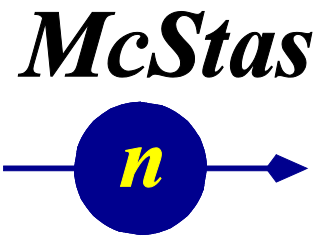




Technical University of Denmark



CAMEA

Costing report

Author:

N. B. Christensen



PAUL SCHERRER INSTITUT



ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

CAMEA costing report

Executive summary: *The cost of the CAMEA spectrometer, involving guides and shielding, the spectrometer itself, key pieces of sample environment equipment needed to fulfill the science goals of CAMEA, and the manpower needed for construction, is estimated at 19.920 M€.*

Since we've attempted to make conservative estimates, this numbers should be seen as an upper limit. Out of the total construction cost, 33% is the cost of guides, shielding and shutters, 40% is the cost of the CAMEA-specific parts, i.e. choppers, analyzer tank, graphite analyzer crystals, ³He detectors, radial collimator, facilities for polarization analysis, Beryllium filter etc. 19% of the total cost corresponds to the estimate prices of the magnets and pressure cells foreseen for CAMEA but useable on other ESS instruments as well. Salaries corresponding to 21 man years are estimated to account for 7% of the total cost.

This document details the elements considered in the costing of the proposed CAMEA spectrometer for ESS, and is subdivided as follows

1. Guides and shielding
 - a. Guides
 - b. Mechanics and installation
 - c. Guide shielding
 - d. Instrument cave and beam stop
 - e. Shutters
 - f. Vacuum pumps for guides
2. CAMEA spectrometer
 - a. Choppers
 - b. Divergence jaws
 - c. Sample table
 - d. Vacuum tank
 - e. Vacuum pumps
 - f. PG analyzer crystals mounted on Si-wafers
 - g. Cooling machines for analyzers
 - h. Detectors
 - i. Be filter
 - j. Radial collimator
 - k. Electronics
 - l. Polarization analysis
3. Sample environment for CAMEA

- a. Magnets
- b. Pressure cells
4. Manpower
5. Summary of construction costs
6. Conclusion

The choice of subdivision is made to emphasize that a significant fraction of the full cost of CAMEA comes from the price of guides and various pieces of shielding. The total price of these will, to a significant extent, be similar for all long instruments at ESS.

We have attempted to give conservative estimates of all components, i.e. estimates that may turn out to be too high. For example, the cost of shielding of guides is highly uncertain and believed to be in the range of 1-2 times the price of the guides themselves. In this case, we have chosen to use the ratio 2. When available, information about the estimated uncertainties is included in individual subsections.

In each sub-section we indicate the sources of information lying behind the estimated cost of a given component. When possible we have used price estimates given by ESS staff members.

We have benefitted significantly from exchange of information with Felix Groitl, EPFL Lausanne, who has collected price estimates for the version of the CAMEA concept which will be built for the RITA-II spectrometer at PSI (PSI-CAMEA). In addition we are thankful to Pascal Manuel (ISIS), Christian Mammen (JJ X-ray), Peter Böni (Swiss Neutronics and TUM), Thomas Krist (Neutron Optics Berlin and HZB), Rasmus Toft-Petersen (HZB), Oleksandr Prokhnenko (HZB) and Uwe Filges (PSI) for information on the cost of various components.

For easy overview, all cost estimates are collected in a table in section 5. This table is reproduced in the costing section of the main proposal.

1. Guides and shielding

In this section, we estimate the cost of the CAMEA guide solution, the price of the guide shielding, and the price of additional shielding of the instrument beyond what is included in section 2d on the CAMEA vacuum tank. Also included is the cost of beam shutters and the pumps for the guides.

a. Guides

For the estimate of the price of the guide solution for CAMEA, we have used a price estimate provided by Swiss Neutronics [1].

The CAMEA guide solution is described in detail in the CAMEA guide report [2]. It can be divided into segments (each based on shorter tapered guide pieces) as indicated in Table 1 below.

Swiss Neutronics estimates the total price of this guide (Ni/Ti on float glass or borofloat glass) as follows:

Cost of guides **1.310 M€**

CAMEA guide				
Segment number	Segment length [m]	Distance from moderator face to the end of the segment [m]	m-value	Shape/Size
No guide				
1	2.16	2.16	No guide	No guide
Parabolic feeder				
2	1.74	3.90	3	Piecewise Straight
3	1.74	5.63	3.5	Piecewise Straight
4	0.87	6.50	3	Piecewise Straight
Chopper space. No guide				
5	0.10	6.60	No guide	No guide
Ellipse 1				
6	6.52	13.12	3.5	Piecewise Straight
7	6.52	19.64	2	Piecewise Straight
8	39.12	58.76	1.5	Piecewise Straight
9	6.52	65.28	2	Piecewise Straight
10	6.52	71.80	3	Piecewise Straight
Straight section (kink)				
11	13.94	85.74	2	Piecewise Straight
Ellipse 2				
12	15.73	101.47	2	Piecewise Straight
13	47.20	148.67	1	Piecewise Straight
14	7.87	156.53	2	Piecewise Straight
15	7.87	164.40	3.5	Piecewise Straight
Total length				

Table 1: CAMEA guide solution as described in the CAMEA Guide report [2]. The guide solution is based exclusively on straight tapered guide pieces forming the longer segments indicated. It consists of a parabolic feeder section (2.16-6.5 meters from the moderator face), and two elliptical sections (6.60 to 71.80 meters and 85.74 to 164.40 meters from the moderator face, respectively) with a straight kink section in between them (71.80 to 85.74 meters from the moderator face). Space has explicitly been allowed for the pulse shaping choppers at 6.5 meters from the moderator face, while choppers further downstream will not take up much space and have been excluded in the price estimate.

b. Mechanics and installation

Swiss Neutronics [1] estimates the following cost of the mechanical support pieces needed for the CAMEA guide (Special housing for the feeder section; Massive steel casing's for the two elliptical sections and for the kink section. I-beams and posts are included), and for installation by Swiss Neutronics using a laser tracker.

- Mechanics (housing, posts, I-beams) 1.209 M€
- Installation using laser tracker 0.086 M€

Cost of mechanics and installation 1.295 M€

c. Guide Shielding

For guide shielding we make the assumption that everything outside of the common bunker which ends at a distance of 30 meters from the moderator face is paid for by the CAMEA budget. Phil Bentley (ESS) estimates the ratio of the price of guides to shielding as being between 1:1 and 1:2. To be conservative we have chosen to use the ratio 1:2 for everything outside the first 30 meters.

With these assumptions and taking a constant price per meter of the CAMEA guide, our estimate for the price of guide shielding is $2 * (1 - 30 / 164.4) * 1.310 \text{ M€} = 2.142 \text{ M€}$

Cost of guide shielding 2.142 M€

d. Instrument cave and beam stop

According to Phil Bentley (ESS) all instruments are foreseen to sit in their own caves/hutches in order to shield neighboring instruments from each other. Combined with the cost of a beam stop, this additional shielding is estimated conservatively at 1 M€. The estimate is based on the experience from ISIS TS2 where the price was 700 kGBP.

Cost of instrument cave and beam stop 1.000 M€

e. Shutters

All instruments will have three shutters. It is at present not clear if one of these will have to be a heavy shutter. Phil Bentley (ESS) estimates the price of a heavy shutter as 0.75 M€, whereas a light shutter costs around 20 k€. Under the conservative assumption that CAMEA needs a heavy shutter, we estimate

the total price of shutters for CAMEA as 0.79 M€. With three light shutters, the price would be significantly less, 60 k€.

Cost of shutters 0.790 M€

f. Vacuum pumps for guides

At the Paul Scherrer institute (PSI), a combination of backing and turbo pumps are used to pump the guides. We assume that this will also be the case for CAMEA. A combination of backing and turbo pumps comes to 10 k€. Adding a 4 k€ control unit, and assuming that one needs one such combination of pumps for every ~40 meters of guide, we arrive at an estimate of $4 \cdot 14 \text{ k€} = 56 \text{ k€}$ for the price of guide pumps for the 165 m CAMEA guide.

Cost of vacuum pumps for the guides 0.056 M€

2. CAMEA spectrometer

In this section, we estimate the cost of the CAMEA spectrometer, excepting the parts directly related to guides and shielding, which were treated in the previous section. We also do not including sample environment, which will be treated in section 3.

a. Choppers

The CAMEA chopper solution is described in the Simulations and Kinematic Calculations report [3] and is reproduced in Table 2 below.

Iain Sutton (ESS) estimates the total cost of the above choppers at 1.425 M€ with an estimated uncertainty of $\pm 20\%$. This includes vacuum systems, cooling, control and integration into the instrument, but does not include installation. We note that Mirrortron [4] provided us with a quote of the above chopper solution of 1.050 M€. This does not include various support systems and integration.

Cost of chopper system 1.425 M€

Chopper section	Description
1	<p>Two pulse shaping choppers</p> <p>Rotation speeds: 14 to 210 Hz Angular openings: 170 degrees Distance: 6.5 m from the moderator. Radius: 35 cm</p>
2	<p>First frame overlap chopper</p> <p>Rotation speed: 14 Hz Angular opening: 20 degrees Distance: 8 m from the moderator. Radius: 35 cm</p>
3	<p>Second frame overlap chopper</p> <p>Rotation speed: 14 Hz Angular opening: 25 degrees Distance: 13 m from the moderator. Radius: 35 cm</p>
4	<p>Tail removal chopper</p> <p>Rotation speed: 14 Hz Angular opening: 157.6 degrees Distance: 78 m from the moderator. Radius: 35 cm</p>
5	<p>Two order sorting choppers</p> <p>Rotation speed: 180 Hz Angular opening: 2 times 80 degrees Distance: 162 m from the moderator. Radius: 35 cm</p>

Table 2: The CAMEA chopper solution as described in detail in Ref. [3].

b. Divergence jaws

We envisage the use of WISH-type jaws [5] to control the beam divergence for CAMEA. According to Pascal Manuel at ISIS, 5 sets of jaws and motor control cost 87500 GBP when they were purchased for WISH a few years ago. Assuming, conservatively, that cost has gone up by 20%, this amounts to 123 k€ on CAMEA.

Cost of divergence jaws	0.123 M€
-------------------------	----------

c. Sample table

A Huber sample table for CAMEA was estimated by the CAMEA team at 34 k€. This is somewhat higher than the 20 k€ paid for the EXED sample table at HZB (information from Oleksandr Prokhnenko, HZB) a

few years ago, and is therefore a conservative estimate. The EXED sample table is capable of supporting 1000 kilos and has 3 translational and 3 rotational degrees of freedom.

Cost of sample table 0.034 M€

d. Vacuum tank

For the vacuum tank hosting the analyzers and detectors, the CAMEA team has estimated a total cost of 0.908 M€. This includes the tank itself, shielding of the tank (Cast B₄C shielding on the outside; Cadmium shielding on the inside), holders and Cadmium shielding for detectors (See below for separate costing of detectors), mechanical holders for the analyzers (Pyrolytic graphite mounted on Si wafers. These are treated separately below), a beam stop inside the tank and Aluminum vanes, covered with Cadmium, designed to prevent cross-talk between different analyzer-detector pairs [6]. Finally, the costing of the vacuum tank includes the mechanics needed to rotate all analyzers around the sample positions.

For cooling of the analyzers, we have used cost estimates from the parallel PSI-CAMEA project for which cooling is being considered. For PSI-CAMEA this is achieved through cooled plates to which the analyzers are thermally anchored. The plates are thermally isolated from the tank (zirconium oxide isolation). Cooling is achieved by pulse tube cooling machines (see below for separate costing). Scaling the solution found by the PSI-CAMEA team, we estimate the cost of this arrangement to be 150 k€ at the ESS version of CAMEA.

Adding the cost of the vacuum tank and the cost of the solution for cooling the analyzers, we arrive at a total price for the analyzer tank (excluding detectors, Si wafers, graphite crystals and pulse tube cooling machines) of 1.058 M€.

Cost of vacuum tank 1.058 M€

e. Vacuum pumps

For the parallel project, PSI-CAMEA, PSI technicians have estimated that a single pump costing 25 k€ is needed for evacuating the vacuum tank. We assume the same price for the ESS version of CAMEA.

Cost of vacuum pump 0.025 M€

f. PG analyzer crystals mounted on Si-wafers

The price estimate of Si-wafers on which to mount the pyrolytic graphite analyzer crystals was collected by the CAMEA team. For 2m² of pyrolytic graphite, the price estimate is 362 k€.

The price of the PG analyzers themselves is estimated from the cost of the graphite purchased for the CAMEA prototype. A single 75 mm x 10 mm x 1 mm pyrolytic graphite piece of 60° mosaicity was priced by Panasonic at 55600 JPY in 2012. Scaling to 2 m² we arrive at 1.104 M€.

Note that we have not made allowance for a reduction in the total price of the graphite upon ordering a very large amount of graphite. Such a reduction should be negotiable and should bring the cost of graphite below 1 M€.

Cost of PG analyzers and Si-wafers 1.466 M€

g. Cooling machines for analyzers

The PSI-CAMEA project is considering 3 low-vibration pulse tube cooling machines to cool the analyzer crystals of the PSI-CAMEA analyzer box which covers 50 degrees in scattering angle. Scaling to the angular coverage of the ESS version of CAMEA, we conservatively estimate that 8 pulse tube cooling machines are needed. One such pulse-tube costs 44 k\$ according to quotes collected by Felix Groitl (EPFL and PSI-CAMEA). Hence we estimate that the cost of pulse tube cooling machines for CAMEA will be 255 k€.

Cost of cooling machines for analyzers 0.255 M€

h. Detectors

The price of detectors was estimated by the CAMEA team based on information from Richard Hall-Wilton (ESS). The estimate combines hardware, vacuum seals and the ³He gas.

Hardware 353.500 €

Vacuum Seals 293.000 €

³He gas (24.7 liters, 7 bar) 250.500 €

Cost of detectors 0.897 M€

i. Be filter

For the Beryllium filter, we use numbers collected for the PSI-CAMEA project for their 50 degree Be filter. We imagine that CAMEA with its 130 degree angular coverage will use a similar filter (Length 10 cm; height 5 cm) and simply scale the cost estimate from PSI for the construction of the housing of the

filter and various pieces of shielding. By this procedure we reach a price for the housing and shielding of 126 k€.

For the Beryllium itself, we assume that CAMEA will use 260 half-degree Be blocks (Materion), each costing 368 € according to quotes collected by Felix Groitl (EPFL and PSI-CAMEA). In total, the purchase of Beryllium amounts to 96 k€, which has to be added to the cost of the housing and shielding of the filter.

Cost of Beryllium filter, housing and shielding 0.222 M€

j. Radial collimator

We're using information received from JJ X-ray [7]. In the case of CAMEA, JJ X-ray estimates the price of a 130 degree, vacuum compatible, radial collimator (vertical coverage 3 degrees; 1.5 degree separation between Gd covered foils) at 50 k€.

Cost of radial collimator 0.050 M€

k. Electronics

Using numbers received from Thomas Gahl, ESS, we estimates a total cost of 402 k€ for electronics for CAMEA. This includes motion control, wiring cabinets and basic power distribution, electronics for the personal safety and shutter systems, PLC control and control boxes for connection to the EPICS control layer. Finally, it also includes an estimated cost of design, installation and commissioning.

Cost of electronics 0.402 M€

l. Polarization analysis

CAMEA will be designed from the outset to have polarization analysis.

Incident beam polarization: Thomas Krist (HZB and Neutron Optics Berlin [8]), estimates the cost of a polarizer-bender at 4.5 k€ per square centimeter. At a distance of around 6.6 meters from the CAMEA sample position, the guide is approximately 8.2 times 10.8 centimeters. Assuming that 10% of the length along each axis is occupied by the mechanical support of the bender, we arrive at a price of 323 k€.

For comparison, Rasmus Toft-Petersen (HZB) informs us that the S-bender setup, including guide translation stage, recently purchased for FLEXX, cost 380 k€. Since the two estimates are very close and

the former does not include translation stage, we estimate that the correct price for CAMEA will be around 400 k€.

Polarization analysis of the scattered beam: The Paul Scherrer Institute has designed and built a polarization supermirror analyzer for the HYSPEC spectrometer at SNS. Scaling the price of this device to scattering angle coverage of CAMEA, we estimate a price of 1.7 M€.

Cost of polarization for CAMEA **2.100 M€**

3. Sample environment for CAMEA

In this section, we estimate the cost of the essential pieces of sample environment required to fulfill some of the main science goals of CAMEA. Note that all pieces of sample environment equipment listed will also be available to other ESS instruments, if they can be accommodated on these.

a. Magnets

For the price of magnets, we use estimates from CAMEA team leader Henrik M. Rønnow. These are based on current quotes from providers of magnets and auxiliary equipment.

- High- T_c split coil magnet capable of going beyond 20T. Costing this device is extremely difficult, since the technology to build one for use on a neutron spectrometer is not fully developed. We tentatively estimate a price of 2.5 M€.
- 10T wide bore magnet for use in combination with pressure cells. Price estimate 500 k€
- Dysprosium boosters capable of adding 2T to the maximum field of a given magnet. Price estimate 50 k€
- Dilution insert for magnets. Price estimate: 180 k€

If the technology for the high- T_c split coil magnet is not mature two years before the construction of CAMEA is finalized, we will instead go for a 16T magnet with an estimated price tag of 1.4 M€

Combining the high- T_c split coil magnet, the 10T wide bore magnet, the Dy boosters and a dilution insert, we arrive at a total cost of 3.23 M€, which drops to 2.13 M€ if the high- T_c technology does not develop at a sufficiently rapid pace.

Cost of magnets and auxiliary equipment **3.230 M€**

b. Pressure cells

We are using price estimates received from Stefan Klotz, Université P. & M. Curie, France

- Paris-Edinburgh pressure cell for low-temperature research, including press, cryostat, CCR and He compressor. Estimated price: 250 k€.
- Diamond Anvil 30 GPa pressure cell for high temperatures. The cell itself and the facilities for external or laser heating, temperature and pressure measurement capabilities and He compressor. Total price estimate: 280 k€.
- High pressure cell for low-temperatures to fit into 10T wide bore magnet. High performance McWhan cell for the 2-3 GPa range. Price estimate 50 k€.

Cost of pressure cells and auxiliary equipment	0.580 M€
--	----------

4. Manpower

We estimate that the total personnel cost related to the CAMEA spectrometer will be 21 man-years, divided as 5 man year for a lead scientist, 5 man years for a lead engineer and 11 man years for various technical tasks, e.g. the construction of the analyzer tank, which was estimated to take up to 3 years. Using current typical Danish salaries for Scientists (Lead Scientist, Lead Engineer) and Technical Staff, we arrive at salary costs of 1.460 M€.

It is assumed that most of the hardware costs for major optical components include installation, as is the case, for example, for the guides. We also assume that electronic solutions are fully incorporated in the quotes for choppers and detectors.

Cost of manpower	1.460 M€
------------------	----------

5. Summary of construction costs

In table 3 we summarize the costing estimates from the previous sections. As can be seen from the table, the total construction cost of the proposed CAMEA instrument, excluding salaries, will be 18.460 M€, while inclusion of salaries brings the total cost to 19.920 M€. Out of the total cost, 33% corresponds to the price of guides, shielding and shutters, 40% corresponds to the cost of CAMEA-specific components such as the chopper system, vacuum tank, polarization analysis, cooled PG analyzers, ³He detectors etc. Finally, 19% of the total estimated cost comes from the specific magnets and pressure cells foreseen in order to be used on CAMEA, most notably a high-T_c split-coil magnet capable of going beyond 20 Tesla, and 7% is the manpower cost. We note that we have attempted to make conservative estimates throughout. Hence, we believe that the quoted cost, 19.920 M€ is an upper limit.

On the primary spectrometer side, the main cost drivers are guides and shielding of guides for the instrument. For the secondary spectrometer, the most costly item is polarization analysis. Finally, the combined price estimate for sample environment equipment is dominated by the cost of the large high- T_c split coil magnet.

Costing item	Price [M€]	Source of information and comments
Guides and shielding		
Guides	1.310	Swiss Neutronics.
Mechanics and installation	1.295	Swiss Neutronics.
Guide shielding	2.142	ESS. This assumes a ratio of guide cost to shielding cost of 1:2. The ratio is expected to be in the range 1:1 to 1:2.
Instrument cave and beam stop	1.000	ESS.
Shutters	0.790	ESS. MCNPX simulations are needed to decide on the need for a heavy shutter (0.75 M€)
Vacuum pumps for guides	0.056	CAMEA team.
Sum for guides and shielding	6.593	
CAMEA spectrometer		
Choppers	1.425	ESS.
Divergence jaws	0.123	ISIS.
Sample table	0.034	CAMEA team.
Vacuum tank	1.058	CAMEA team.
Vacuum pump	0.025	CAMEA team.
PG analyzer crystals and Si wafers	1.466	CAMEA team.
Cooling machines for analyzers	0.255	CAMEA team.
Detectors	0.897	ESS and CAMEA team.
Beryllium filter	0.222	ISIS.
Radial collimator	0.050	JJ X-ray.
Electronics	0.402	ESS.
Polarization analysis	2.100	Neutron optics Berlin, PSI and CAMEA team.
Sum for CAMEA spectrometer	8.057	
Sample environment for CAMEA		
Magnets	3.230	CAMEA team. This includes a 20+ Tesla split coil magnet estimated at 2.5 M€
Pressure cell	0.580	Stefan Klotz. Université P. & M. Curie, France.
Sum for sample environment	3.810	
CAMEA cost excluding manpower	18.460	
Manpower		
Lead scientist (5 years) Lead engineer (5 years) Technical staff (11 years)	1.460	CAMEA team.
Sum for manpower	1.460	
Total cost of CAMEA	19.920	

Table 3: Summary and overview of the cost of the proposed CAMEA spectrometer.

6. Conclusions

We conclude that the CAMEA spectrometer as proposed here, can be constructed at a total cost of 19.920 M€.

References

- [1] Swiss Neutronics web page <http://www.swissneutronics.ch/>
 - [2] J. O. Birk, CAMEA Guide report.
 - [3] J. O. Birk, CAMEA Simulations and Kinematic Calculations
 - [4] Mirrotron web page: <http://www.mirrotron.kfkipark.hu/>
 - [5] L. C. Chapon, P. Manuel, P. G. Radaelli, C. Benson, L. Perrott, S. Ansell, N. J. Rhodes, D. Raspino, D. Duxbury, E. Spill, J. Norris, Neutron News 22 (2), 22-25 (2011).
 - [6] J. O. Birk, CAMEA Technical solution report.
 - [7] JJ x-ray webpage: <http://www.jjxray.dk/>
 - [8] Neutron Optics Berlin webpage: <http://www.neutronopticsberlin.com/>
- CAMEA reports can be downloaded here: <http://infoscience.epfl.ch/search?ln=en&p=camea&f=>