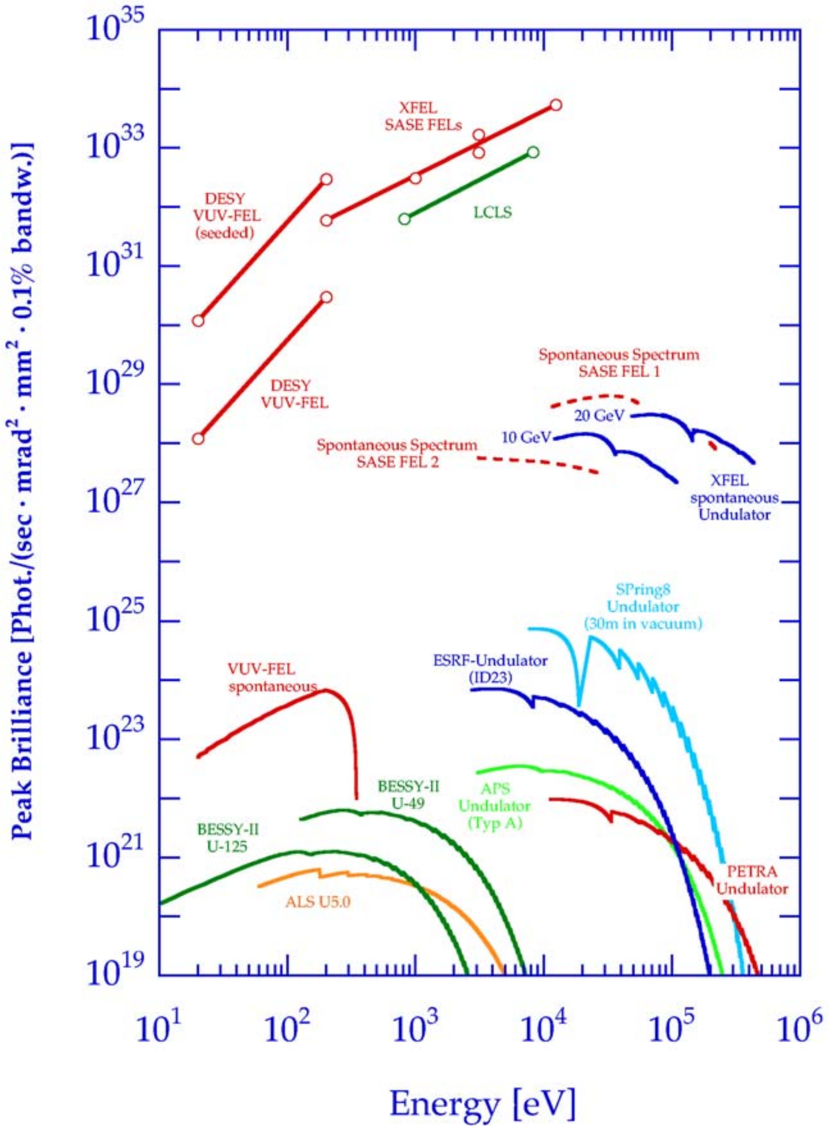

Figure 3.1: Peak Brilliance of SASE FELs (European XFEL and LCLS/SLAC, Stanford) in the X-ray regime compared to other light sources (http://tesla.desy.de/new_pages/tdr_update/ supplement.html).

3) <u>Baseline Configuration for the European XFEL Facility</u>

The technical challenges in realising this unprecedented machine are many, but there exists today the technology to successfully meet these challenges and provide a baseline design of the European XFEL Facility, as described in Annex 3. This facility will allow users, from the beginning of operation, access to an X-ray source with unprecedented parameters. A baseline design will be possible within a forecasted, escalated budget envelope not exceeding 1000 M€, and within a construction period of six years plus a commissioning period of two years, from the starting date of the project.

This baseline design includes:

i. The photocathode RF-gun injector, pre-accelerator and bunch compressor sections.
ii. A 2 km superconducting linac, accelerating electrons up to 20 GeV.

iii. A SASE based design to produce FEL radiation down to 0.1 nm wavelength.
iv. Five radiators feeding ten user experimental stations.

The present budget envelope does not take into account contingency factors.

4) The European XFEL Facility Design: Flexible and Upgradable

The baseline layout gives room for further developments such as:

- Shorter pulse lengths reaching into the atto-seconds regime. This will give access to ultrafast atomic processes.
- Controlling peak intensities via femto-second electron- and photon beam diagnostics.
- Developing and incorporating schemes other than Self-Amplified-Spontaneous-Emission (SASE) such as seeding and High Gain Harmonic Generation (HGHG).
- Pushing the XFEL process to wavelengths significantly shorter than 0.1 nm.
- Conceiving duty cycles higher than those foreseen in the baseline design including CW-like operation at lower beam energy. This may become attractive if injector development and possibly advanced FEL concepts permit FEL-radiation in the 0.1 nm regime at lower electron beam energies where the cryogenic load in CW mode becomes tolerable.
- Novel technologies for the conditioning and exploitation of the beam (novel optics e.g. nano-focussing, fast 2-D detection, new routes in sample preparation and handling),

The possibility of relevant upgrades for future phases of the facility must be considered from the beginning, and a flexible design of the accelerator complex is strongly encouraged.

5) Reaching 0.1 nm Wavelength

The primary reason for bringing many countries together to collaborate on the construction of this new European facility is to extend the FEL process into the X-ray regime. All the planning and strategies must be focussed on reaching this spectral region. This will automatically provide the technological capability to access wavelengths longer than typical X-ray wavelengths if desirable. At this point the interest of the Member Countries in developing a European XFEL Facility lies in a baseline design for the production of X-ray pulses with wavelengths of 0.1 nm, peak brilliance of 10^{33} photons/s/mm^2/mrad^2/0.1bw, pulse length of 100 femto-seconds or below and high transverse and partial longitudinal coherence. The spatial, angular and temporal stabilities aim to be better than 10% of the X-ray pulse’s spatial, angular and overall temporal dimensions at the target brightness values. In order to achieve these goals, R&D on bunch-to-bunch and femto-second electron- and photon beam diagnostics as well as the development of adequate feedback systems will be mandatory.

6) State-of-the-Art Superconducting LINAC

The heart of the machine is the linear accelerator, which will have to deliver the performance required in the baseline layout, as well as providing a large amount of flexibility for baseline operation and the realization of future options. The XFEL-STI fully recognizes that the technological issues are addressed today by the superconducting technology developed by the TESLA collaboration. It unanimously supports basing the European XFEL Facility on a superconducting linear accelerator, similar to the one developed by the TESLA collaboration and tested at the TTF and VUV-FEL facilities at DESY. The XFEL-STI recommends a strong accelerator R&D programme to foster research aiming for further improvements of the XFEL process.

7) Endorsement of the Hamburg Site
The XFEL-STI supports that the European XFEL Facility is located in Hamburg and that the accelerator complex is developed and constructed by DESY in cooperation with partner Institutes, according to a collaboration contract with the European XFEL Facility. The XFEL-STI supports the general lines of the planning for civil engineering that DESY is developing in order to host the European XFEL Facility. These plans foresee the injector on the DESY site, a 2 km long linear accelerator followed by two independent tunnel systems for the phase-I and the phase-II parts of the project, and two experimental halls at approximately 3 km from the DESY site. The land acquisition plans for the XFEL campus are appropriate and will allow for future expansion and the needs of ancillary service buildings.

8) Collaborative Approach for the European XFEL Facility
Several European Institutes have already been contributing for various periods of time, as members of the TESLA collaboration, to technical developments relevant for the European XFEL Facility. Examples (not exhaustive) are: LAL-Orsay (RF power couplers), CEA-Saclay (BPMs for the linac, cavity tuner), INFN-Milano (acc. modules/cryostats, RF-gun cathodes), INFN-Frascati (beam diagnostics), CIEMAT (superconducting magnets), PSI (feedback systems, electronics). Operation, maintenance, refurbishing and upgrading will be in the hands of the European XFEL Facility.

IV. The XFEL Scientific Case

The XFEL's unique combination of unprecedented peak and average brilliance, beam coherence and polarization, X-ray wavelength tunability, short pulse duration and number of photons per pulse, together with its potential for synchronization with other sources of excitation of the samples, will deliver exemplary breakthroughs in key areas of Science and Technology.

1. The European XFEL Facility's intense and short X-ray pulses will allow recording of the **structural evolution of chemical and physical processes on atomic timescales**. The field of ultra-fast dynamics on electronic, atomic and molecular levels will open the door to a new understanding of structural changes and intermediates, chemical reactions and ultimately even in biological processes. The trigger sources for reactions and transformations may comprise optical lasers, the XFEL, a Terahertz source, pulsed electric and magnetic fields, shock waves, and/or others. The importance of this new scientific field cannot be over estimated and investigations will result in major impacts on Physics, Chemistry, Biology, Materials Science and Geology.

2. The European XFEL Facility's intense, short and spatially highly coherent X-ray pulses will revolutionize the field of coherent diffraction, which is in its infancy at third generation synchrotron radiation sources. The gain – which will extend to a factor of 10^{10} in coherent flux compared to that available today – will make routine new **Correlation Spectroscopy and Speckle Diffraction techniques** in the X-ray region

for the study of **structure and dynamics** of liquid and condensed matter at correlation lengths down to the nano-meter range.

3. The European XFEL Facility's intense and short X-ray pulses will allow reconstruction, with atomic resolution, of the **structure of macromolecular assemblies and intermediates** without the need for crystals. This will become possible because the short duration of the X-ray pulses and their high intensity will permit recording of the data before the inevitable radiation damage destroys the sample. Moreover, achieving the same objective at the level of a single macromolecule is possibly within reach. The potential impact in Chemistry, Structural Biology and Materials Science is enormous.

4. The European XFEL Facility's intense and short X-ray pulse will create and probe **high energy-density states of matter**, filling the gap in equation of state determinations between quasi ground-state properties and those of the plasma state. This knowledge will have enormous impact, among others, in novel energy sources research, and in planetary- and geo-physics studies, where information on the properties of matter at 1-10 eV temperatures, 1-10 MBar pressures and 1-10 T magnetic fields is almost completely nonexistent, and fundamental for the understanding of the earth and solar planetary cores.

5. The European XFEL Facility's intense, short and coherent X-ray pulse will allow direct access to **non-linear phenomena in atoms, molecules and clusters**, providing new experimental insights into the physics of the fundamental building blocks of condensed matter.

6. The European XFEL Facility's spontaneous radiation extending down to very short wavelengths (0.01 nm) will enable novel time-resolved studies in condensed matter, with foreseeable impacts on the various forms of **X-ray imaging, diffraction and spectroscopy**. It will add the time dimension to the most successful scientific programmes at third generation sources in material sciences and condensed matter science in general. It will allow, for example, direct studies of fast order/disorder and nucleation processes as well as time-resolved magnetic studies in bulk samples under extreme conditions and under extremely high pulsed magnetic fields.

7. The European XFEL Facility's baseline design will allow for upgrades to incorporate new ideas and facilitate an increasingly challenging scientific programme which is already on the horizon today. One intriguing example is the possibility of experimental investigation of fundamental physics questions related to **ultra high-field electrodynamics**.

V. The Accelerator Complex

5.1 General Layout

The majority of the R&D work on the accelerator necessary to prove the feasibility of the facility, with the parameters specified for the baseline design, has been successfully completed. An immediate start of the project is possible. The accelerator complex of the European XFEL Facility includes the photocathode RF-gun injector, pre-accelerator and bunch compressor sections, the superconducting main linac, diagnostics, collimation and beam distribution sections, as well as the sub-systems and infrastructure required to operate the accelerator components. The main parameters for the XFEL accelerator are specified in Annex 3.

1. The superconductivity-based linac, built in the technology developed by the TESLA collaboration and successfully tested at the TESLA Test Facility, combines optimum properties in terms of beam quality and stability with a broad flexibility regarding operational energy and beam time structure and is thus the superior and preferred solution for a 0.1 nm XFEL, compared to any normal conducting technology. A detailed study of the accelerator complex is provided by the TESLA collaboration Technical Design Report Supplement, published by DESY. (http://tesla.desy.de/new_pages/tdr_update/supplement.html; http://tesla.desy.de/ new_pages/TDR_CD/PartII/accel.html).

2. Detailed simulation studies of the injector (RF gun, pre-accelerator and single stage bunch compressor) show that the beam emittance required to safely reach saturation for 0.1 nm XFEL radiation is achievable. Recent tests at the PITZ photo-injector test facility, DESY-Zeuthen, have experimentally demonstrated a normalized beam emittance of 1.7 mm·mrad in full accordance with the corresponding simulations for the presently existing PITZ set-up. Further improvements are part of the ongoing R&D programme. The simulations for the XFEL injector predict that the design value of 0.9 mm·mrad will safely be reached. The design value for the beam emittance in the undulators is 1.4 mm·mrad and thus includes a margin of more than 50% for emittance dilution.

3. The duty cycle and time structure of the baseline design represents the optimum compromise between operational efficiency (radio-frequency systems), budgetary constraints (cryogenics) and the flexibility needed to meet user demands. A bunch-by-bunch beam distribution system as suggested in Annex 3 will provide flexible time structures to different user stations and allow parallel operation of the maximum number of beamlines without compromises in intensity at the basic 10 Hz macro-pulse repetition rate.

4 The accelerator is designed for a nominal electron beam energy of 20 GeV (using a moderate accelerator gradient of 23MV/m) permitting SASE FEL radiation on the 1^{st} harmonic down to a wavelength of 0.08 nm. Recent performances of superconducting cavities justify the expectation that higher accelerating gradients will be possible. The RF and cryogenic systems are laid out to reach beam energies up to approximately 25 GeV corresponding to radiation wavelengths of about 0.05 nm.

5. Different concepts for beam switching are available which will permit distribution of photon beams to multiple users with time patterns varying over a broad range (from single bunches to full bunch trains per pulse). An energy modulation within an RF pulse by ±1.5% will be possible.

6. Intra-bunch train feedback is necessary for stable user operation and should be available to stabilize the beam (beam trajectory stability, energy and time). For stable operation it is expected that the transverse beam position and angle can be kept stable to within one tenth of a standard deviation of the beam size and the angular spread, and the relative energy variation maintained within a few 10^{-4}. Timing stability can also be facilitated by feedback techniques. However, synchronization at levels well below the bunch length (~100 femtoseconds) is a considerable challenge with present state-of-the-art technology.

7. The superconducting linac permits, in contrast to normal conducting technology, operation at high duty cycles, up to continuous wave (CW), if the accelerating gradient and thus the beam energy are reduced. The anticipated cryogenic and accelerator layout will allow for CW operation at beam energies up to 6–7 GeV. A second low power CW RF system would have to be added and space would need to be available in the tunnel to permit such a future upgrade to the accelerator.

5.2 R&D on the Accelerator Complex

1. The R&D programme aimed at industrial production for the major accelerator components is well under way and will permit moving into the construction phase for the facility in about two years from now.

2. The first phase of the TTF Linac and FEL programme has yielded a vast amount of experience with superconducting linac operation, beam dynamics and the SASE FEL process. The second phase (VUV-FEL) will continue to provide further invaluable experience as a true pilot facility, acting as a test-bed for and covering practically all aspects relevant for the larger scale XFEL. Substantial time of the operation of the VUV-FEL facility will be committed to XFEL related R&D.

3. Further improvements on the Injector/Gun beyond the design goals have to be an integral part of the baseline XFEL facility and should be conducted in cooperation with R&D programmes for other projects. An improved Injector/Gun operation will allow future extension of the baseline design to include more advanced XFEL concepts and improved radiation quality at 0.1 nm wavelength and below. This could also open up the possibility of generating FEL radiation at lower wavelengths with higher beam energy (down to 0.05 nm at 25 GeV) without modifying the undulators. An improved beam quality from the injector is crucial if the above mentioned CW-option at lower electron beam energy is to be used for FEL radiation at Å wavelength (with modified undulators). This would in addition require a new gun concept capable of matching the CW time structure.

VI. The Production of the XFEL Beam, and the Associated XFEL R&D Programme

6.1 XFEL Source

Impressive progress during the last fifteen years in our understanding of the interaction of low emittance relativistic electron beams with a periodic electromagnetic structure has led to major technical advances. Revolutionary experiments have already been proven possible at wavelengths down to the 100 nm range and more are expected in the near future at wavelengths down to a few nm. These experiments show among other achievements that X-ray pulses with high peak power, short pulse length, and coherence, i.e. a laser-like X-ray source, are technically within reach.

1. Among an increasing number of approaches towards an FEL source, SASE FELs represent the most developed technology to achieve ultra high brightness X-ray radiation at target wavelengths of 0.1 nm and below. A Self-Amplified Spontaneous Emission (SASE) XFEL will be able to provide X-ray pulses with unique properties in terms of photon flux, brightness, and partial (transverse and longitudinal) coherence, far exceeding any other X-ray source.

2. SASE FELs exhibit beam characteristics that are inherently spiky both in the spatial and temporal domains. This will require efforts towards seeding schemes and on shot-to-shot diagnostics.

3. The planned accelerator complex, providing an electron beam of operating energy 20 GeV (17.5 GeV), will ensure safe operation at 0.08 nm (0.1 nm) wavelength with conservative assumptions on beam quality and provide flexibility for future upgrades.

4. The European XFEL Facility phase-I baseline design will provide five branches of radiation located in 5 tunnels. Initially, each branch will be equipped with a single radiator. This arrangement will allow for multi-user operation and a step-by-step modification, upgrade and extension of photon beamlines as well as parallel operation of a separate electron R&D beamline, with minimum effect on user operation at the other lines.

5. The definition of the baseline layout for the phase-I beamlines is rapidly advancing. Possible configurations for the 5 radiators include:

   i. Three variable-gap undulators to cover the wavelength range from 0.1 to 1.6 nm continuously at a fixed energy of the electron beam. A fourth undulator covers the XUV range up to 6 nm wavelength where the spectral range of the VUV-FEL ends.

   ii. The variable-gap undulators will allow, from the beginning, tuning for maximum output power (sub-TW level); effective generation of second harmonic radiation and generation of attosecond pulses (in combination with a few-cycle optical laser), either parasitic or dedicated with 100 GW peak power.

   iii. Multi-user capabilities can be significantly enhanced in terms of experimental stations, through switching between different wavelength ranges and scientific applications, by putting three or four undulators in series together with the use of optical elements. In particular, this arrangement offers the unique possibility of combining 100 GW VUV and X-ray pulses for pump-probe experiments (e.g. in High Energy Density Matter Science).

iv) The phase-I layout also comprises radiators for spontaneous emission (0.0025nm-0.025nm). At the present planning stage the flexible concept foresees two of these devices as indicated in Annex 3.

6.2 R&D on the XFEL Source

1. A European XFEL Facility based on the SASE scheme needs efforts on both accelerator and undulator technologies, and on electron and photon beam diagnostics. Dedicated R&D will be required to develop reliable measurement and synchronisation schemes for electron and photon beams at the femto-second level. The required pulse-to-pulse (spatial and temporal) stability of the XFEL beam should be better than 10% of the beam angular, spatial, and temporal dimensions. Of similar importance will be the task of beam distribution to different beamlines within a macro-bunch - a concept still to be demonstrated experimentally. These tasks must be included from the beginning in the facility R&D plan. They must fully benefit from initiatives such as those already ongoing in Europe and abroad.

2. The planned superconducting accelerator complex will provide the flexibility to implement schemes beyond the phase-I baseline design based on SASE. These alternative approaches must be pursued in order to reach even more advanced beam parameters such as shorter wavelengths (possibly even down to 0.03 nm), shorter pulses (possibly down to 10 femto-seconds and below), control of the pulse intensity, improved temporal and spatial source stability, and improved control and efficiency of beam repetition rates and beam delivery to experimental stations. In this context, HGHG (High Gain Harmonic Generation) and seeding are particularly promising schemes. Progress in VUV-EUV radiation generation from HHG in gases and from other sources, as well as improvements in the design and understanding of cascaded FEL configurations may provide the capability and reliability for the generation of sub-nm radiation in other facilities. The European XFEL Facility will thus stimulate and catalyse corresponding activities in Europe and abroad. Although the European XFEL Facility baseline design is based on SASE, the phase-I design needs to take account of the possible incorporation of these and other alternative XFEL schemes in the accelerator complex, including the civil engineering implications, the accelerator infrastructure upgrades and the laser system requirements. These measures will facilitate the incorporation of future performance upgrades in the European XFEL Facility as soon as the required technologies are matured.

VII. The Photon Beamlines and the R&D Programme

7.1 General Layout

1. The European XFEL Facility baseline design must provide a portfolio of **phase-I beamlines** that will address the scientific case outlined in IV.1-IV.7 and described in more detail in the XFEL TDR Supplement, October 2002, and in Part V of the TESLA TDR, March 2001. The European XFEL Facility should begin its operation with a minimum number of five independent beamlines. Each beamline comprises 2 experimental stations, i.e. a total of 10 experimental stations in phase-I. The phase-I beamlines should be commissioned at a pace of two beamlines per year. Particular attention has to be paid to the appropriate staffing of the beamlines (scientists, dedicated engineers, fully dedicated technicians and post-doctoral fellows).

2. The European XFEL Facility must implement from its beginning a strong **In-House Research programme** covering the areas described in Section IV. This will be necessary to commission the scientific programme at the phase-I beamlines and it is also essential to ensure early planning of a phase-II wave of experimental beamlines of the XFEL. The European XFEL Facility must be staffed with personnel in the support structure(s) associated with the scientific programme.

3. Partners in the XFEL Project may contribute to the Research programme by carrying out supporting programmes within their own countries, thereby establishing and exploiting the appropriate expertise available within Europe. This is necessary for the efficient development and full exploitation of the facility.

7.2 The R&D Programme(s)

The **Instrumentation R&D programme** can benefit from similar activities and programmes which are already existing or being developed at third generation sources. However, there are crucial aspects which are very specific to the exploitation of XFEL driven science and which must be aggressively developed and implemented at the European XFEL Facility. These are:

- Fast 2-dimensional X-ray detectors and detection schemes, aiming at femto-second time resolution.
- In-House expertise in operating and using a synchronized high-power – femto-second Laser facility matched to the XFEL beam properties.
- Development and construction of photon pulse diagnostics equipment: To determine the time of arrival, the time profile and the spectral contents of femto-second (and, in a second stage, sub femto-second) individual X-ray pulses. Such systems will be indispensable characterization tools for the acquisition and evaluation of experimental results.
- A dedicated R&D programme addressing the random nature of the SASE-FEL beam.
- Development of a sample environment infrastructure (sample positioning, exchange, control in the XFEL beam), as well as the development of equipment for providing low and high temperature, high pressure and strong electric and magnetic fields at the samples.

- Optics and beam transport: Micro- and Nanofocussing, coherence preservation, beamsplitting and monochromatization.
- Data retrieval, analysis and real time processing capabilities.

VIII. Human and Capital Resources

8. 1 Introduction

This section addresses the resources necessary to accomplish the recommendations of the XFEL-STI Working Group, which were expressed in general terms through the key statements in section III and more specifically in sections IV to VII.

The present section starts from considerations based on the human and financial resources analysis as presented in the TESLA XFEL Technical Design Report (TDR-2001): http://tesla.desy.de/new_pages/TDR_CD/PartV/xfel.pdf) and the Supplement to the Technical Design Report (TDR_Suppl.-2002): (http://tesla.desy.de/new_pages/tdr_update/supplement.html).

The XFEL-STI decided to review the existing cost estimates described in the above documents. They were adjusted for inflation ("escalated") to the projected construction period 2006-2012. The XFEL-STI complemented the result with additional, user programme related, items that were not considered in the TDR or its supplement, such as a strong detector development programme.

The cost estimate presented in the TDR_Supplement-2002 seems sufficiently realistic and prudent, and will allow the construction of a flexible facility. It results in an escalated budget envelope for the construction of the European XFEL Facility of 908 M€. For the above mentioned (user programme related) items an additional budget of 50 M€ is viewed to be necessary.

The analysis of these resources, as presented here, will not follow rigorously the separation into the three areas described separately in sections IV to VII. It will follow a presentation format, which refers to the construction phase (in sub-section 8.2) and to the operation phase (in sub-section 8.3), as previously prepared in the context of the original TESLA project.

In sub-section 8.2 the minimum configuration necessary to exploit the phase-I facility, according to the scientific case presented in section IV, will be considered. Sub-section 8.3 will cover Commissioning and Operational Costs. Sub-section 8.4 discusses additional resource requirements not considered in the 2002 TDR Supplement.

Conclusions are provided in sub-section 8.5, including possible ideas that should be investigated as potential contributions to the construction phase. These are based on commitments already existing at the European funding level relating to activities relevant to XFEL projects, as well as on a highly developed network of scientific and R&D collaborations: Both of these, through appropriate coordination, can tremendously boost the construction of the XFEL.

A budget estimate for the XFEL phase-II, which will fully develop the facility through the construction of new radiators in the second tunnel system, new beam lines and possibly further accelerator upgrades, will not be discussed in detail. Its overall cost will depend crucially on the success of phase-I. This second phase may not enter construction until 10 years after the beginning of the phase-I construction. Its detailed design may be finalized a few years before, and its budget will be a considerable fraction of the construction costs of the phase-I facility.

8.2 Construction Cost (Based on 2002 TDR Supplement)

In the Supplement to the Technical Design Report for the XFEL, the cost of the project, then planned to be situated in Ellerhoop, Schleswig-Holstein, was estimated as **684M€**, based on year 2000 prices. A total of 2800 FTEs was assumed at an average cost of **50k€** per person per year and included in the cost figure of **684M€**. In addition, **25M€** was foreseen for R&D. No contingency or risk budget was included in these figures.

Investment costs had been evaluated for a facility consisting of a linear accelerator capable of reaching 20 GeV at an accelerating gradient of 23MV/m, three SASE undulator beam line tunnels, two beam line tunnels for spontaneous radiation, and a total of 10 user experimental stations (on average two for each beam line). The manpower required for the different stages of the project (design, procurement, fabrication and assembly, testing, installation and commissioning) had been estimated mainly on the basis of the experiences gained at TTF, in large projects like HERA or the ESRF, and from the considerations made for TDR-2001. The estimated total of 2800 person years was divided into 2200 person years for the accelerator and 600 person years for the photon related part of the facility.

Based on the above numbers, calculated on the year 2000 price basis, the total project costs to the end of construction have been estimated taking into account the following three major assumptions:

i) The manpower related costs of 140 M€ in the TDR Supplement used an average of 50 k€ per FTE per year. It is estimated by the XFEL-STI that in order to cover salaries, pension funds and some fringe costs, the cost per FTE should be increased to approximately 70 K€. This number better reflects the actual costs and current experience in other European laboratories and is also in line with a similar estimate made by the German Federal Ministry for Education and Research. The manpower costs hence were increased by 54 M€ compared to the TDR Supplement.

ii) By adding the above mentioned 54 M€ for personnel costs the estimated 684 M€ increased to a new total of 738 M€, still based on year 2000 prices. To cover inflation this number has been escalated by adding 1.5% for the years 2000 until 2006 and 3% for the construction phase from 2006 until 2012, according to the annual rate of outflow. The total cost sums up to 877 M€.

iii) A new estimate for additional funding for preceding R&D which takes into account an update of subsystem needs has increased this number from 25 M€ to 31 M€.

Summing up the different contributions discussed above, the total project cost, escalated to the end of construction, is **908 M€.**

In the present organizational structure of the XFEL project group located at DESY, the project has been divided up into a total of 37 work packages (WPs). The WPs are grouped into 6 main topics:

WP group	Topic
01	Linear Accelerator
02	Accelerator Subsystems
03	Undulators and Photon Beam Lines
04	Controls and operation
05	Infrastructure
06	Site & Civil Engineering

The overall construction cost has been subdivided into the individual work packages, resulting in a distribution to the WP groups as shown in Figure 8.1. and specified in Table 8.1.

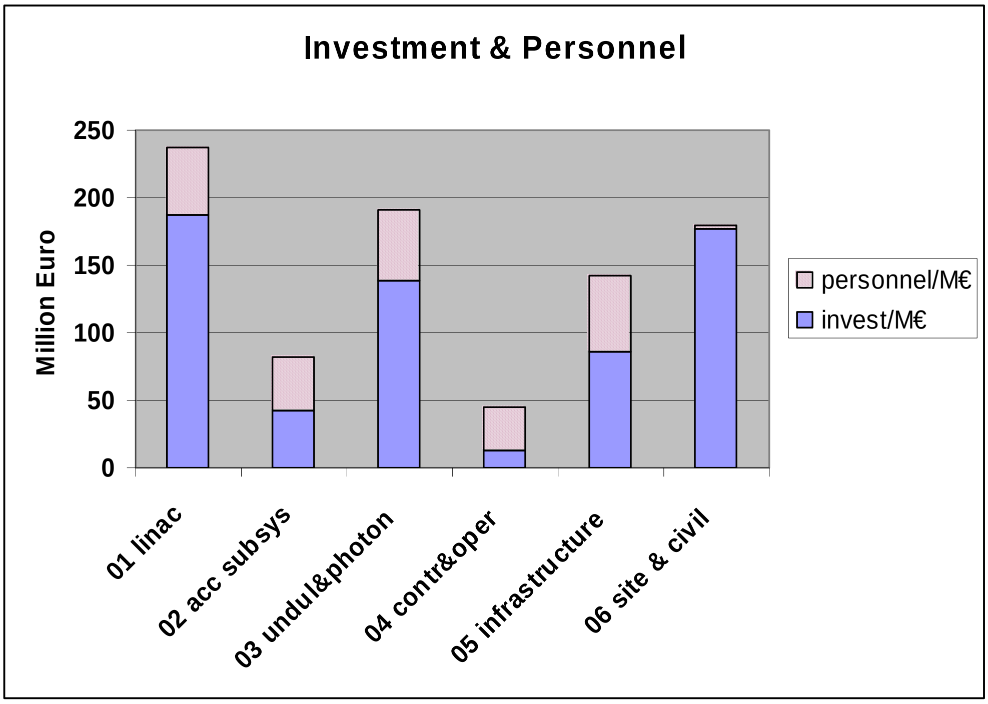

Figure 8.1: Distribution of total escalated project costs (Investment and Personnel) excluding preceding R&D.

In the following, some information on the basis for these cost estimates are given, largely extracted from Chapter 5 of the TDR supplement from October 2002. Sub-sections for individual WP groups describe how the estimates for the investment costs were derived for major items of the XFEL project (compare also Table 8.1.).

	XFEL Work Package Group					
	01 Linac	02 Accelerator Subsystems	03 Undulators & Photon Beam Lines	04 Controls & Operation	05 Infrastructure	06 Site & Civil Engineering
Work Packages	01 RF System 02 Low Level RF 03 Accelerator Modules 04 SC Cavities 05 Power Coupler 06 HOM Coupler 07 Frequency Tuner 08 Cold Vacuum 09 Cavity String Assembly 11 Cold Magnets	12 Warm Magnets 14 Injector 15 Bunch Compressor 16 Lattice 17 Stand. Beam Diagnostics 18 Spec. Beam Diagnostics 19 Warm Vacuum 20 Beam Dump	21 Undulators 22 Hard Photons Beamline 23 Medium Photons Beamline 24 Photon Diagnostics 25 Experimental Areas 26 Detector Development 27 FEL Concepts	28 Control Systems 29 Operability 35 Radiation Safety 36 General Safety	10 Module Test Facility 13 Cryogenics 32 Survey 33 Tunnel Installation 34 Utilities	31 Site and Civil Construction 37 Plan Approval Procedure
Invest:	157.463 k€	36.098 k€	111.808 k€	11.000 k€	72.176 k€	155.540 k€
Manpower:	30.540 k€	23.659 k€	30.613 k€	19.087 k€	34.216 k€	1.885 k€
Sum:	188.003 k€	**59.756 k€**	**142.421 k€**	**30.087 k€**	**106.392 k€**	**157.425 k€**
	Costs escalated to the year 2012 (see text)					
Invest:	186.574 k€	42.772 k€	138.511 k€	13.034 k€	85.520 k€	176.538 k€
Manpower:	50.661 k€	39.246 k€	53.094 k€	31.662 k€	56.759 k€	2.995 k€
Sum:	**237.235 k€**	**82.018 k€**	**191.605 k€**	**44.696 k€**	**142.279 k€**	**179.533 k€**
Sum Invest:		**544.085 k€**	**Sum Invest escalated:**	**642.949 k€**		
Sum Manpower:		**140.000 k€**	**Sum Manpower escalated:**	**234.417 k€**		
Sum Total:		**684.085 k€**	**Sum Total escalated:**	**877.366 k€**	**With Preceding R&D:**	**908.366 k€**

Table 8.1: The costs of the European XFEL Facility distributed over the different Work Package Groups.

WP group 01 - Linear Accelerator

For the Technical Design Report of the TESLA project published in March 2001 the cost estimates for all major components were obtained from studies made by industry and were based on the large number of components needed for the Linear Collider (LC). For the European XFEL Facility, now decoupled from the linear collider, industrial prices for smaller quantities were partially available. For other components, prices from the TESLA Test Facility were used. Using the latter prices directly for the components of the European XFEL Facility would lead to an overestimate of the cost in most cases. Therefore industrial scaling laws have been applied, where it seemed appropriate, to obtain a probable price for each component.

Linac modules

The cryo-modules for the linear accelerator with the superconducting cavities are the largest cost item. The cost is dominated by the superconducting cavities, the cryostat and the assembly of the module. Niobium, cavity fabrication and treatment procedures each constitute a substantial part of the cavity costs.

Superconducting cavities
Major cost components for the superconducting linac are the mechanical fabrication (deep-drawing of half-cells, electron beam welding of 9-cell structures) and preparation (surface treatment and cleaning) of cavities. The cost of cavity fabrication for the TDR-2001 was estimated using industrial studies made by companies with expertise in niobium production, cavity fabrication, and the planning of mass production plants. For the 2002 report there were no studies of equivalent depth available. However, there is a quotation for the mechanical fabrication of 2000 cavities against which the scaling has been cross-checked. An industrial estimate of the cavity preparation for 1000 cavities is available.

Niobium production
The amount of material needed for the cavities for the XFEL linear accelerator is about 20 tons of high purity (RRR 300) niobium. For the TDR-2001 there exist price quotations for 500 tons. The price for the TDR-2001 was in part based on savings on sheet cuts for re-melting and streamlining of facilities for continuous production. These savings will most probably not be applicable for 20 tons. This has been accounted for in the cost estimate and its uncertainty in this report. There is an additional uncertainty in the price of niobium as prices are quoted in US-$: the price used in the cost estimate is based on 1 US-$/EUR.

Cavity fabrication
For the TDR-2001 the TTF cavity production was analyzed in terms of cost driving and critical procedures in an industrial study. In the fabrication of TTF cavities, electron beam welding has been identified as the dominant cost driving procedure. A new fabrication facility was planned with three vacuum chamber welding installations for the fabrication of 20000 cavities. The facility, together with the use of multiple welding tooling, substantially reduced the welding costs, so that they were not the main cost driver anymore. The total facility costs were determined in detail (planning,

investment, effort for ramping up and closing the facility, personnel, repair and maintenance, consumption, quality insurance). The same study was also done for the fabrication of only 2000 cavities. The price quotation for 2000 cavities and the price for the present small number production for TTF have been used to estimate the price for this report.

Cryomodules
For the TDR-2001 two industrial studies were made for the mass production. The price for the cryostat from these studies and the present price for the small number production have been used to estimate the price for the cryostats. Costs for other components were derived from the experience gained from the procurement of similar components for TTF using industrial scaling laws. The costs for the module assembly were evaluated in an industrial study together with the cavity treatment.

Linac RF system

The RF system is also a large cost item for the linear accelerator. The most relevant parts with respect to cost are: klystrons, modulators and pulse transformers, wave guide distribution system, interlock and controls, low level RF system, HV cables.

Klystron
The cost estimate assumes the production of the total number of 30 klystrons by one manufacturer. For the TDR-2001 a mass production study was made by the prototype manufacturer. The prices for klystrons and for the auxiliary systems are based on present TTF costs with additional cost reductions assumed.

Modulator and pulse transformer
The cost estimate is based on the production of the total number of 30 modulators (HV power supply, pulser, internal modulator interlock) and pulse transformers by one manufacturer. Again the actual numbers from TTF, assuming some savings for the larger number, have been used.

Low level RF system, waveguide distribution system and cables
The cost for the low level RF system is based on TTF experience assuming some cost reduction for the larger number. The cost estimate for the wave guide system is based on experience with the existing TTF system, adjusted for the production of a larger number. Different parts of the system will be supplied from different manufacturers.

WP group 02 - Accelerator Subsystems

Injection Systems
The costs for the injector have been taken from the TDR-2001. Included in this item are the photocathode RF gun, the accelerator modules for the pre-accelerator, RF-systems and the bunch compressors.

Electron beam lines and beam dumps systems

The cost estimate for the magnets, power supplies, cables, the vacuum system and the diagnostics is based on the original TDR-2001 numbers as many components are similar in layout. The difference in number has been compensated by an increased price per unit. The beam dump system has been modified with respect to the TDR-2001, where a water dump capable of handling 2 MW beams had been used, a system similar to the beam dumps for the linear collider. To save cost for this first stage of the project the average beam power of the facility has been reduced to 300kW allowing the use of a simpler solid beam dump, for which cost numbers are available from TTF. Costs for the kicker magnet and pulser system have been evaluated from the experience with the HERA beam dump system.

WP group 03 - Undulators and Photon Beam Lines

Undulator segments

For the realization of undulator segments an industrial study has been done in 2000 by Vacuumschmelze, Hanau, Germany. For each undulator segment a vacuum system with chamber and pumping, and an intersection element is needed including phase shifters, magnets, quadrupoles, beam position monitors, as well as the required power supplies and front-end electronics.

Photon beam lines and diagnostics

The photon beam lines cover the entire handling of the X-ray beams and its guidance to the experimental hall. This includes a large vacuum system for the long drift distances, beam collimation and photon shutter. For this large system a cost reduction compared to a smaller series is included. The photon beam lines further include the photon diagnostics station, monochromators and mirrors. Price estimates take current quotations for smaller series into account. The total number of devices is still small and additional requirements to the devices are expected to prohibit any further reduction. Costs for optical and experimental enclosures are based on recent quotations (e.g. for the ESRF, Grenoble, France).

Experiments

The cost estimate for experiments is based on detailed listings of components for a variety of four different experiments as outlined in the TDR-2001. The costs are proportional to the number of experiments and have been scaled accordingly. The costs for experiments, the preparatory laboratories required for the experiments and the needs for laser and detector installations on site were considered.

WP group 04 - Controls and Operation

A major cost item under this topic is the accelerator control system, including e.g. the computers and interfaces needed for steering and controlling the accelerator components such as RF systems, tuners, magnets, feedback systems, etc. and for acquisition and processing of data from standard and special diagnostics devices, as well as the installations needed for the central accelerator control room. Further items are the installations required for general and radiation safety. The cost evaluation has been performed on the basis of experience with large scale facilities like HERA and with the VUV-FEL user facility.

WP group 05 - Infrastructure

For the infrastructure the major cost items are the cryogenic plants, distribution lines, and connection boxes and the superconducting cavity and accelerator module test facility. Additional items included are: the main power connection and distribution; water cooling and ventilation systems; safety installations and interlocks; test equipment for RF components. The cost of these items has been evaluated on the basis of large scale projects such as HERA.

WP group 06 - Site & Civil Engineering

Civil engineering is a major cost item. It includes all tunnels, shafts, underground and surface buildings for the linear accelerator, the beam distribution, the switchyard building and the experimental hall plus other buildings needed for the user operation on the (original) Ellerhoop site, including special laboratories for installation and performance test of components, and the cost for the land at the sites originally foreseen (Ellerhoop and Borstel-Hohenraden). The costs for the land were estimated using 2002 market prices. The construction cost estimate for the linear accelerator tunnel, shafts, underground and surface buildings was taken from an actual cost estimate by an engineering team, which prepared the detailed layout of the facility for the plan approval procedure (Planfeststellungsverfahren). Cost estimates for other buildings are based on experience at DESY during recent years. A certain percentage of the total construction cost has been taken into account for the services of architects and civil engineers according to HERA experience and public regulations.

8.3 Commissioning and Operational Costs (Based on 2002 TDR Supplement)

The start of the commissioning of the facility is defined as the first operation of the linear accelerator with beam (commissioning of its technical components is part of the construction phase). Accelerator commissioning will be followed by a stepwise commissioning of the undulator beam lines. Operation of one beam line with beam, while installation and technical commissioning work is still ongoing in others, will be possible (see Annex 3) and is thought to be the most efficient way to proceed. It is estimated that the accelerator related commissioning process will take of the order of two years. After two years the operational costs will have reached a constant level.

The total cost for operation has been estimated as 50 M€ per year in the TDR supplement. This includes the electrical power consumption, the regular replacement or refurbishing of klystrons, the maintenance and refurbishing of optical components and detectors, and the helium losses. The numbers are determined assuming year 2000 prices and an annual operation time of 5,000 h. Costs for general maintenance and repair have been included, assuming 2% per year of the original total investment costs corresponding to the DESY experience. A total staff of 450 persons with a cost of 50k€ per year was included, distributed between accelerator and XFEL experiments in the approximate ratio 2:1 and also taking into account personnel for administration and central services.

8.4 Resource Requirements Not Considered in the 2002 TDR Supplement

As described in Annex 3 the layout of the European XFEL Facility has been further developed compared to the status as described in the 2002 TDR Supplement. The modifications are partially due to the new site and partially the result of an improved and more detailed design. Furthermore, additional operational flexibility and possible future options have been incorporated to some extent in the present layout. In addition, the results of the discussions and suggestions inside the XFEL-STI Working Group have been taken into account. In particular, the scope of the project has been extended to give a stronger emphasis to the R&D phase required for the user experiments. This includes efforts in XFEL adapted X-ray optics, a laser facility, sample positioning issues, and the important area of detector developments. Given the novelty of this pioneering machine, ongoing R&D efforts and a continued refurbishment programme are mandatory.

8.4.1 Construction cost

The modifications to the design presented in the TDR supplement can be grouped as follows:

a) Changes due to moving the **site** for the facility from Ellerhoop to Schenefeld

b) **Optimization and Detailing** of the facility design and civil engineering layout
   - The choice of a second injector and the modification of the bunch compressor.
   - 12m TTF-like accelerator modules instead of 17m types foreseen for TESLA.
   - An improved accessibility of individual undulator and photon beam line tunnels parallel to the user operation of other beam lines.
   - The increase of size of the experimental hall.
   - The increase of the tunnel diameters in the distribution fan to allow ample space for additional and new options like seeding.
   - Provision for the replacement of one of the two spontaneous undulator beam lines with another (soft) SASE beam line.
   - The realization of the integration of phase-II into the electron beam distribution layout

c) The **recognition of the need to reserve funds for specific R&D programmes** not included in the baseline cost estimate of the facility but deemed vital for the overall success and which are not likely to be funded through other channels:

   - Recognition of the need for a **dedicated detector development programme (Annex 5.1)**

   - Extended need for **optical laser systems (Annex 5.2).**

   - **Sample environment and handling (Annex 5.3)**

   - R&D for **X-ray optics and beam transport (Annex 5.4)**.

The goal of the next 12 months will be to complete and review this list, evaluate the overall cost impact of the various items in as detailed a way as possible, to arrive at an integrated and optimized new cost estimate for the construction of the facility. The XFEL-STI Working Group estimates Item 8.4.1c to require additional funds of **50 M€.** The Working Group is of the opinion that the modifications described in this chapter will be essential for the operation and success of the user experiments programme of the future European XFEL Facility.

8.4.2 Operational cost

During the discussions of the XFEL-STI Working Group it was decided that the operational costs for the facility should be modified as follows:

a) An increase of the **cost per FTE** per year from 50k€ to 70k€ (see 8.2) (this corresponds to an increase in the cost for the yearly human resources from 22M€ to 31M€).

b) The introduction of a cost item reflecting the need for continued R&D, of approximately 2% of the initial investment (11 M€).

c) In order to also continually perform refurbishment and upgrade of the facility another 2% of the initial investment (11 M€) per year is included, to account for the novelty of this pioneering machine and to permit the improvement of components and sub-systems as a result of operational experience.

d) Costs for general maintenance and repair have not been changed and are estimated to amount to 2% per year of the original total investment costs (approx. 11M€).

e) The cost for power, consumables (helium, water, oil) and replacement of klystrons amounts to 3 M€.

Escalation of the operating costs to the first year of operation (2013) and employing the same escalation model as used for the construction costs then yields operating costs of **90 M€ per year.**

8.5 Concluding Remarks

An overall cost estimate for the European XFEL Facility, based on present knowledge has been presented. Resources have been divided into the construction and operational phases. For the construction of the European XFEL Facility the overall cost estimate **is 908 M€ including 2800 FTE, plus 50 M€ for R&D for detectors, optical laser systems, X-ray optics, sample environment and handling**. **Escalated operational costs are estimated as 90 M€ per year.**

The XFEL-STI Working Group endorses this overall estimate for human and capital resources for the construction and operational phases of the European XFEL Facility. The requested resources will allow an important degree of flexibility both during construction and operational phases. The cost estimate was prepared, and its distribution onto different areas of the project was discussed and considered rather realistic and prudent. The XFEL-STI

Working Group itself suggested increasing the resources for R&D during construction and operation in order to achieve higher performance of the user experiments. The XFEL-STI Working Group expects that a complete review of the overall project cost will be carried out during the preparation phase of the project.

The present considerations of the required project resources do not explicitly take into account the rapidly developing context worldwide, namely a growing interest in superconducting accelerator technology and the development of ultra-short photon pulse facilities based not only on SASE schemes, but also on other approaches such as high harmonic generation and energy recovery linac schemes. These activities are fostering a new culture, and therefore they will be of enormous benefit to the realization of the European XFEL Facility discussed here. Significant benefit will come from activities such as:

1. The present strong commitment of European resources in funding activities in the field of accelerator based coherent sources in the VUV and X-ray region. This fosters developments in, for example, photo-cathode guns, photon and electron diagnostic and synchronization tools, pilot experiments and other areas.

2. The new knowledge that will be generated by experiments already running, or expected to run in the next few years, at laboratories such as SPPS at Stanford, VUV-FEL at DESY, FERMI at Elettra, as well as those being discussed or already approved at LCLS in Stanford. Furthermore, the R&D and design work for facilities proposed or under consideration in Europe, like the FEL at BESSY, MAX-IV at Lund, 4GLS at Daresbury, ARC-EN-CIEL in France and SPARC(X) at INFN.

3. A large number of institutes from many countries are working together in the TESLA collaboration, an activity which will be further strengthened with new partners in the context of the cold-technology choice for the International Linear Collider (ILC) Project. In view of the large overlap between the XFEL and ILC projects regarding the linac technology, it is likely that developments for the ILC will also yield significant benefits for the construction of the XFEL accelerator complex.

4. There is an increasing awareness of the need for major coordinated instrumentation efforts at third generation synchrotron sources, both in Europe and worldwide. This is particularly true for detectors, nano-positioning of samples, time-resolved studies, X-ray optics, and for large data-sets acquisition and processing. These efforts will be of great benefit for the European XFEL Facility, and will contribute with working solutions to instruments necessary for full exploitation of the XFEL.

An important consideration in terms of providing the resources necessary for the construction of the European XFEL Facility relates to mechanisms for actively involving contributions such as the provision of components, services and personnel, from Academia and Laboratories of the signatory Nations, from the beginning of the XFEL construction phase. This was unanimously regarded as important by the XFEL-STI. It is the XFEL-STI's opinion that a careful investigation of this matter should constitute one of the next steps of the present preparatory phase of the European XFEL Facility. This possibility is already well developed for parts of the accelerator complex within the TESLA collaboration. It should be possible, therefore, to develop it also on matters directly connected with the construction of the users' facility, in order to include, already from the beginning of the European XFEL Facility construction, relevant expertise from academic institutions and industries of the participating countries.

The XFEL-STI recognizes also that approaches of this kind are most applicable during construction, because contracts can easily identify delivery of components and services, and seconding of people on specific projects. These approaches, however, are less evident in the operation of the facility, where the smooth operation and a steady improvement of the facility performances must be guaranteed. During operation, therefore, it is important to guarantee that the facility is a stand alone entity capable of providing the necessary service to the users and also the R&D necessary for effective exploitation of both accelerator and users programmes in collaboration with external institutions.

IX. Conclusions and Summary Recommendations

This Interim Report of the XFEL-STI was formulated to fulfil the request of the Steering Committee, **to assess the scientific goals and the overall layout of the European XFEL Facility, and to explore the construction and operational costs of the facility.**

The scientific case for the European XFEL Facility is extremely strong and based on the unique features of brilliance, spatial coherence and time structure of this new source. It will open the route to revolutionary experiments, allowing, e.g., to:

- probe the time evolution of solid-state structures and chemical reactions on the femto-second timescale;
- solve the structure of biomolecules without the need for crystallization;
- explore the non-linear properties of matter in the X-ray range and the dynamics of fluctuations on interatomic length scales and femto-second time scales;
- produce and investigate matter in portions of its phase diagram inaccessible to other probes.

These breakthroughs are not possible without an X-ray free electron laser. The peak brilliance and the transverse coherence of the XFEL is impossible to achieve with storage rings, the X-ray range appears today inaccessible to other kinds of lasers, and femto-second pulses can be achieved in existing X-ray sources only at the cost of a daunting reduction in intensity.

There are at present several efforts to build VUV and soft X-ray FELs in Europe, but **the scientific promise of a source capable of reaching photon wavelengths of 0.1 nm and below, is so great that it calls for a joint European endeavour to turn it into reality.** FEL projects are underway in the US, Korea and Japan. The Linac Coherent Light Source (LCLS), under construction in Stanford, is using the existing normal-conducting linear accelerator to power an X-ray FEL, with wavelengths between 0.15 and 1.5 nm; it is expected to begin operation in 2009. The European XFEL Facility project is adopting superconducting technology for the accelerator, which will allow a very flexible time structure, access to higher photon energies and it is conceived from its inception as a user facility.

The cost estimate developed by the DESY group seems sufficiently realistic and prudent, and should allow the construction of the facility. Following a request from the XFEL-STI

Working Group, the capability of incorporating technological advances, which are likely to mature and to improve the performance of subsystems during the coming years, has been included in the costing. **Total construction costs for the source and 5 beamlines, with 10 experimental stations, amount to 908 M€, and operational costs are estimated to be 90 M€ per year. The XFEL-STI has in addition identified the need for 50 M€ covering R&D on fast area detectors, optical laser systems, X-ray optics, sample environment and handling.**

The STI working group recommends proceeding as soon as possible towards the foundation of the European XFEL Facility in Hamburg.

Annex

Annex 1

The XFEL Working Group on Scientific and Technical Issues (XFEL STI)

In accordance with the conclusions of the ESFRI Trieste meeting, November 2003, the main task of the STI working group is to reach consensus on the scientific goals and the overall layout of the facility which will form a part of the Memorandum of Understanding to be signed by the partner countries in 2005. The group should start working as fast as possible.

In its constituent meeting the STI working group

- elects the deputy chair person and completes its membership according to scientific and technical expertise independent of the nationality of the invited new members of the group.

- agrees upon the charge letter as defined by the Steering Committee or modifies it if necessary.

- evaluates the site of the facility as proposed by DESY, i.e. stretching from the DESY campus at Hamburg to the town of Schenefeld in Schleswig-Holstein.

- discusses the overall layout of the facility with the aim to fix the basis for the plan approval procedure (Planfeststellungsverfahren):

    - What are the implications for the layout caused by the extension of the spectral range to longer wavelengths? The extent to which the softer spectral range should be served has to be determined, considering the XFEL primarily as the European Centre for SASE free-electron lasers with emphasis on hard X-rays.

    - What are the implications for the layout caused by the installation of seeding: Requirements of the different seeding schemes and auxiliary buildings needed. At what stage of the project the realization of seeding should be envisaged?

- discusses the flexibility of the proposed XFEL scheme, especially of the different options for the time structure of the pulse sequence provided by the facility.

- plans a series of workshops for an update of the scientific case of the XFEL, possibly including both hard and soft X-ray applications.

- plans one or two workshops for in depth discussions on the design parameters of all key components, on the corresponding R&D programmes, work packages and nominates the institutes and people in charge:

  - Superconducting Linac
    - Cavities
    - Accelerator modules
    - RF system
  - Accelerator sub-systems
    - Injector
    - Bunch compressor
    - Beam distribution and stabilisation
    - Undulators

  - FEL concepts
  - Photon beam lines
  - Infrastructure
    - Tunnels and halls
    - Utilities
    - Component test facilities

- discusses the relationships between the XFEL company and the host laboratory (DESY) with respect to the

  - provision of technical and scientific infrastructure.

  - operation and continuous evolution of all components of the XFEL facility.

  - interplay between the research activities of the XFEL company and DESY research in the fields of photon science and accelerator research and development.

Annex 2

Memorandum of Understanding
Between
Institution A
Institution B
Institution C

on the Preparatory Phase of the
European X-ray Free Electron Laser Facility

Preamble

A source of high-brilliance, coherent X-rays (below 1 nm) with a high repetition rate and pulse lengths in the femtosecond region will open up totally new research possibilities in solid state physics, geophysics, chemistry, materials science, medicine and structural microbiology. Free-Electron Lasers based on the principle of Self-Amplified Spontaneous Emission (SASE) and realized by using a linear accelerator as the driver provide such radiation.

A Technical Design Report for the realization of an X-ray free electron laser (XFEL) was published by the international TESLA collaboration in 2000 and supplemented in 2002. These documents constitute the Initial Design. Based on a recommendation by the German Science Council, the German Ministry of Education and Research proposed in February 2003 to build the XFEL in Germany (Hamburg) as a European project to which it is ready to contribute 50% of the funding.

Based on these developments, the signatories of this Memorandum of Understanding want to enter the preparatory phase of a European XFEL Facility.

The present Memorandum of Understanding is of limited duration and implies no legal commitment for the construction and operation of the European XFEL Facility.

However, by signing this Memorandum of Understanding the Parties express their interest in participating in the construction and operation of the European XFEL Facility.

Article 1
Purpose

The purpose of the Memorandum of Understanding is to provide the basis for the international co-operation regarding the preparatory phase of the development of the European XFEL Facility.

During the preparatory phase all documents will be generated which are needed to decide on the construction and operation of the European XFEL Facility such that it can reach the performance goals in a cost effective manner.

These documents include at least

- A technical design report for the injector, accelerator, undulators and the experimental facilities, that further develops the Initial Design
- A time line for the construction and commissioning
- A proposal for the operation of the facility
- A determination of the cost and the cost break down for all phases of the project (design, construction, operation and de-commissioning)
- A funding scenario
- A proposal concerning the organisational structure of the project in its two phases, construction and operation
- A Draft Agreement on partnership for construction and operation

Article 2
XFEL Steering Committee and Working Groups

The work in the preparatory phase of the European XFEL Facility is co-ordinated by the XFEL Steering Committee (XFEL-SC), consisting of one representative for each of the signatories of this Memorandum of Understanding. The representatives are appointed by the signing bodies.

The XFEL-SC will supervise all work and aspects related to the project in the preparatory phase.

Two Working Groups have been established with the following functions:

1. The Working Group on Science and Technical Issues (XFEL-STI) will assess the scientific goals and the overall layout of the European XFEL Facility, including its technical design. It will explore the cost for the construction and operation of the facility.

   The Working Group on Administrative and Funding Issues (XFEL-AFI) will work out a legal framework and an organisational scheme for the construction and operation of the European XFEL Facility. It will reach consensus on the cost for the construction and operation of the facility.

   Both Working Groups will report to the XFEL-SC.

2. The XFEL-STI and XFEL-AFI working groups and the XFEL project team located at DESY will work together to prepare
- an interim report of their findings at the end of 2004,
- by the mid of 2005 the elements specified in Article 1 which are necessary for the decision by the participating countries to construct and operate the European XFEL Facility and
- by the end of 2005 the final documents as specified in Article 1, including the Technical Design Report for the European XFEL Facility

Article 3
Host Laboratory

The European XFEL Facility will be located in the Hamburg area, with DESY as host laboratory. DESY will provide the necessary administrative support for the Steering Committee and the working groups during the preparatory phase.

Article 4
The European XFEL Team

A European XFEL project team will be established by the XFEL-SC and hosted by DESY.

Article 5
Forms of Cooperation between Participating Institutions

The R&D work during the preparatory phase is being carried out within the framework of international collaboration.

Within the framework of this Memorandum of Understanding common activities may be identified which can include the exchange of personnel and equipment, workshops, the exchange of information etc. These activities and their funding will be specified in Appendices which will be appended to this Memorandum in due course and will serve as a record of contributions during the preparatory phase.

Article 6
Duration

This Memorandum of Understanding will become effective for each party upon signature. The preparatory phase covered by this Memorandum of Understanding should be completed by mid 2006. It can be extended by mutual consent.

Article 7
New Parties

This Memorandum of Understanding is open to European and international parties, upon unanimous agreement by the XFEL-SC.

Article 8
Difficulties

The parties in the framework of this Memorandum of Understanding will do their utmost to settle amicably any differences and difficulties which may arise out of this Memorandum of Understanding or the co-operation itself.

Article 9
Changes, Language

1. Changes of this Memorandum of Understanding have to be agreed upon in writing by all signatories.

2. This Memorandum of Understanding is done in English language only, in as many copies as there are parties, each of them equally valid.

Annex 3

Update of the project design status

1. INTRODUCTION

The overall design of the European XFEL Facility, in its version with a linac separate from the TESLA Linear Collider, has been described in the Oct. 2002 supplement to the TESLA TDR. Since then the layout has been further developed. Several modifications were applied, partially due to the new site, partially in view of an improved and more detailed design. Furthermore, additional operational flexibility and possible future options have, to some extent, been incorporated in the present layout. The purpose of this brief overview is to provide an update of the facility design, emphasising the changes from the 2002 report to today's (Dec. 2004) status.

2. BASIC LAYOUT AND PARAMETERS

The European XFEL Facility in the present design will, in its phase-I, have 5 undulator beamlines, three of which are SASE-FELs (two for the 0.1 nm wavelength regime, one for softer X-rays), the other two for hard X-ray spontaneous radiation. The layout of the tunnels in which the undulator beam lines are housed has been adjusted such that optionally one of the two spontaneous undulators could be replaced by a SASE-type undulator. Furthermore, in the SASE-1 and SASE-2 tunnels sufficient space is available to house two undulator sections in sequence as a future upgrade option.

The undulator sections have a maximum total length of 250m. Variable gap (min. 10mm) type 5m long undulator segments are foreseen, which not only permit independently adjusting the photon energy within certain limits, but will also facilitate precise steering of the electron beam for optimum overlap with the photon beam.

Initially, 10 experimental stations are foreseen. The underground hall has a floor space of 42×85m^2 available for installation of experimental stations and depending on the layout and space requirements of the experiments, it is conceivable that more stations can be added later. The site will allow extension of the user facility to five more beam lines in a phase-II development (see Figure A3.1).

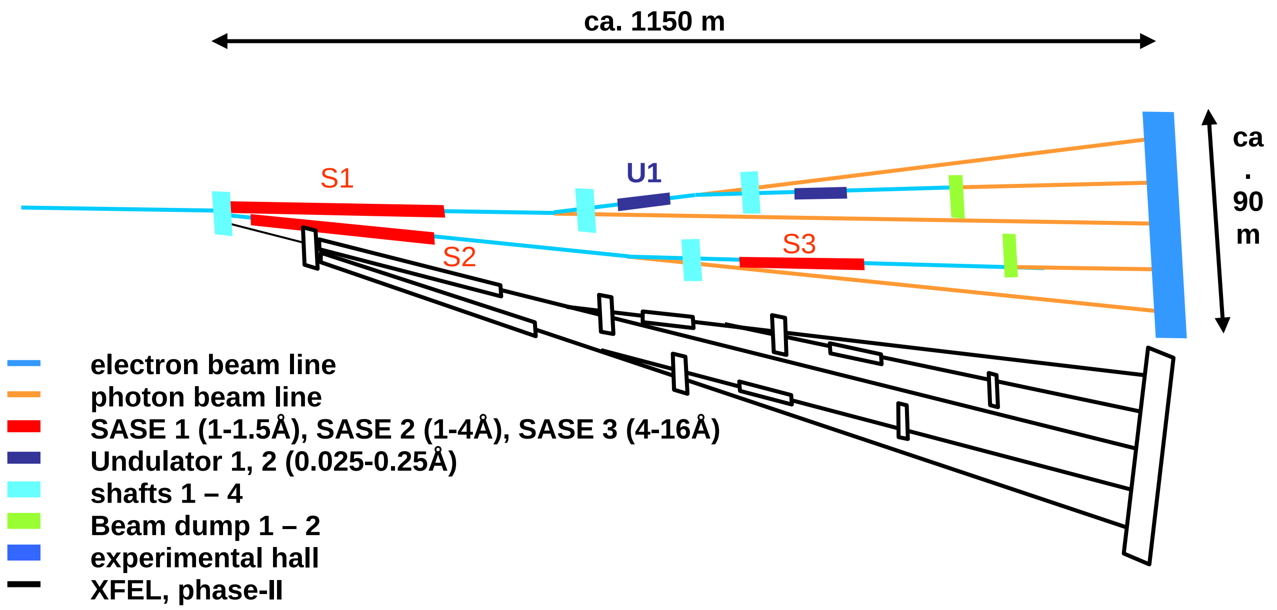

Figure A3.1: The phase-I user beamline layout (coloured) and the possible phase-II extension**.**

An overview of the main XFEL parameters is given in Table A.1. The undulator parameters have been optimised for 0.1 nm wavelength at a beam energy of 17.5 GeV. This implies that at the nominal maximum beam energy from the linac of 20 GeV at 23MV/m accelerating gradient, the ^{57}Fe nuclear resonance at 0.08nm, of interest for certain experiments, will be accessible. Furthermore, the expected higher performance of the superconducting cavities (see below) will permit operating at even shorter wavelengths, provided that the electron beam quality can also be further improved to guarantee saturation in the SASE FEL process.

Table A.1: XFEL Design Parameters

Performance Goals for the Electron Beam	
Beam Energy Range	10 - 20 GeV
Emittance (norm.)	1.4 mrad · mm
Bunch Charge	1 nC
Bunch Length (1σ)	80 fs
Energy-Spread (uncorrelated)	<2.5 MeV rms
Main Linac	
Acc. Gradient @ 20 GeV	23 MV/m
Linac Length	approx. 1.5 km
Beam Current (max)	5 mA
Beam Pulse Length	0.65 ms
# Bunches p. Pulse (max)	3250
Bunch Spacing (min)	200 ns
Repetition Rate	10 Hz
Avg. Beam Power (max)	650 kW
Performance Goals for SASE FEL Radiation	
photon energy	15 – 0.2 keV
Wavelength	0.08 – 6.4 nm
peak power	10 – 20 GW
average power	40 – 80 W
number photon per pulse	$0.5 – 4 \times 10^{12}$
peak brilliance	$2.5 – 0.08 \times 10^{33}$*
average brilliance	$1 – 0.03 \times 10^{25}$ *
* in units of photons / (s $mrad^2$ mm^2 0.1% bw)	

3. SUPERCONDUCTING LINEAR ACCELERATOR

The basic accelerator layout is sketched in Figure A3.2. The main linac includes 116 12m long accelerator modules with 8 superconducting 9 cell cavities each, grouped in 29 RF stations. Twelve spare modules and three RF stations, are included in the design in order to guarantee the overall availability of the accelerator in case of failures. The XFEL linac design is based entirely on the technology which has over the past few years been developed by the TESLA collaboration as the most essential part of the R&D programme towards a superconducting linear collider. The successful completion of the first phase of the TESLA Test Facility (TTF) has demonstrated that superconducting 9-cell Nb cavities can be reliably produced with the XFEL design performance of 23MV/m. Stable beam acceleration at (or near) this gradient was also demonstrated with complete 12m long accelerator modules, containing 8 cavities each, in the TTF linac. The latest generation accelerator module #5, now installed in the upgraded phase-2 TTF/VUV-FEL, has performed in RF tests at a gradient of 25MV/m for all cavities simultaneously (higher for 6 out of 8 in single cavity RF tests).

The continuing TESLA superconducting RF technology (SRF) R&D programme has by now delivered state-of-the-art cavities with a performance well exceeding the XFEL baseline requirements. With the electropolishing (EP) method, pioneered at KEK, to improve the Nb surface quality, five 9-cell cavities were tested at gradients of 35 – 40MV/m. One cavity was installed in the first module of the TTF linac and a gradient of 35MV/m previously obtained on the test stand was reproduced in a measurement with beam. The SRF linac for the XFEL will be fabricated with the EP technique and the recent results clearly justify the expectation that the machine will be able to provide the above mentioned flexibility to operate at higher energies without the need to extend the linac length.

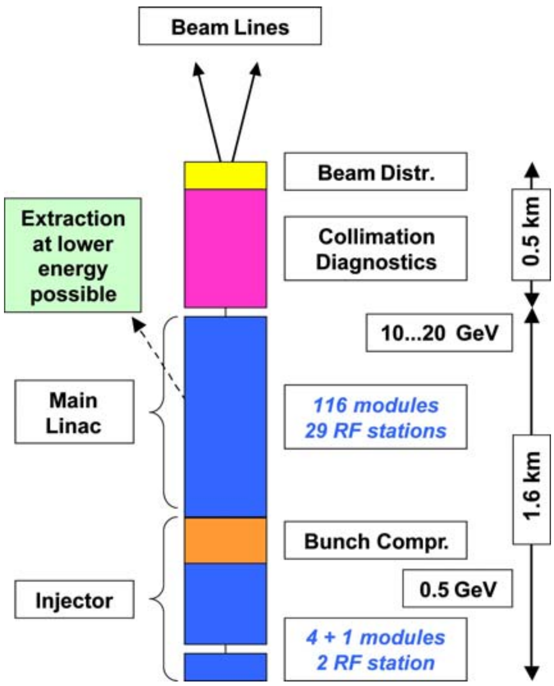

Figure A3.2: Basic Layout of the XFEL Accelerator

The required klystron power per station is 4.8MW, well below the maximum power of 10MW of the multi-beam klystrons developed by industry for the TESLA project. This will not only cover the power needs for the above mentioned operation at higher energies, but will also allow operation of the linac at higher repetition rates (and duty cycles) at lower energy (the main limitation then being the *average* power of the RF system). In a recent test, a pulse repetition rate of 40Hz was reached with one RF station.

In contrast to conventional linacs, even continuous wave (CW, 100% duty cycle) operation of the linac is conceivable with superconducting accelerator technology, although only at reduced energy/accelerating gradients in order to avoid excessive cryogenic loading of the Helium coolant at 2K. Such an option is not viewed as being part of the initial stage of the facility, but could become attractive if lower-emittance, high duty cycle electron beam sources become available. It is estimated that with a gradient of 7 – 8 MV/m (~7 GeV beam energy) this mode of operation would be compatible with the anticipated cryogenic plant. A list of preliminary CW-parameters is shown in Table A2. The additional investment for an additional low-power-CW RF system would be necessary, with inductive output tube (IOT) devices as possible candidates for the power source. In order to reach the 0.1 nm wavelength regime at the lower electron beam energy, different undulators with a reduced period length (possibly in a scheme with high gain harmonic generation) would also be required.

Beam energy [GeV]	6.5 – 7.5
Acc gradient [MV/m]	7 – 8
Beam current [mA]	0.18
Bunch spacing [μs]	5.5
RF power / module [kW] (incl. regulation overhead)	~20 – 30
Dynamic cryo load 2K [kW]	~2.4 – 3.2

Table A2: Preliminary parameters for a possible future CW operation mode of the linac.

4. INJECTOR AND BUNCH COMPRESSOR

To optimise availability, there are two parallel injectors to produce and accelerate the electron beam before combining the beam lines at 100 MeV energy. The injector tunnels are shielded from each other, so that maintenance, repair or modifications of one of them would be possible while continuing to operate the facility with the other. A short accelerator section at the 3rd harmonic RF frequency is then used for the linearization of the longitudinal phase space. This section is followed by a booster linac increasing the energy to 500 MeV. At this energy the electron bunches are compressed by about a factor of 100 down to $\sigma_z \cong 22\mu m$, corresponding to approx. 5 kA peak current for 1nC charge bunches. Operation in this extremely short bunch length regime presents considerable technical and beam dynamics challenges.

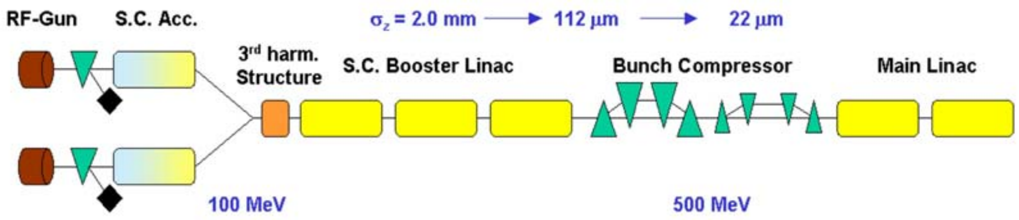

Figure A3.3: Injector Layout

Simulation results for the photocathode RF gun indicate that an rms normalised emittance of 0.9mm·mrad is achievable. The R&D for low-emittance electron beam sources has been performed within the TESLA collaboration and is supported by the 6^{th} EU Framework Programme. Beam tests of the latest version of the RF gun have been carried out at the PITZ test stand at DESY-Zeuthen, yielding a normalised emittance of 1.7mm·mrad. Further improvements are expected by increasing the accelerating field on the cathode from 40 to 60MV/m and optimising the homogeneity of the transverse laser beam profile. The gun previously tested at PITZ is now installed at the VUV-FEL and commissioning with beam has started.

The bunch compressor has in comparison to the earlier version been simplified by going from a 3-stage to a single stage layout. This approach turned out to be more robust against the potential problem of the micro-bunching instability. The latter can lead to strong amplification of initially small modulations in the longitudinal bunch charge distribution by coherent synchrotron radiation (CSR) and space charge effects. The effect of CSR on the beam emittance is, in the present layout, strongly reduced by splitting up the magnetic chicane of the compressor into a first section with large momentum compaction (transfer matrix element R_{56}) and a second section with small R_{56}. The weak bends in the second section avoid excessive CSR at a position where the bunch becomes shortest. The residual emittance growth obtained from extensive beam dynamics simulations is of the order of 10%, well within the 50% total budget for emittance dilution from the source to the undulators. Further dilution in the downstream main linac is small as a result of very weak wakefields in the TESLA accelerating structures, so that the overall design includes a reasonable safety margin regarding the beam emittance requirements.

The large bunch compression ratio is inevitably connected with tight tolerances on timing, RF phases and amplitude of the gun and the booster section. The effects of jitter in these and other parameters on the FEL photon beam properties have been studied in a simplified model calculation. Even with tight assumptions of 0.05°, 0.02% and 0.1ps in RF phase, amplitude and gun timing jitter (rms) respectively, the fluctuations of photon pulse length and saturation power are not negligible (19% rms and 41% rms, respectively) and efficient photon diagnostics are likely to be required to monitor the beam and correlate variations with experimental data. An advantage of the SRF concept is the possibility of stabilising the RF parameters within a pulse by feedback. The ongoing R&D programme for the RF control is aiming for a phase stability of 0.01°. In principle, a two-stage compressor system can have potential advantages regarding jitter tolerances. Furthermore, recent studies show that the transverse space charge effects in the diagnostics beam line directly following the compressor chicane can cause some emittance growth for the bunch when compressed to its final length in a single stage at 0.5 GeV energy. This could be avoided by performing the final compression in a second step at higher energy. It is the subject of ongoing studies to assess whether these advantages would justify such a 2^{nd} stage.

5. ELECTRON BEAM DISTRIBUTION

The XFEL linac can accelerate more than 3,000 bunches per RF pulse and serious beam dynamics problems related to higher order modes in the cavities are not expected. User requirements regarding beam time structures will vary over a large range, from single or few bunches to partial or full trains per RF pulse. Generation of such patterns is possible at the source, at the end of the linac or by a combination of both. From the point of view of maximum flexibility a system using programmable fast kickers appears to be the optimum solution. Beam loading conditions in the linac could be quasi static, i.e. the same from pulse to pulse, and bunches could be distributed to different beam lines according to the needs of the respective experiments. The required switching devices are demanding regarding jitter tolerances and reliability. The development programme for these devices is ongoing. Recent test results for pulser devices developed for the linear collider project and for the BESSY FEL project look very promising. In addition to switching the electron beam, switching the FEL process itself on and off by phase shifters can also be envisaged, such that different photon pulse time structures can be generated in a beam line within a sequence of several undulators.

The beam transport lattice, from the end of the linac to the undulators, includes sections for diagnostics and collimation to protect the undulators from potentially large amplitude halo or mis-steered beams. A large momentum acceptance is foreseen so that energy modulation with a bunch train by up to ±1.5% is possible. The lattice layout and the civil construction in the beam distribution region for the phase-I of the user facility also take into account the possibility of later adding more beamlines (see below).

Among the options to add features to the range of possible photon beam properties, very short pulses in the sub femto-second regime appear very attractive for certain classes of experiments and could be generated by modulating the energy distribution in the bunch with a very fast laser just upstream from the SASE undulators.

6. SITE AND CIVIL ENGINEERING

The German government decision in 2003 to go ahead with the XFEL as a European project and to postpone the decision on the linear collider led to a revision of the choice of site, with synergy arguments for a common site for both facilities no longer in effect. The new site layout, sketched in figure A3.4, has the XFEL linac starting on the DESY site, permitting optimum use to be made of existing infrastructure, and has the user facility in a rural area about 3km west-northwest from DESY. The legal procedure (*Planfeststellungsverfahren*, PFV) to obtain permission for construction is in preparation and expected to be completed by end of 2005. As part of the preparation for the PFV, the civil construction is already being planned in quite some detail.

The linac will be housed in a tunnel (Figure A3.5) 15 – 30m underground. Construction taking account of the ground water will be carried out with a tunnel drilling machine with a well proven technique already applied 20 years ago for the 6.3km HERA tunnel in similar soil conditions. The klystrons will be in the tunnel and connected by 10kV pulse cables to the modulators located in an easily accessible surface building on the DESY site.

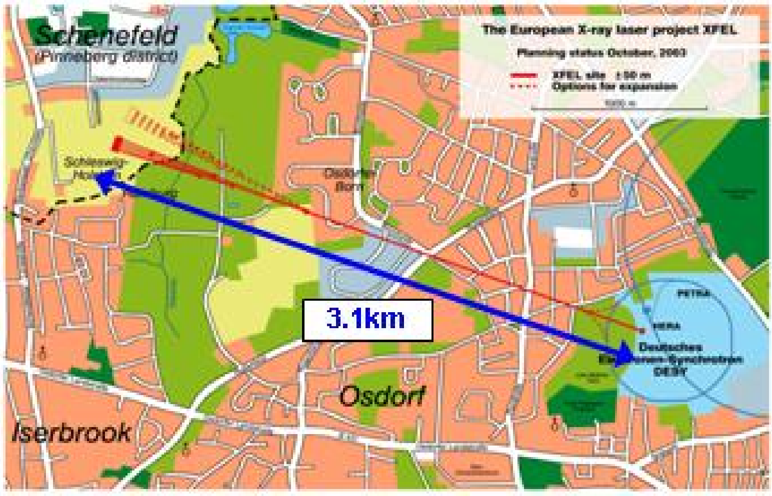

Figure A3.4: Sketch of the new XFEL site near DESY.

The SASE undulator beam lines will also be housed in 5.2m diameter tunnels. For the photon beam lines, a diameter of 4m is sufficient. At the positions where the beam lines split up, underground shafts are foreseen. This is necessary for civil construction reasons, to provide access to the tunnels from outside and for feeding in cables, water cooling, ventilation etc. Particular attention in the recent design work has been given to the first beam distribution shaft directly at the end of the accelerator tunnel (named "XS1"). The present layout permits starting a later extension of the facility (phase-II) from this shaft (3rd tunnel branching off, see figure A3.6). The design also includes a beam dump line in this shaft, which will be used for commissioning the accelerator while still being able to perform installation work in the undulator tunnels. Furthermore, the radiation shielding between the undulator tunnels is laid out such that one tunnel is accessible while another undulator line is operated with beam. This concept is thought to facilitate an efficient and fast start-up of the facility and to enhance the flexibility for later operation.

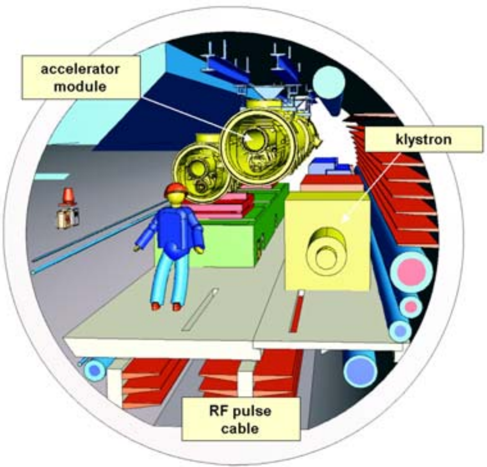

Figure A3.5: Sketch of the 5.2m diameter main linac tunnel. The accelerator modules will be suspended from the ceiling.

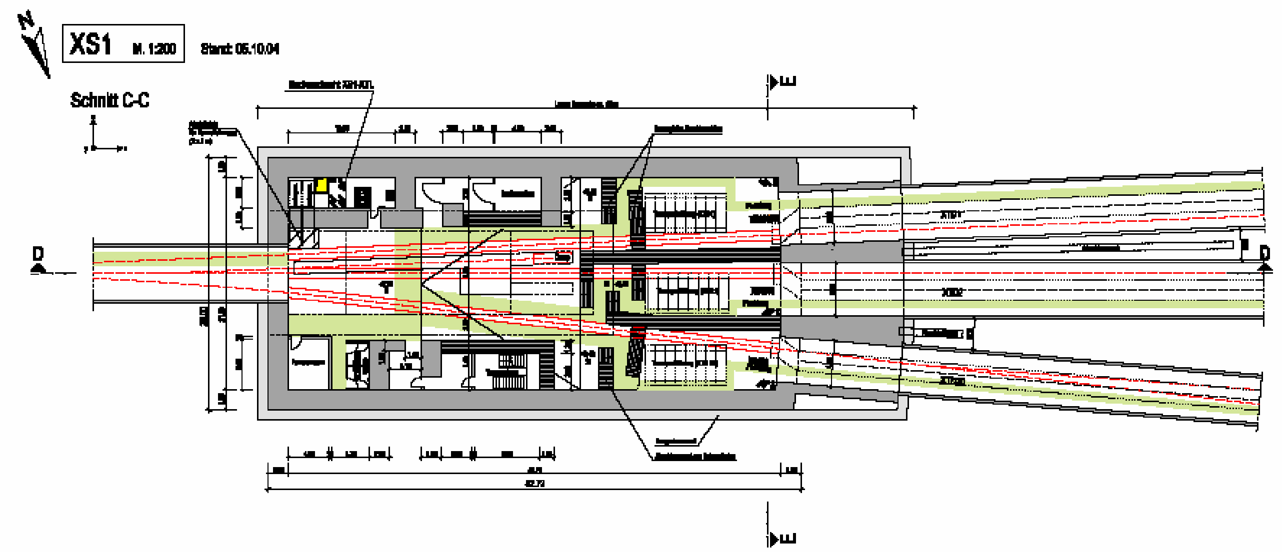

Figure A3.6: Top view of the XS1 beam distribution shaft. The linac tunnel is to the left. The upper two tunnels to the right belong to the SASE-1 and SASE-2 beamlines of the phase-I development, the lower tunnel branches off to the later phase-II of the facility.

The experimental hall with a floor space of 4,500m^2 is shown (in side view) in Figure A3.7. The hall floor is approximately 14m underground. A surface building providing space for offices, meeting rooms, etc. is placed on top of the underground hall.

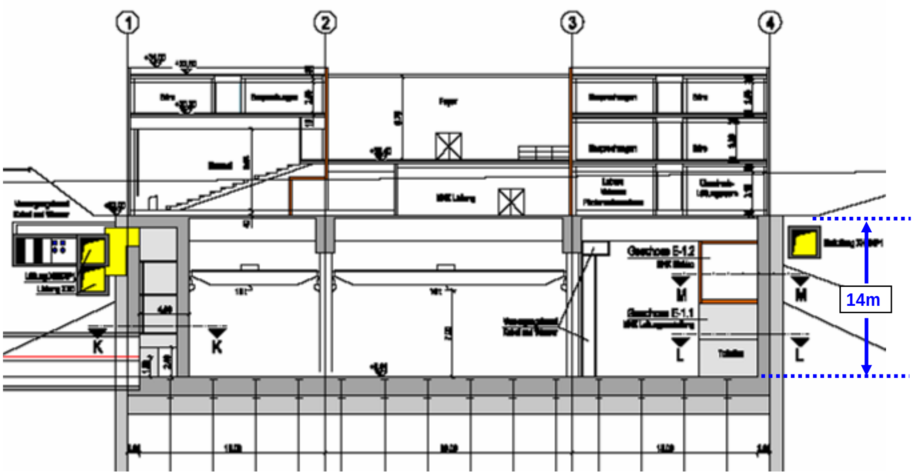

Figure A3.7: Side view of the experimental hall (photon beam lines are to the left) and of the surface building on top.

Interim Report of the Scientific and Technical Issues Working Group on a European X-FEL Facility in Hamburg

Annex 4

http://xfel.desy.de/content/e761/e830/index_eng.html

STI Round Table Meeting June 2004

A round-table meeting as part of the STI (Science and Technology Issues) working group took place at DESY on June 22 - 24, 2004. The topics discussed were the science case, accelerator related issues and the XFEL process.

Available Presentations

Title	Speaker
Science Case I	
Opportunities and Challenges for XFELs for Ultrafast Science	J. Hastings
Introduction on Coherent X-rays from an XFEL	B. Stephenson
Ultra-fast Chemical Dynamics	S. Techert
High Energy Density Science on XFELs	R. Lee
Imaging of Single Particles and Biomolecules.	J. Hajdu
New Frontiers in Atomic Molecular Optical Physics with a VUV/X-FEL	J. Ullrich
Accelerator Related Issues	
The VUV-FEL as Pilot Facility for the XFEL	J. Rossbach
XFEL Accelerator Overview	R. Brinkmann
Generation of High Quality Beam	K. Flöttmann
Beam Distribution and Stabilisation	W. Decking
Science Case II	
Ultrafast Structural Dynamics in Solids	K. Sokolowski-Tinten
Magnetization Dynamics: the 1st Picosecond	H. Dürr
Ulta-fast X-ray Science	E. Collet
Clusters Structure and Dynamics studied with XFEL Pulses	T. Möller
Fundamental High Field Science with an XFEL Facility	A. Ringwald
XFEL Process	
Baseline Design of the SASE Radiators of the European XFEL	J. Feldhaus
Alternative Coherent Sources of Short-wavelength Radiation in the Soft and Hard X-ray range, not Based on Accelerators	J. Tisch
Seeding and High Gain Harmonic Generation Schemes in the European XFL Framework	L. Giannessi
Different Approaches for the Generation of femtosecond and sub-femtosecond X-ray Pulse	D. Garzella
Attosecond Option for the XFEL	E. Saldin
Future Options	M. Yurkov

Participating Speakers, Experts and STI Committee Members:

Round-Table Meeting, June 22-24, 2004, at DESY/Hamburg

Altarelli	Massimo	Committee Member	Science Case (II)
Andreev	Nikolaj	Committee Member	
Bocchetta	Carlo	Speaker	Accelerator Session
Brinkmann	Reinhard	Expert	Accelerator Session
Bordas	Joan	Committee Member	
Collet	Eric	Expert	Science Case (II)
Daillant	Jean	Expert	Science Case (II)
Danared	Hakan	Expert	Accelerator Session
Decking	Winfried	Speaker	Accelerator Session
Drescher	Markus	Speaker	Science Case (I)
Duerr	Herrmann	Speaker	Science Case (II)
Eriksson	Mikael	Committee Member	
Feidenhans´l	Robert	Committee Member	
Feldhaus	Josef	Speaker	XFEL Process
Floettmann	Klaus	Speaker	Accelerator Session
Garvey	Terry	Expert	Accelerator Session
Giannessi	Luca	Speaker	XFEL Process
Garzella	David	Speaker	XFEL Process
Hastings	Jerry	Speaker	Science Case (I)
Hajdu	Janos	Speaker	Science Case (I)
Hutchinson	Henry	Committee Member	
Jaeschke	Eberhard	Committee Member	
Kennedy	Eugene	Committee Member	
Kleyn	Aart W.	Committee Member	
Knobloch	Jens	Expert	Accelerator Session
Krausz	Ferenc	Expert	Science Case (I)
Krämer	Dieter	Expert	XFEL Process
Lee	Richard	Speaker	Science Case (I)
Limberg	Torsten	Expert	Accelerator Session
Materlik	Gerhard	Chairmen	Science Case (I)
Möller	Thomas	Speaker	Science Case (II)
Napoly	Olivier	Expert	Accelerator Session
Noelle	Dirk	Expert	Accelerator Session
Pellegrini	Claudio	Chairmen	XFEL Process
Palumbo	Luigi	Expert	Accelerator Session
Pflüger	Joachim	Expert	
Poulsen	Henning	Speaker	Science Case (II)
Richter	Jürgen	Committee Guest	
Ringwald	Andreas	Speaker	Science Case (II)
Rivkin	Lenny	Expert	Accelerator Session
Rossbach	Jörg	Speaker	Accelerator Session
Rousse	Antoine	Committee Member	
Saldin	Evgueni	Speaker	XFEL Process
Schlarb	Holger	Expert	Accelerator Session
Schlott	Volker	Committee Member	
Schneider	Jochen	Committee Member	
Schneidmiller	Evgeny	Expert	
Sette	Francesco	Committee Member	
Sokolowski-Tinten	Klaus	Speaker	Science Case (II)
Stephan	Frank	Expert	Accelerator Session
Stephenson	Brian	Speaker	Science Case (I)
Techert	Simone	Speaker	Science Case (I)
Tisch	John	Speaker	XFEL Process
Ullrich	Joachim	Speaker	Science Case (I)
Wark	Justin	Chairmen	Science Case (I)
Werin	Sverker	Expert	Accelerator Session
Weise	Hans	Expert	Accelerator Session

Interim Report of the Scientific and Technical Issues Working Group
on a European X-FEL Facility in Hamburg

Annex 5.1-4

Annex 5.1: Dedicated detector development programme

The unique properties of XFEL radiation impose unprecedented requirements on X-ray detection systems (ultra-high (spatial-) resolution, multi-element detection, ultra-high time resolution and high quantum efficiency). Such detectors do not exist today but are of central importance for experiments at free electron lasers. An appropriate detector development programme is therefore mandatory.

A dedicated programme will have to pursue several approaches from ultra fast X-ray streak cameras operating in the femto-second regime, through linear devices to multi-element (≥2K x 2K) pixelated systems with sub-microsecond time resolution. The complexity of the systems will be similar to High Energy Particle Physics Detectors and it is desirable to initiate a broad (multi-national effort) to launch such a programme. A preparatory phase to establish specifications and evaluate technological choices will be inevitable. A minimum R&D period of 5 years for the first generation of prototype devices will be necessary.

The required resources for such a programme, but in particular for a first 5 year period, will have to be evaluated, preferentially by a body such as a Detector Advisory Committee (DAC). Eventual options for combined efforts between the Photon Science and Particle Physics communities need to be explored.

Annex 5.2: Optical Laser System

In time-resolved experiments the use of pump-probe techniques using ultra-short pulse optical lasers is mandatory in many cases. Ultra-short pulse (USP) lasers with pulse durations of the order 30 femto-seconds and pulse energies of a few 10mJ can today be purchased commercially. For the European XFEL Facility the layout of the experimental stations foresees at least one USP laser system per beam line.

Since the publication of the Technical Design Report a number of experiments have been described in more detail that will require pump or probe lasers, exceeding today's commercially available USP lasers either in delivered power or in time performance. Higher laser power up to 1kJ pulse energy may be required e.g. in experiments aiming to create plasmas with the laser and using the XFEL for spectroscopic investigation of these plasmas.

With respect to pulse duration the envisaged possibility of shortening the X-ray pulse duration opens the possibility of investigating solid-state dynamics at a few femto-seconds time-resolution. These experiments require USP laser systems with pulse durations of equivalent duration and are therefore more demanding in their optical components.

A combination of high power and pulse duration of a few femto-seconds will be required for laser systems to modulate the electron beam energy (seeding). The above cited lasers, together with other more 'standard' USP systems, are crucial for the success of the scientific programme of the XFEL. The total cost of laser systems, including dedicated staff for installation and operation of these lasers, will exceed the budget currently foreseen for 'standard' laser systems.

Annex 5.3: Sample environment and handling

The intensity fluctuation, the small beam size, and the high power of the XFEL photon beam lead to constraints for the sample environment and sample handling that are uncommon in SR or other types of X-ray experiments. One can expect e.g. for solids in certain experiments the requirement to change the interaction volume of the sample at the repetition rate and accuracy determined by the XFEL beam. Monitoring of the sample position and interaction volume will be of further importance for single-shot experiments.

For nano-sized particles and molecule imaging experiments new sample preparation, selection, and injection systems will be required. Sample environment systems as the ones described above are currently not available and require R&D and construction. Although some R&D efforts, FTE and investment costs for sample handling systems has been included in the TDR it is the general opinion of this Working Group that this topic will require still more attention. This is particularly important as the sample environment and handling play a crucial role when it comes to user aspects of this facility.

Annex 5.4: X-ray optics and beam transport

X-ray FEL radiation provides beams of extreme peak brilliance and intensity. The high peak power and the related power density will play a critical role when it comes to the stability and performance of the X-ray optical elements preparing the beam for the experiments.

Of particular importance for the European XFEL Facility will be the time structure of the X-ray beam with repetition rates exceeding the thermalisation of matter placed into the beam. Advanced cooling and stabilization schemes will require extensive R&D to enable the construction of an X-ray optical system that will provide the stability required for the XFEL experiments.

Another new feature of the radiation is its coherence leading to the requirement for optical elements to either not disturb the wave fronts or completely destroy coherence depending on the type of experiment.

Finally for the distribution of the beam via switchable X-ray optics, extremely reliable mechanisms and controls have to be developed that will allow steering of the X-ray beam with sub-microradian precision.

Although an R&D programme is foreseen within the present budget the XFEL-STI Working Group feels that this topic must receive still higher support. It is hence suggested to provide a specific budget for a dedicated X-ray optics and beam transport R&D programme.