Chapter 1

Introduction

1.1 The evolving story

ESS, the European Spallation Source, will be a major user facility at which researchers from academia and industry will investigate scientific questions using neutron beams. Neutron methods provide insights about the molecular building blocks of matter not available by other means. They are used for both basic and applied research. European nations are working together in order to build, in southern Scandinavia, this slow neutron source of unparallelled power and scientific performance. ESS will deliver its first protons to a solid, rotating tungsten target in 2019, which will in turn generate neutrons for delivery to an initial suite of seven neutron scattering research instruments. ESS will reach its full design specifications in 2025, with a suite of 22 research instruments.

The road to achieve such a European high-power spallation source has been long and winding, with many twists and turns, but always with a determination to succeed. The production of this *Technical Design Report* is a concrete demonstration that this project, long in gestation, is now reaching a state of maturity signalling its readiness to move forward with construction activities.

Let us look briefly at the history of the project. Neutron scattering, as a tool for the investigation of materials in all their diversity and complexity, was pioneered in the north American sub-continent in the 1950s. The neutron itself had been discovered in 1932 in Cambridge by James Chadwick. The first moderately intense sources of neutron beams, as shown in Table 1.1, were extracted from the early research reactors that were first constructed in a number of national laboratories in the USA as well as in Canada. It was on these research installations that the early instrumental techniques using neutrons were developed in order to begin to unravel the atomic structures of relatively simple materials and, uniquely, the atomic dynamics of these same materials. For this work Cliff Shull and Bert Brockhouse were awarded the Nobel prize in physics in 1994, too many years after their pioneering work had been done, but at a time when the power of neutron beams to investigate the very wide spectrum of materials upon which much of our daily lives depend had been well and truly demonstrated.

As with all new technologies, there was a rapid rise in capabilities over the following two decades that culminated, in the late 1960s, in the construction in Grenoble in south-eastern France of a purpose-built high flux reactor source of slow neutrons that was rapidly to become the focus of world attention and scientific endeavour in this discipline. Building upon the global effort in instrumentation, the *Institut Laue-Langevin*, as it was named, became the flagship of neutron research and an exemplary demonstration of how two European countries could work together for the good of mankind. ILL secured a scientific lead that, even 40 years later, it has retained and in many ways, consolidated.

In parallel, and with a somewhat different purpose, accelerator-driven sources of neutrons were also being developed. These facilities were excellent generators of fast neutrons that were used to great effect to compile a nuclear cross section database of all the elements and their isotopes in order to support the nuclear power industry. These sources were pulsed in nature with a very high peak brightness. It was realised rather early on that such accelerator-driven sources held out significant opportunities for neutron beam experimentation on materials, provided that some of the disadvantages could be overcome. The early sources of this genre were based on electron linear accelerators that had significant background problems caused by the very intense gamma radiation bursts which were generated. Nevertheless, opportunities for neutron scattering investigations were demonstrated with these early machines, which were built around

Facility	Location	Status	First operation	Power [MW]	Instruments	Flux	
						Average	Peak
						$[10^{15}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	
ESS	Lund	Pre-construction	2019	5.0	22	1.60	40
J-PARC	Tokai	Operating	2009	.3	20	.10	20
ISIS-TS2	Oxford	Operating	2009	.03	7	.01	6
SNS	Oak Ridge	Operating	2006	1.0	14	.10	8
LANSCE	Los Alamos	Operating	1988	.1	13	.01	3
ISIS-TS1	Oxford	Operating	1984	.13	20	.01	2
SINQ	Villigen	Operating	1996	1.0	15	.15	–
IBR-II	Dubna	Upgrading	1977	2.0	12	.01	5
PIK	St. Petersburg	Construction	2014-15	100	10	1.20	–
CRR-II	Beijing	Operating	2010	60	6	.80	–
ARR-III	Sydney	Operating	2006	20	12	.20	–
FRM-II	Munich	Operating	2004	20	24+6	.80	–
JRR-III	Tokai	Operating	1990	20	34	.27	–
RSG	Serpong	Operating	1987	30	10	.25	–
Dhruva	Mumbai	Operating	1985	100	15	.18	–
BER-II	Berlin	Operating	1984	10	16+3	.12	–
LLB	Saclay	Operating	1980	14	22+3	.30	–
ILL	Grenoble	Operating	1971	58	27+10	1.30	–
NIST	Washington	Operating	1967	20	30	.40	–
HFIR	Oak Ridge	Operating	1965	85	11	1.50	–
LVR	Řež	Operating	1957	10	10	.15	–

Table 1.1: The European Spallation Source facility in comparison to other high-level neutron sources that are operating, or are close to operation.

the world. These machines produced their beams of neutrons as sharp pulses, unlike the research reactors that produced continuous beams. Each type of source has its own unique characteristics that can be harnessed for the study of materials. The complementarity evident then still exists today.

At about this time – the late 1970s and early 1980s – the use of proton-driven neutron sources, generated by cyclotrons, synchrotrons, or linear accelerators, was beginning to be explored. Proton sources do not suffer from the gamma background problems that affect electron sources, overcoming the fundamental disadvantages of the earlier machines. Pioneering work at Argonne National Laboratory and Los Alamos National Laboratory in the USA and in Tsukuba in Japan indicated that pulsed proton sources held out a significant technological advantage over the most intense research reactors. This was because the spallation reaction employed in proton machines generates significantly less heat per useful neutron than does a fission reactor. In addition, the generation of neutrons in pulses provides peak brightnesses that far exceed those available from reactors.

The enthusiasm for such proton machines led to ambitious conceptual designs for neutron sources that went well beyond the technological capabilities of the time. Far-sighted projects such as the Intense Neutron Generator (ING) in Canada, the *Spallations Neutronen Quelle* (SNQ) project in Germany and the pulsed reactor SORA (*Sorgente Rapida*) of the European Community were planned. None of these were ever built, but they provided the seeds from which the European Spallation Source has grown. In the late 1970s, construction began on the world's first proton spallation source that was powerful enough to challenge the supremacy of ILL. It was a pioneering endeavour that had many doubters but which succeeded, over a difficult decade, in achieving its design specification and overturning the accepted wisdom. This source, built close to Oxford in the UK, was called ISIS. Despite having a design power of only 180 kW, it demonstrated that world-class science could be carried out very effectively on such sources. ISIS was the birthplace of many new instrument concepts, some of which had been prototyped on other neutron sources. ISIS also provided a degree of support to the user community that surpassed the contemporary accepted relationship between the central facility and its user community.

The next chapter in this story sees the OECD Megascience Forum producing a study of the future evolution and needs for neutron beams in a global context. This study took place in the early 1990s. It resulted in a report to the research ministers of the OECD countries in 1998 that recommended that a megawatt-class spallation neutron source be built in each of the three developed regions of the world, a recommendation that the OECD Ministers endorsed [4–6].

Europe in the late 1990s was therefore in an enviable position in this scientific field. It not only had the world's leading reactor and accelerator-based neutron sources, but it also was blessed with a network of medium and low intensity neutron sources that were breeding grounds for innovative instrumentation built by excellent young scientists, which proved to be the origin of new scientific ideas. Accordingly, the community of researchers in Europe who used neutrons for a significant part of their scientific research programme, grew rather spectacularly in number and in scientific diversity. The figure today, according to a survey made by the European Neutron Scattering Association, sits at around 6000 individuals [7, 8]. It was therefore a completely logical step that many of these scientists started to lay down plans for the European facility that had been foreshadowed in the OECD recommendation. An international task force was assembled, originating from around 20 countries, which began the task of defining the scientific case for such a facility and designing a neutron source that would be capable of delivering this scientific goal. This resulted in a 2002 design study for ESS that comprised a 10 MW spallation source with two targets and that was furnished with more than 40 neutron instruments [9–11]. It was to be powered, not by a proton accelerator, but rather by an H-minus accelerator, the beams from which could be injected into a compressor ring and compressed in time to less than 1 μs in duration. By this time, the United States and Japan had both begun the construction of megawatt capacity spallation neutron sources, SNS and J-PARC, both of which are operational today.

Europe however, furnished with its rich network of neutron sources, collectively allowed itself a more relaxed procedure which has, in the long-run, been beneficial, even though at that time this slowness in decision-making was not universally appreciated. This ongoing deliberation resulted in a comprehensive set of documents being produced that laid down the scientific case for ESS together with extensive technical documentation and costings [9–13]. These studies were presented to a plenary meeting of ESS stakeholders in May 2002 in Bonn attended by more than 700 scientists and science policy-makers. Although this meeting was a very positive endorsement of the use of neutrons for materials science and was excellently organised, in retrospect it proved to be the beginning of a reshaping of the whole project that created an opportunity for sites other than those in Germany and Britain to consider bidding for the location of ESS. In 2003, a new concept was put forward for ESS that involved descoping the whole facility and a fundamental change of technical orientation. The new design comprised a 5 MW proton linear accelerator delivering a 2 to 3 millisecond-long pulse to a single target station surrounded by a suite of 20 to 25 neutron instruments. The H-minus beam, the compressor ring, the second target station and the constrained moderator configuration were all abandoned. This initiative held out the promise of neutron intensities that were a factor of six more intense, per megawatt of proton beam power, than contemporary existing or planned facilities.

It is this concept from 2003, which was endorsed by the user community in Europe and which is now nearing the end of its pre-construction period, that will deliver first neutrons in 2019. During this pre-construction period, ESS has completed an update of its design, and a totally revised cost estimate and time-schedule. It is poised to begin with construction, with ground breaking scheduled to commence in 2014. In the intervening years from 2003 to 2009, a number of significant steps were taken. Following the Bonn meeting, the British and German sites were withdrawn as site candidates. At the same time, three new sites emerged as contenders for the location of ESS. These were Debrecen in eastern Hungary, Bilbao in northern Spain, and Lund in southern Sweden. The three site contenders worked both competitively and collaboratively in an intense and determined process which led, via the European Strategy Forum for Research Infrastructures (ESFRI) and ultimately overseen by the Czech Republic's Ministry of Research during its period of Presidency of the European Union, to the selection of Lund in Scandinavia as the preferred site. This choice followed a site review process during the summer of 2008 that resulted in a report presented to the major ESS stakeholders in September of that year. In Brussels on the evening of May 28, 2009 a decision on the site was made. It was a milestone.

Thereafter, following further negotiations, Spain and then Hungary endorsed the choice of Lund. The team in Lund had, since the year 2000, been administered within Lund University as a special entity and funded by Scandinavian organisations. With the site decision, a new governance of the growing organisation, with its important tasks to fulfil, was put in place. ESS Aktiebolag (ESS AB) was established. Two lines of governance were created: A Steering Committee with representatives from the scientific institutes and Research Ministries of the various partner countries, and a legal Board representing the formal owners of the project which were, for administrative and legal purposes, Sweden and Denmark who were co-hosts and therefore co-owners of the emerging facility. At the time of writing – April 2013 – ESS AB is a shareholding company under Swedish law with Sweden holding approximately 75% of the shares and Denmark holding the remaining 25%. The Steering Committee includes representatives from 17 partner countries: Sweden, Denmark, Norway, Latvia, Lithuania, Estonia, Iceland, Poland, Germany, France, the United Kingdom, the Netherlands, Hungary, the Czech Republic, Switzerland, Spain, and Italy. Various advisory committees actively provide counsel to the ESS organisation and the governing bodies. The 17-partner international collaboration was secured by the signing of a memorandum of understanding (MOU) in Paris at the Swedish Embassy on 3 February, 2011. This MOU was a non-binding agreement that contained three guiding principles. These were an acceptance of Lund as the site for ESS, an agreement to engage in and to proceed with the update of the design, and an agreement to make best efforts to continue on to the construction phase in a timely manner.

This present *Technical Design Report* represents the technical and scientific work carried out during the almost 24 months between the signing of the MOU and its second anniversary. It was preceded by a *Conceptual Design Report* that was delivered prior to the first anniversary of the signing of the MOU. The current work programme, just concluding, contains three separate streams: The design update and revised costing activities; the start of the preparation for construction, which includes the prototyping of key equipment in order to minimise future risk; and the necessary work for integration and acceptance by all stakeholders.

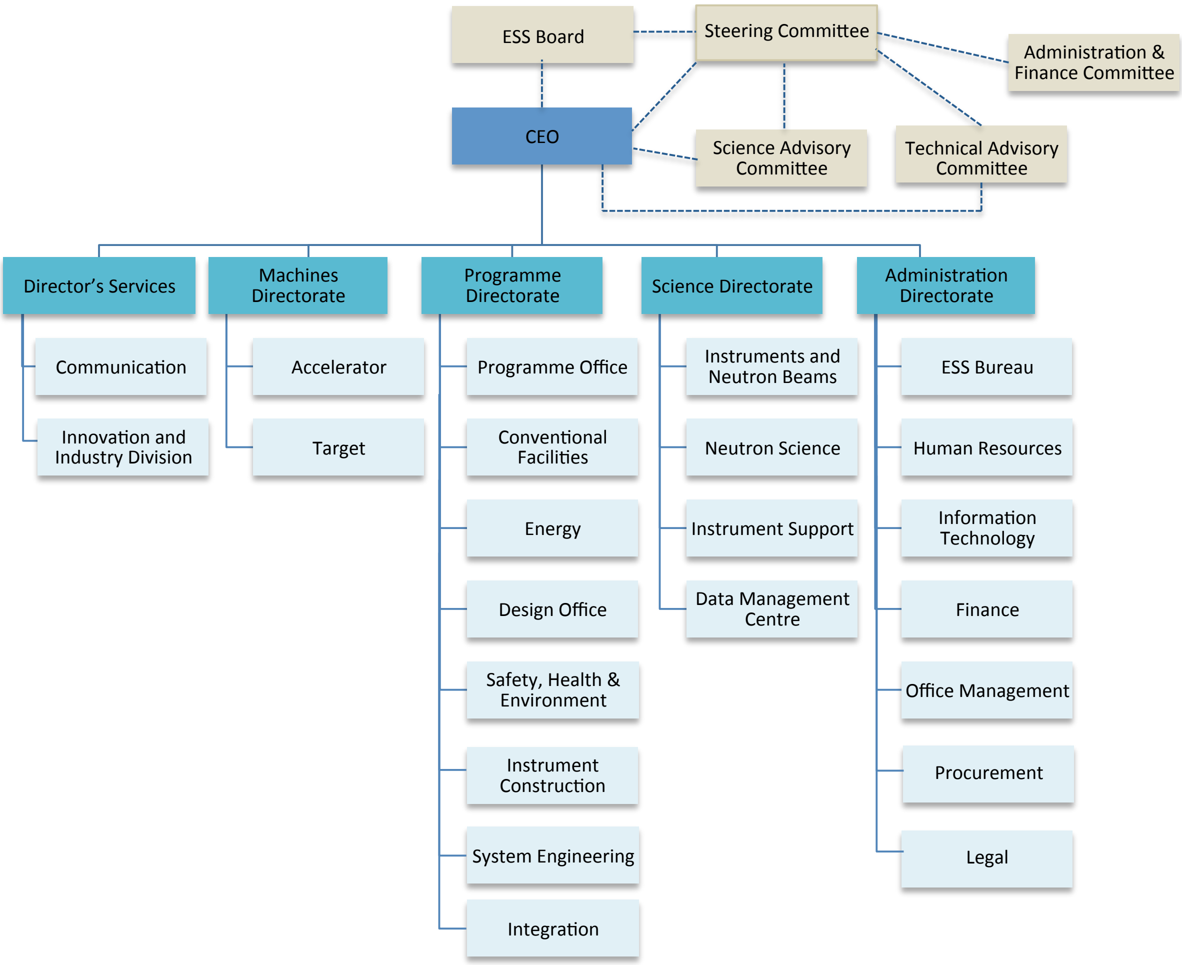

Figure 1.1: ESS high level organigramme.

1.2 The ESS programme

With 17 European partners committed to construct ESS, it is inevitable that a significant source of revenue will be components manufactured and supplied as in-kind contributions. For planning purposes, the ESS organisation has worked under the expectation that 75% of the capital cost will be covered by cash contributions and that 25% will be in-kind. Currently, representatives appointed by the Swedish and Danish governments are engaged in bilateral discussions with the other partners in order to determine the potential of each country to engage in the construction process starting in 2013. The significant fraction of in-kind contributions brings with it particular challenges. Management of in-kind contributions is the key issue in delivering the ESS on time, to budget and fully operational. The technical risks of managing interfaces need special attention. Additional resources will be required to do this effectively, and 100 M€ is not an unrealistic sum for this purpose.

The governance of ESS is illustrated diagrammatically in Figure 1.1. Legally and administratively, ESS reports to a governing Board populated by Swedish and Danish members reflecting the 3:1 shareholding of the two countries and their status as co-hosts. A Steering Committee (STC), which gathers together delegates from the 17 partner countries, functions in parallel to the ESS AB Board. The STC is a more traditional governing body, being populated by scientists with experience of large scientific infrastructures together with ministerial or research council personnel who are close to the funding authorities from their individual countries. The STC is aided in its job by an Administrative and Finance Committee, which is formally a sub-committee of the STC, populated by national delegates. Two further advisory committees exist that are directly related to the ESS organisation itself and are the source of independent advice. These are the Scientific and Technical Advisory Committees. They are populated by international scientific and technical experts and are nominated by the ESS organisation itself. They do not map onto the 17 ESS partner countries.

The ESS organisation itself is undergoing rapid growth. This requires careful guidance and management. Currently ESS is composed of 200 people organised into five directorates. The five directorates are: Director General's Services, Machine, Science, Administration and Programme Office. The organisation operates on a customer-supplier basis managed by the ESS Management Team (EMT), which the Director General chairs. The architecture of authority and responsibility is not organised in a vertical hierarchical structure but rather is built on a strong team with distributed authority and responsibility. The organisation is significantly flatter than equivalent organisations set up in the second half of the twentieth century, with which ESS is often compared.

Table 1.2 records ESS's high level parameters, and its guiding scientific goals. The starting point for the generation of these parameters was the 2008 ESFRI Roadmap specification. The parameters shown were updated and approved on April 18, 2011 by the ESS Steering Committee. ESS will offer unparallelled cold neutron beam brightness, delivering a peak flux 30 times higher than the world's brightest neutron source, and 5 times more power than any spallation source. ESS's pre-construction period, which was

Parameter	**Unit**	**Value**
Average beam power	MW	5
Number of target stations		1
Number of instruments in construction budget		22
Number of beam ports		48
Number of moderators		2
Separation of ports	degrees	5
Proton kinetic energy	GeV	2.5
Average macro-pulse current	mA	50
Macro-pulse length	ms	2.86
Pulse repetition rate	Hz	14
Maximum accelerating cavity surface field	MV/m	40
Annual operating period	h	5000
Reliability	%	95

Table 1.2: High level parameters, approved by the ESS Steering Committee on April 18, 2011.

launched in 2009, is now over, following the timeline shown in Figure 1.2. The programme contains within it three additional life-cycle phases:

1. Construction.
2. Operations.
3. Decommissioning.

As shown in Figure 1.2, construction activities will take place over a period of 12 years. They will partly overlap with operations activities, which will last for 45 years, beginning in 2017.

This *Technical Design Report* is the fruit of design activities that took place during the pre-construction period. The task of the design phase is to complete an exercise in conception, design, computation and, critically, project organisation. The goal is to deliver a design for the whole facility, rather than a ready-for-procurement design. Detailed design will be an ongoing activity using resources as and when necessary to ensure on-time procurement, manufacture and delivery. A central part of this process will be an updated time plan and an updated costing report indexed to 2013 values. In the meantime, ESS works with its current time plan, which calls for first protons to the target and first neutrons to the day-one suite of seven instruments in 2019, with full specification achieved in 2025. At that point, the accelerator will be operating at 5 MW proton power, 22 neutron scattering instruments will be taking data, and a healthy but still growing neutron user community will be generating top-class science. Opportunities for future upgrades will be evaluated as appropriate, and pursued subject to authorisation by ESS's governing bodies.

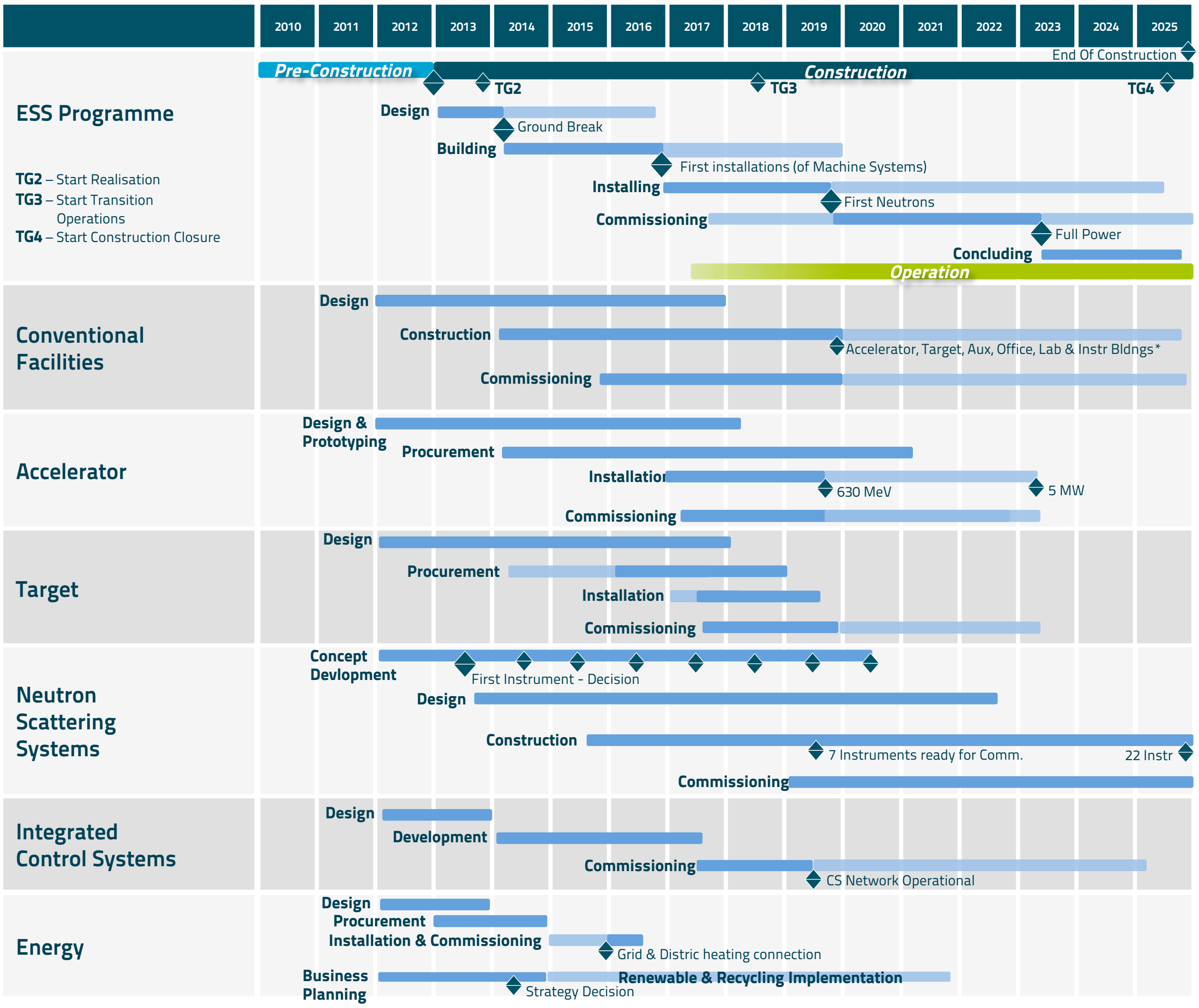

Figure 1.2: An overview of the schedule for key activities during the Construction Phase.

While the major thrust of the *Technical Design Report* is to describe the design of the major components of the operating facility, the report also encompasses planning for the factory and site acceptance testing of key components, such as RF cavities and cryomodules, and for the installation and commissioning of accelerator, target and instruments that will occur as the programme makes the transition to operations (see Chapter 9). In addition, the report describes the general approach that ESS will take towards decommissioning, in particular, the decision to return the site to greenfield status and to do so through a strategy of immediate dismantlement that will make it possible to take advantage of the accumulated experience of the facility's operating staff (see Chapter 10). This approach is outlined in the preliminary decommissioning plan that ESS has prepared as part of the Swedish licensing process for the facility.

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