

# 10 Cost and time schedule

In this chapter, a summary of the complete project cost is given, the basic schedule from start of construction until end of commissioning is discussed and the resulting budget profile over all phases of the project is described.

## 10.1 Total project cost

All costs from the project preparation to the commissioning phase (i.e. prior to the start of operation) have to be summed up in order to determine the total project cost (TPC, which is covered by the construction budget). As explained in Chapter 8, there will be a period of about 2.5 years during which an overlap of construction and commissioning (which are covered by the construction budget), on the one hand, and operation (which is covered by the operation budget), on the other, will occur (see also the discussion of time schedule and budget profile below). The contributions to the TPC, summarised in Table 10.1.1, are:

- The project preparation costs. These are the expenses since the X-Ray Free-Electron Laser (XFEL) Memorandum of Understanding (MOU) came into effect (end of 2004) between Deutsches Elektronen Synchrotron (DESY) Laboratory and those institutes which have concluded collaboration contracts with DESY.
- The project construction costs in the proper sense, as described at the end of Chapters 4 to 7.
- The cost for commissioning the facility with beam, as described in Chapter 8.
- An addition to the personnel cost, to take into account allowances for personnel moving from their home country to work at the XFEL company.
- An addition to the XFEL company personnel cost overhead for management and support.

Recurrent costs during the construction phase (electricity, water and Helium) are not included in the TPC since they will be covered by the DESY operation budget free of charge to the XFEL project. Costs related to land acquisition are also not included in the TPC.

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Project preparation	38.8 M€
<i>Project construction, capital investment</i>	<i>736.3 M€</i>
<i>Project construction, personnel</i>	<i>250.1 M€</i>
<b>Total construction cost</b>	<b>986.4 M€</b>
Beam commissioning	56.4 M€
<b>Total project construction cost</b>	<b>1,081.6 M€</b>

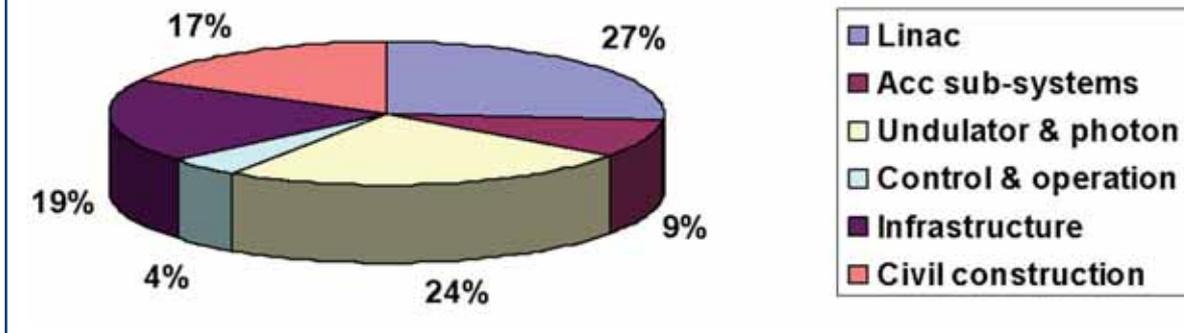
**Table 10.1.1** *Total project cost, including preparation – commissioning phases. All cost figures are on the price basis of the year 2005. - The original Table 10.1.1 of the TDR has been slightly re-arranged: the additional personnel cost (allowances) and the additional management overhead of the XFEL GmbH, initially shown in separate lines of the table, are now included in the cost for construction and commissioning.*

Using the present organisational structure of the project (see Chapter 9) with six groups of work packages and 38 work packages in total, a breakdown of the construction costs is shown in Figure 10.1.1. The relation between the work package groups and the chapters in this report is shown in Table 10.1.2.

Work package group	Chapter 4	Chapter 5	Chapter 6	Chapter 7
WPG1 linac	X			
WPG2 Accelerator sub-systems	X			
WPG3 Undulator and photon		X	X	
WPG4 Controls and operation				X
WPG5 Infrastructure				X
WPG6 Site and civil				X

**Table 10.1.2** *Relation between chapters in this report and work package groups in the present organisational structure of the project.*

XFEL construction cost distribution



**Figure 10.1.1** Breakdown of project construction cost (sum of capital investment and personnel cost) into the work package groups.

The evaluation of personnel costs has been performed in accord with the rules approved by the XFEL Working Group on Administrative and Funding Issues (AFI) [10-1]. The salary structure (2005 basis) of the different technical groups in the DESY Divisions has been used to determine the cost per full-time equivalent (FTE) for each of the 38 work packages in the XFEL project, depending on the percentages of scientific and technical personnel in each work package. To this an overhead of 13k€ per FTE, also derived at DESY, has been added. This approach, which was also used for the earlier cost estimations since 2002, has so far been maintained in order to permit a better follow-up and comparison of the various updates of the project costs, related to scientific and technical issues or to external economic parameters. However, two items are not, or not sufficiently, taken into account by this procedure.

The Administrative and Financial Issues Working Group (AFI) "Guidelines for establishing the XFEL cost estimates and control tools" indicate that *"the transformation of...FTE into personnel costs may, in the first instance, be based on salaries and social charges according to the German Public Service. The amount has to be revised once the actual employment conditions for the XFEL personnel are specified."* This question is not yet fully settled, however, one aspect is relatively clear: in view of being able to attract personnel from partner countries, underlining the international character of the project, an addition to the salaries as defined above should be taken into account for personnel moving from their home country to work at the XFEL company. Based on the practice at the European Synchrotron Radiation Facility (ESRF), such allowances are assumed to amount to 16% of the salaries (without overhead) which have been derived from the salary structure at DESY. As a model to estimate the total amount of these additional personnel costs (see Chapter 9), it is assumed that the XFEL company's personnel ramps up continuously from the beginning of 2007 to its full "steady state" staff in 2016

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(see Chapter 9) and that, on average, half of the company's personnel receive the allowances.

The other item concerns the way the cost for general expenditure is taken into account. This includes all staff posts not directly related to the accelerator and beamline work packages, such as Management, Administration and other central services. Their costs enter the calculation exclusively through overheads on the costs per FTE. The previous cost estimates have used the overheads calculated for DESY. However, in the XFEL company, due to its much smaller amount of staff, the relative part of management and support is significantly higher than at DESY. This is all the more the case, if the accelerator part were to be constructed, to a large extent, by DESY personnel, as a contribution in kind. In addition, the XFEL Management, essential parts of the XFEL Administration and some other general services need to be in place well before the major part of the personnel of the Experiments Division. Treating their costs only as part of the overhead of the Experiments Division staff would result in a wrong cost profile. This discrepancy has been solved by adding a global overhead of 1.5 M€ per year. For the first years this simply corresponds to advancing by one year the recruitment of about 20 staff under management and general support, when compared to the cost profile resulting from the overhead view. In the transition phase, this figure of 1.5 M€ per year is accounted partially as TPC, partially as operation cost, in proportion to the amount of personnel allocated to construction/commissioning and operation, respectively.

## 10.2 Risk analysis

As part of the construction cost evaluation, every item in the budget book is estimated with an expected lowest and highest price based on the current knowledge about the component or system. Using these price ranges, a statistical probability distribution of the project construction cost can be derived. According to the AFI recommendations [10-1], the estimated prices were chosen such that the estimated construction cost is in the centre of this probability distribution, i.e. at 50% probability.

In order to generate an estimate of maximum cost risk for the project, for several large cost items, the upper limit of the cost range was increased using more pessimistic assumptions. In particular, it was assumed that the expected cost reduction in going from present prototype manufacturing to later industrial series fabrication cannot be achieved as planned – only half of this reduction can be realised. Using these artificially extended cost variation ranges, a statistical analysis of the construction cost was again performed. The result of this analysis is a curve which gives a probability value for a given budget that the project can be completed successfully within that budget. From this probability curve a risk budget can be derived, which is needed to guarantee a high probability (98% as recommended by AFI) to complete the project in budget (= estimated cost + risk budget). From the construction of this **maximum risk** analysis, it is clear that the estimated (i.e. **most likely**) construction cost is at a point well below 50% in the probability curve.

The statistical analysis was performed using Monte Carlo methods implemented in the commercial risk analysis tool @Risk for Excel [10-2]. The price range for each cost item

is given by three values: the lowest and highest expected price and the central value which is used to calculate the project cost. A typical random distribution used in financial mathematics is the log-normal distribution:

$$C = C_0 e^{aZ}$$

where  $Z$  is the standard normal distribution and  $C_0$  and  $a$  are the parameters. This distribution finds its application in processes where the variation of prices is multiplicative, i.e. the prices vary in percentages rather than in absolute units [10-3]. For the statistical analysis it was therefore assumed, that the price distribution follows a log-normal distribution. The parameters  $C_0$  and  $a$  were chosen in a way that the expectation value and the variance of the log-normal distribution are equal to the expectation value and variance of a triangular risk function defined by the three cost values of each item as suggested by [10-3].

Not all of the more than 2,500 cost items can be considered independent of each other. Therefore, it is necessary to include correlations between items in the statistical analysis. Correlations were defined on the work package level. Three correlation classes are defined:

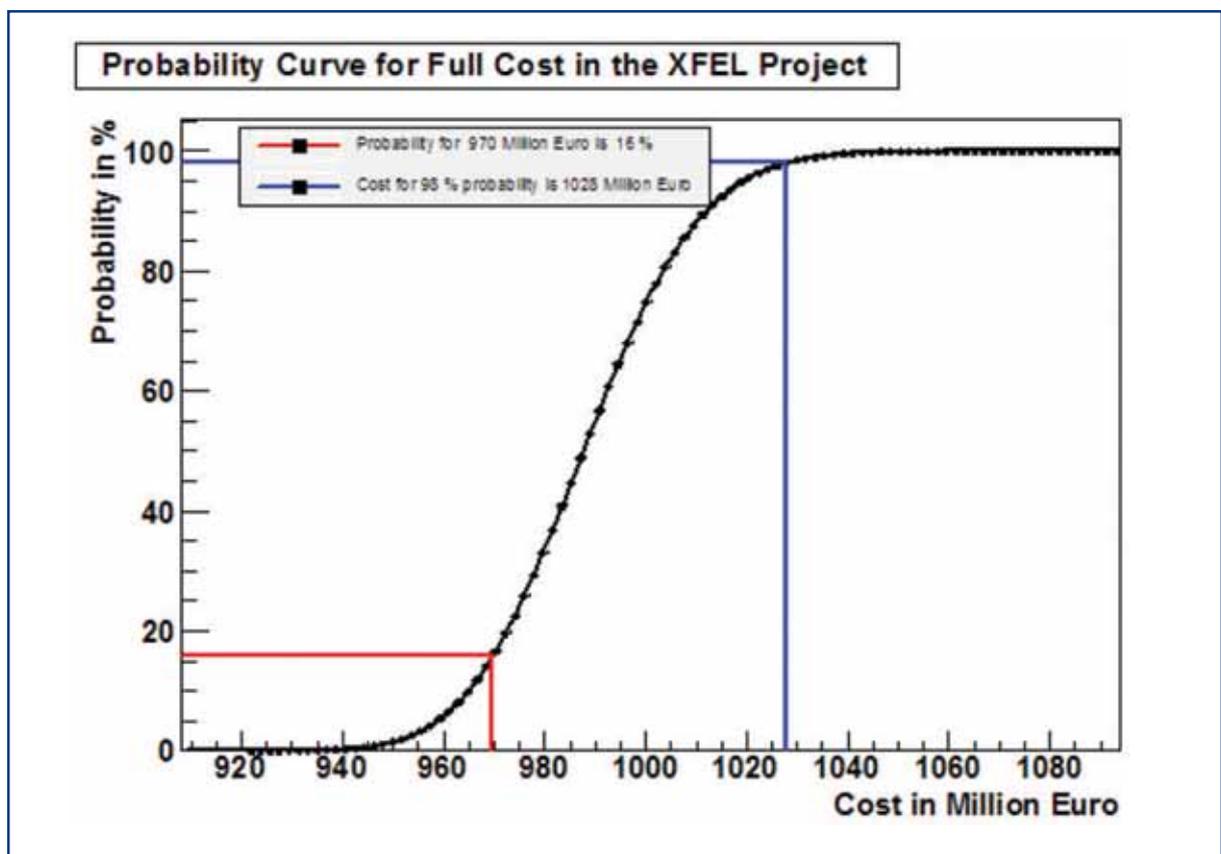
- **fully uncorrelated cost items in a work package:** all costing items can be considered independent of each other, so that each item is included with its own log-normal random distribution in the analysis; an example for a fully uncorrelated group of cost items is the accelerator module;
- **fully correlated cost items in a work package:** the majority of the items in a work package are subject to the same cost uncertainty, so that only the total sum of the correlated items with its uncertainty is included in the analysis; an example of a fully correlated group of cost items are the normal conducting magnets;
- **partially correlated cost items in a work package:** big blocks of cost items within a work package are subject to the same cost uncertainty; these blocks of cost items within a work package are then taken to be fully correlated; an example are the costs for electric power, air conditioning and water supplies, respectively, of the utilities work package.

The statistical analysis of the project costs was performed by means of Monte Carlo methods. In a Monte Carlo experiment, a random price value distributed according to the log-normal distribution discussed above was generated for the cost item taking into account the three correlation classes. A total (or sub-total) price corresponding to these randomly distributed values was calculated. After performing many such Monte Carlo simulations, a distribution of expected total project costs was obtained. Integrating this distribution and normalising it to the number of performed Monte Carlo experiments then yielded the probability curve discussed already (see Figure 10.2.1). As the final result, a risk budget of 6% of the estimated construction cost has to be allocated in order to provide a 98% probability of completing the project within budget even with the pessimistic assumptions on cost variations already described.

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An additional cost risk results from possible delays, caused, for example, by companies being over-committed or, as an extreme case, going into bankruptcy. Delays due to such events can, to a certain extent, be mitigated by re-scheduling other parts of the project (e.g. rearranging the sequence of component installation), but additional cost resulting from project personnel not being able to continue the work as efficiently as planned will be hard to avoid. The cost risk due to delays has been estimated as half a year of personnel cost in the middle of the construction phase, corresponding to 2% of the project constructions cost.

In summary, the estimated risk budget amounts to 8% of the construction cost (78 M€).



**Figure 10.2.1** Result of the statistical construction cost risk analysis (see text).

### 10.3 Operation cost

The yearly costs for operating the facility, as explained in more detail in Chapter 8, are reproduced here in Table 10.3.1. As in the construction phase, budget items have been added here to cover allowances for GmbH personnel and overhead for the GmbH management and support (see Section 10.1). This budget represents the “steady state” value when the facility is fully operational. During the transition phase, the budget ramps-up in a way following the sequence in which the different parts of the facility are put into operation, as described in Chapter 8. The resulting evolution of the operation part of the yearly budget with time is shown in Section 10.5.

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Consumables	11.5 M€
Maintenance and refurbishment	22.0 M€
Research and development	11.0 M€
Personnel accelerator and technical infrastructure	19.8 M€
Personnel photon beamlines and experiments	13.8 M€
User support	1.8 M€
Visitor and student programme	1.7 M€
Additional personnel cost (allowances) GmbH	1.0 M€
Global management and support overhead GmbH	1.5 M€
<b>Total yearly operation cost</b>	<b>83.6 M€</b>

**Table 10.3.1** Overview of operations costs (in year 2005 Euros), including allowances and overhead for the GmbH management and support.

### 10.4 Time schedule

At the time of completing this report, the project preparation has advanced to a state which, from the point of view of project planning and technical readiness, allows the construction phase to begin without delay. In order to put the schedule on a realistic absolute time scale, it is assumed that the official start of project construction will be January 2007.

A description of the fully detailed scheduling for all technical components and sub-systems of the facility, including complex inter-relations between them, is beyond the scope of this report. In the following, a simplified overview of how the project will proceed from start of construction to beginning of operation is given. For each of the major parts of the facility, phases during construction (which can partially overlap in time) can be defined as:

- design, prototyping and industrialisation;
- fabrication (including pre-series);
- installation;
- commissioning (technical and with beam).

A schematic view of these phases for each of the six work package groups is shown in Figure 10.4.1. The beginning of operation and its partial overlap with ongoing construction, as discussed in Chapter 8, is also shown.

**Civil construction** is scheduled to start very soon after the project receives the official go-ahead. Based on very advanced planning, the call for the bids procedure on the underground part of construction work can already be completed by the time of the official project start. Excavations of shafts and underground halls will go in parallel on the DESY site and at the user facility (Schenefeld/Osdorfer Born). Installation work on the accelerator tunnel, access shafts and injector building will be ready to start in autumn 2009. Civil construction, including all surface buildings, will be completed after four years.

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For the **linear accelerator/linac**, the ongoing work on industrialisation of its main components will continue until approximately the middle of 2008, by which time first orders on series fabrication can be placed. About one year is foreseen for the companies to set up fabrication. In total, three years are foreseen to manufacture all linac components, including a low-rate start-up of pre-series fabrication. The existing infrastructure at DESY (clean rooms and treatment facilities, test stands, etc.) will be used to help setting up industrial production in an efficient, time-saving fashion. While series fabrication and component testing is ongoing, installation and technical commissioning work in the tunnel will proceed in parallel. The linac is scheduled to be ready for acceleration of a first beam up to the commissioning dump at the end of the linac tunnel in the middle of 2013.

For the **accelerator sub-systems**, the design phase stretches out over a longer period in time. This results from the expected research and development (R&D) work closely linked with the experience to be gained at the Free-electron LASer in Hamburg (FLASH) facility over the next years in certain areas of challenging special beam diagnostics, beam stabilisation and femtosecond-synchronisation systems. Furthermore, installation of the second electron beamline will take place while the first is already commissioned with beam. While, therefore, accelerator sub-system construction extends over a relatively long time, certain parts are scheduled to be completed early. This applies in particular to the injector, which will be installed and commissioned already in 2010-2012, which has the advantage of having a stable beam of good quality available at the time when linac beam commissioning begins.

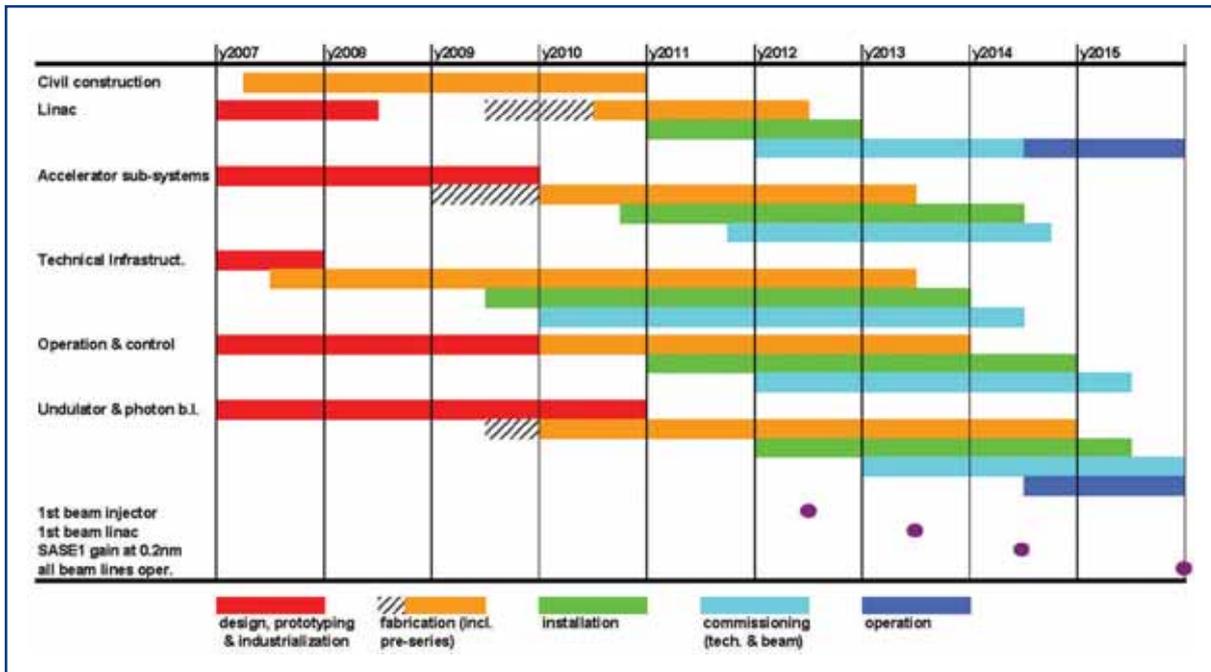
Realisation of the **technical infrastructure** has to start early in the process, since the schedule of other work package groups often depends on having completed certain parts of infrastructure work. For example, the cavity and module test facility has to be completed and operational when the series production of linac components starts. Another example is infrastructure in the tunnel (cables, water pipes, etc.) which has to be installed before the first radio frequency (RF) systems and accelerator modules can be installed.

The schedule for **operation and control** systems naturally reflects that the completion of this part of the facility is required relatively late in the construction phase. A considerable amount of time can be allocated to working out the final design.

**Undulators and photon beamlines** are the parts of the facility which come latest in the commissioning sequence. Consequently, the schedule foresees an appreciable amount of R&D time. The fabrication and installation of the components stretches out over several years, in accord with the plan of building up and commissioning the beamlines in a sequential fashion.

In summary, construction has been scheduled to meet the milestone of first beam through the linac 6.5 years after construction start. At this point in time, the first branch of beamlines with the SASE 1 undulator will also have been installed. As described in Chapter 8, beam commissioning will then progress until the performance milestone of SASE 1 radiation is reached. This beamline will then become operational for first experiments. Commissioning of the other beamlines follows in the sequence described in Chapter 8.

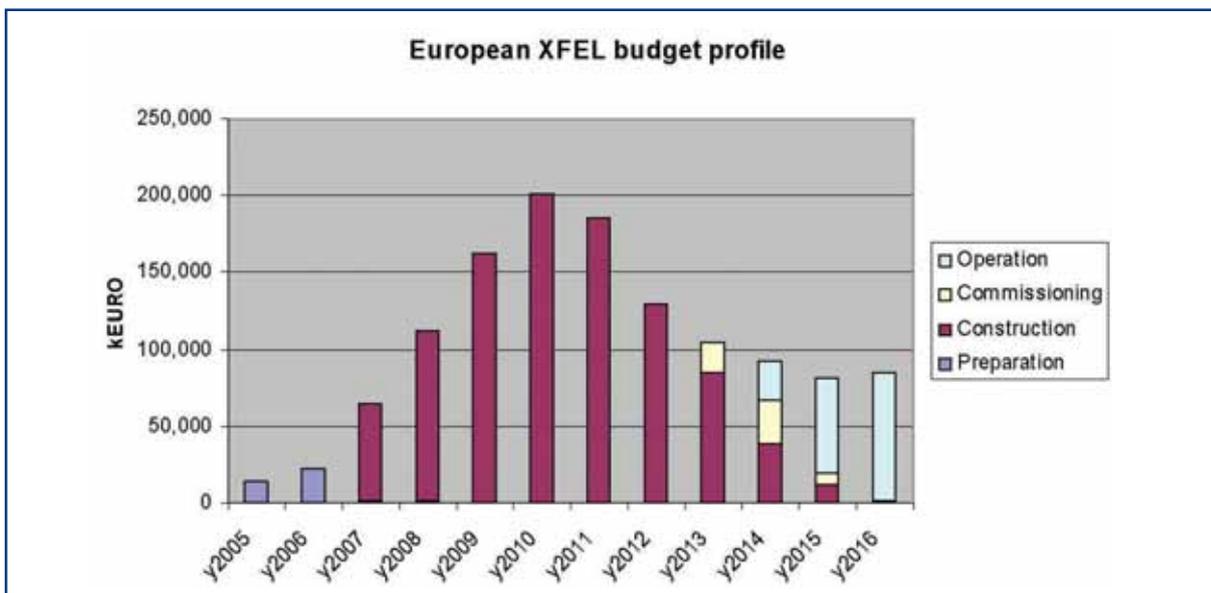
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**Figure 10.4.1** Sketch of the schedule for the six work package groups from start of construction to beginning of operation.

## 10.5 Budget profile

With the different contributions to the TPC as summarised above, the construction time schedule and the operation costs as described in Chapter 8, a complete budget profile for all phases from preparation to operation can be constructed. The result is displayed in Figure 10.5.1 and Table 10.5.1, showing the yearly budget from 2005-2016 on the price basis of 2005 (i.e. without applying an escalation to take into account inflation).



**Figure 10.5.1** Budget profile (sum of capital investment and personnel cost on year 2005 price basis) from preparation to operation phase of the project.

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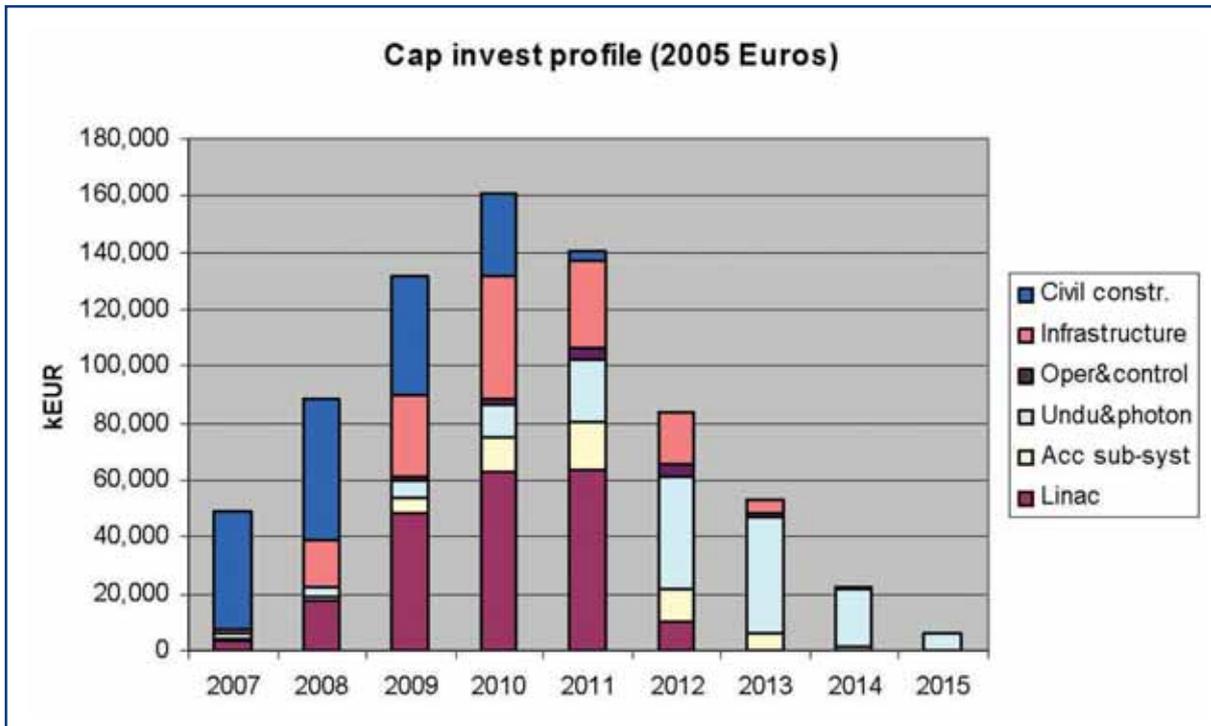
	Preparation	Construction	Commissioning	Operation	Sum	
2005	14.2				14.2	M€
2006	22.5				22.5	M€
2007	1.0	63.6			64.6	M€
2008	1.2	110.9			112.0	M€
2009		161.9			161.9	M€
2010		200.8			200.8	M€
2011		185.3			185.3	M€
2012		128.7			128.7	M€
2013		84.9	20.1		105.0	M€
2014		38.3	28.0	25.4	91.7	M€
2015		12.0	7.1	62.9	82.0	M€
2016			1.2	83.4	84.6	M€

**Table 10.3.1** Yearly budget of the European XFEL through all phases from preparation to operation (in year 2005 Euros), including GmbH personnel allowances and overhead for management and support (16.7 M€ under construction and 1.5 M€ under commissioning).

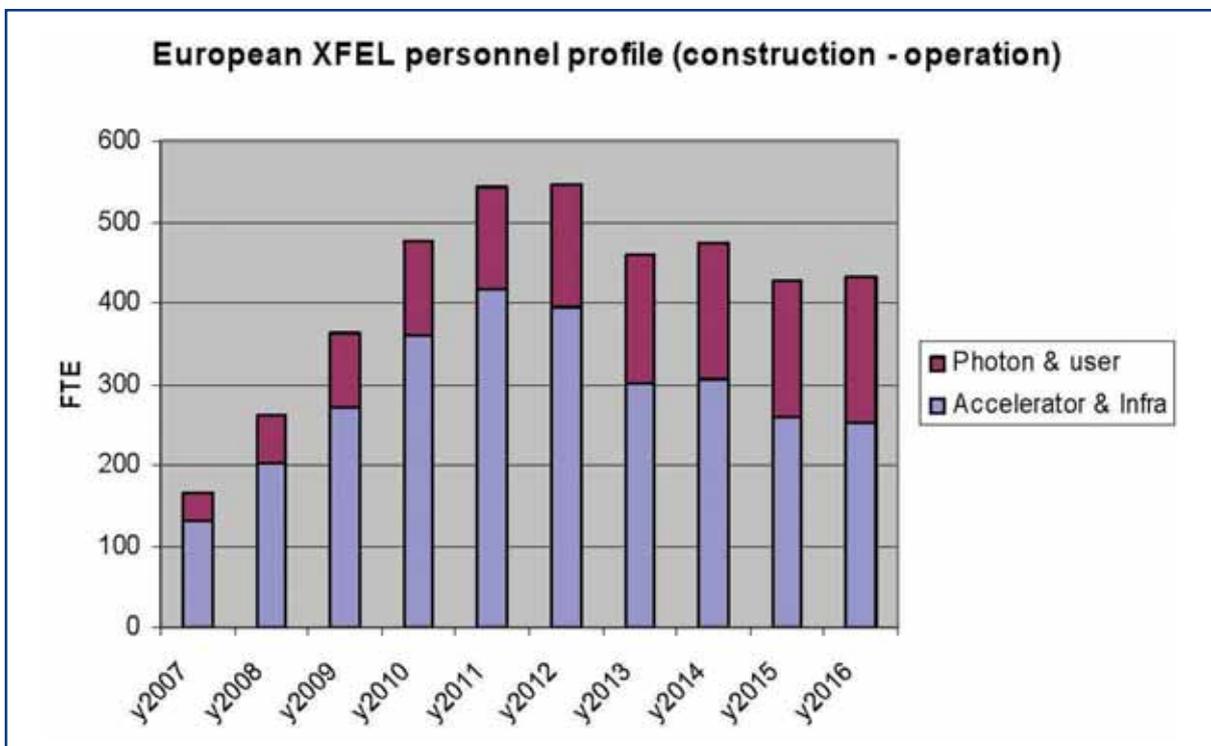
In Figure 10.5.2, the distribution of capital investment (construction phase) over the six work package groups as a function of time is displayed. The differences with which the cost contributions from the six work package groups evolve with time are clearly recognisable.

Figure 10.5.3 shows the evolution of personnel for the accelerator/infrastructure and photon beamline/experiments parts of the project, respectively. While the latter evolves in a rather smooth way into the “steady state” staff required for operation, a “peak” occurs for the accelerator/infrastructure part, which is essentially related to the test facility operation and installation work going on in parallel. Such a situation may be somewhat difficult to handle. One way could be to temporarily detach personnel from collaborating institutes to the project, another one to avoid this “peak” in project staff by involving the industry which is manufacturing the technical components in the testing and installation procedures as well.

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**Figure 10.5.2** Yearly capital investment for the six work package groups during the construction phase.



**Figure 10.5.3** Personnel profile from start of construction to operation phase of the project.

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### References

- [10-1] Final Report of the Sub Group of Full Cost Issues (FCI) in respect of the European Free-Electron Laser Facility XFEL.
- [10-2] Microsoft Excel Add-on @Risk4.5 for Excel (Standard Edition), Palisade Corporation Europe, Middlesex, UK, <http://www.palisade-europe.com>
- [10-3] A. Bovier, A. Schied, *Probabilistic evaluation of cost risks in large scale projects*, report to the XFEL project team, TU Berlin, 15. Nov. 2005.