The International Design Study for the Neutrino Factory:

Organisation and responsibilities, resources, and potential for developing CERN's role

This document has been prepared in response to a request from the CERN SPC Neutrino Panel on behalf of the International Design Study for the Neutrino Factory (the IDS-NF) collaboration. The motivation for the study and the timescale on which the collaboration seeks to carry it out are summarised. The organisation of the IDS-NF and the present division of responsibilities is presented. The modest resources presently available to carry out the study are summarised and an estimate of the resources required to deliver the RDR is presented. CERN is already actively involved in the IDS-NF, supported in part by the EUROnu Framework Programme 7 Design Study. Four areas are identified as being particularly well matched to the expertise and experience at CERN: support and consultancy in addressing the various safety issues that the facility presents, particularly the high-power, pion-production target; support for, or perhaps coordination of, the costing of the facility; the development of the SPL as a proton driver for the Neutrino Factory; and the development of the muon front-end including the RF and magnet engineering. In the short-term, an additional 3 staff years of effort are requested. For CERN to play a roll in the development of the Reference Design Report (RDR) commensurate with its breadth of experience and tracker record, this additional complement should increase to 8 by 2012 when the RDR is being completed.

1. Goals of the International Design Study for the Neutrino Factory

The principal objective of the International Design Study for the Neutrino Factory (the IDS-NF) is to deliver a design report in which [1]:

- The physics performance of the Neutrino Factory is detailed and the specification of each of the accelerator, diagnostic, and detector systems that make up the facility is defined;
- The schedule for the implementation of the Neutrino Factory facility is presented;
- The cost of the Neutrino Factory accelerator, the diagnostics, and the detector systems are presented at a level of accuracy appropriate for the report to inform a decision to pursue the Neutrino Factory project; and
- The outstanding technical and financial uncertainties are documented and an appropriate uncertainty-mitigation plan is presented.

The timescale for the study was set taking into account the recommendation of the Strategy Group of CERN Council that [2]:

> *'Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; Council will play an active role in promoting a coordinated European participation in a global neutrino programme.'*

The Reference Design Report (RDR), conceived as the document on which requests for resources resources to carry out the first phase of the Neutrino Factory project can be made, is required in 2012/13. This timescale is well matched to that on which the T2K and Double Chooz experiments that seek to determine the small mixing angle, θ_{13}, are expected to produce results. As a step on the way, an Interim Design Report (IDR) will be produced in 2010/11. The IDR has three functions [1]:

- The IDR marks the point in the IDS-NF at which the focus turns to the engineering studies required to deliver the RDR;
- The IDR documents the baseline for the accelerator complex, the neutrino detectors, and the instrumentation systems; and

- The IDR defines example sites to be taken forward in the RDR; and it forms the basis of the proposals required to raise the resources that are required to deliver the RDR.

2. Resources presently available, or identified, to carry out the IDS-NF

The following paragraphs summarise the efforts directed towards the International Design Study for the Neutrino Factory. There is an energetic international programme of system and component R&D directed towards establishing the feasibility of each of the key components of the Neutrino Factory. This programme, coordinated in part through the annual 'NuFact' workshops, includes:

- *MERIT*: The liquid-mercury jet proof-of-principle experiment, which was mounted at CERN by a US-lead international collaboration;
- *MICE:* The international Muon Ionisation Cooling Experiment, which is being built at the Rutherford Appleton Laboratory;
- *EMMA*: The Electron Model of Many Applications non-scaling FFAG accelerator which is being built at the Daresbury Laboratory by a UK-led international collaboration; and
- *MuCool*: The US programme that seeks to develop the techniques to provide high-gradient copper RF cavities for the Neutrino Factory cooling channel; and
- *Music*:.The first stage of the Japanese programme to demonstrate curved solenoid channels and phase rotation in the FFAG.

In addition, there are a number of H^{-}-ion injector development programmes designed to be used in multi-MW pulsed proton sources. These programmes include the HIPPI project at CERN, the Front-end Test Stand project at RAL, and the High Intensity Neutrino Source project at FNAL.

The IDS-NF in Europe is coordinated through the EUROnu Design Study. EUROnu is organized in six work packages. EUROnu work package three, the 'Neutrino Factory' work package supports work on the muon front end, the large-aperture, rapid, muon acceleration system, the handing of the spent proton beam in the target, and the development of an end-to-end simulation of the facility. Aspects of the design of the target station itself will be addressed in the 'Super beam' work package. The 'Detector' work package (work package 5) and the Physics work package (work package 6) address detector and physics issues related to super-beams, beta-beams, and the Neutrino Factory. Great care is being taken by the management of EUROnu and the IDS-NF to ensure that all the work on the Neutrino Factory carried out through EUROnu is directly related to the IDS-NF. The resources provided through EUROnu in support of the IDS-NF are summarised in table 1. In some European countries additional resources are also available to support the IDS-NF, these contributions are also closely coordinated within EUROnu and the IDS-NF. These additional resources are also listed in table 1.

The largest contribution to the IDS-NF from North America comes from the US Neutrino Factory and Muon Collider collaboration (the NFMCC). The work of the NFMCC is supported as a rolling programme by the DOE and through grants by the NSF. The resources presently directed at the IDS-NF are presented in table 1. The NFMCC has recently submitted a request to the DOE for a five-year programme of Neutrino Factory and Muon Collider R&D. The IDS-NF forms an important part of the five-year plan and the resources that have been requested are also presented in table 1. Additional contributions to the IDS-NF are made by Canadian institutes. These contributions are also listed in the table.

Support for the IDS-NF in Asia comes from India and Japan. The Indian contribution is based largely on the possibility that the INO detector could be developed to become the far detector for the Neutrino Factory. Japanese contributions to the study are in the areas of the muon FFAG and in evaluating the opportunities that the large muon flux at the Neutrino Factory has to offer the search for charged lepton flavour violation. The resources from Asia available to the IDS-NF are also summarised in table 1.

3. Organisation and responsibilities within the IDS-NF

The IDS-NF [3] is coordinated by the Steering Group (see table 2) [4]. The IDS-NF is organised in three working groups: the Physics and Performance Evaluation Group (PPEG); the Accelerator Working Group; and the Detector Working Group. The conveners of the various working groups are listed in table 2. The Accelerator Working Group has broken down the study into a number of subsystems and task leaders have been defined for each of the tasks (see table 3) [5]. Similarly, the Detector Study has been broken down into a number of tasks (see table 4). Task leaders have been identified for the majority of the tasks, work is in hand to fill the remaining slots. An IDS-NF note defining the responsibilities within the Detector Group is in preparation (a draft is available in [6]). The objectives of the PPEG have also been defined [7].

4. Estimate of resources required to deliver the Reference Design Report

A detailed plan of the content and scope of the RDR has yet to be made and it is therefore difficult to make a precise estimate of the resources required to deliver it. However, a rough, 'order of magnitude' estimate may be derived by considering the various tasks that must be carried out, identifying the type of expertise required, and then assigning a 'reasonable' number of staff to the task by expertise category. The number of staff arrived at in this way may reasonably be taken to indicate the size of the team required in the year in which the RDR is prepared.

4.1 Accelerator Study

The estimate of the effort required to prepare the RDR has been made by assuming that, for each system or sub-system, a core team will be established. The core team will comprise:

- Two accelerator physicists working on the lattice design, tracking, and system design. Depending on the experience of the individuals involved, it may not be necessary for two physicists to be working full-time;
- An RF/electrical engineer to work on the design and collaborate on the cost estimation of the RF and electrical systems; and
- A mechanical engineer to work on the mechanical design and collaborate on the cost estimation of the system. Since one of the key objectives of the design study is to deliver a cost estimate for the facility, it may be necessary to increase the effort in this category.

In addition, since it will be important to address the system and integration issues as well as aspects of the civil engineering, each core team will need to be supported by a civil/systems engineer. This role will be supplied on a consultancy basis and, for the purposes of this cost estimation, it has been assumed that 3.5—4.5 staff years of effort per system should be budgeted. This gives a core team of 3.5 staff per system in the accelerator complex.

A number of systems require additional expertise to address safety or other particular issues. To define these roles will require further discussion, but, for the purposes of this estimate it is reasonable to assume that the following additional expertise will be required:

- *Target station:* Arguably, the target station presents the most difficult operational safety issues. The free, liquid mercury-jet target that is the baseline target technology presents issues in containment of thermally and radioactively hot mercury and in the chemical processing of the mercury during operation. In addition, the normal and superconducting solenoids that form the pion capture system, challenging in themselves, require to operate in the high-power, high-radiation environment. It seems prudent therefore to assume that the core team working on the target station should be supported with a chemical engineer, a radiation safety expert, and a magnet engineer. It is likely that this expertise will be made available on a consultancy basis, so, for the purposes of the present estimate, an additional requirement of 1.5 staff has been assumed;

- *Muon front end:* The lattices proposed for the cooling channel and, to a lesser extent for the phase rotation system, call for complicated, compact magnetic lattices and the operation of high-gradient cavities in the presence of strong magnetic fields. It seems prudent to support the core team working on the ionisation cooling channel with a magnet engineer. Again, it is likely that this expertise will be provided on a consultancy basis and an additional staff requirement of 0.5 has been assumed;
- *Linear accelerators:* Large (201 MHz) superconducting RF cavities are specified for the linac and RLAs. The design and cost estimate of superconducting cavities is specialised and the linac/RLA core team will require the support of a superconducting RF specialist and a magnet engineer: since this expertise is likely to be provided on a consultancy basis, an additional staff requirement of 0.5; and
- *Storage rings:* The storage rings for the baseline Neutrino Factory configuration require tunnels to be dug at angles of up to ~40° to a depth of several hundred metres. The core storage-ring team will therefore require the support of a mining engineer and a civil engineer with appropriate experience, again on a consultancy basis: an additional staff requirement of 0.5.

To provide an appropriately robust cost and schedule analysis will require a coordinated approach to be adopted. A ‘Project Office’ of at least 2 persons should therefore be established to coordinate this analysis. The Project Office should also contain a ‘Safety coordinator’ (on a consultancy basis) with responsibility for ensuring that appropriate consideration is given to the safe implementation of the various systems.

This analysis is summarised in table 5 and indicates that a total of 41.5 staff will be required for the Accelerator Reference Design Report to be completed.

4.2 Detector Study

A similar analysis can be applied to the preparation of the Detector Reference Design report. The systems that will require design, engineering, and costing effort include:

- The far (7000—8000 km) detector, including the cavern and service issues;
- The intermediate (3000—5000 km) detector, including cavern and services;
- The near detector, which is likely to include a number of detector technologies, for example for the reconstruction of final states including charm; and
- The instrumentation of the storage ring.

As in the case of the accelerator study, for the purpose of estimating the effort required to deliver the RDR it is reasonable to assume that a core team of two physicists to develop the simulation and reconstruction codes and to perform the analysis will be required. The core team will require the support of a mechanical engineer and an electrical engineer, not necessarily on a full time basis. For the far and intermediate detectors mining engineers will be required to advise on the excavation and costing of the cavern. The near detector is likely to require a number of detector experts to design the various systems that are required. For the purposes of this estimate it has been assumed that three such personnel will be required. The storage ring instrumentation task must be carried out in close collaboration with the storage ring design team. For the purposes of this estimation it has been assumed that a core team of two physicists with the support of a mechanical and electrical engineer will be required.

Again, given the importance of arriving at a robust cost estimate, a coordinated approach will be required, making it necessary to include two staff in the Project Office with a brief to oversee the costing of the detector and instrumentation systems. A deep-underground laboratory safety advisor (on a consultancy basis) will also be required.

The effort required to complete the Detector Reference Design Report is summarised in table 5. The table indicates that a total of 26 staff will be required.

4.3 Physics Performance and Evaluation

A variety of contributions are required for the physics study ranging from theorists developing models that may be tested at the Neutrino Factory, to phenomenologists seeking to predict the performance of the facility, to experimenters evaluating the performance of the detectors they propose. One of the key 'missions' of the IDS-NF is to engage with the relevant communities in order to develop the best experimental programme. Since the physics study is unlikely to be run in the same way as the accelerator or detector design activity it did not seem appropriate to make an estimate of the resources required as has been done in the preceding sections.

5. CERN role and contributions

Through EUROnu, CERN is already actively engaged in the development of the design for the muon front end. Clearly, given the depth of expertise and experience, CERN has the potential to play a highly influential or decisive role in the study. The following paragraphs present a request for additional CERN contributions in the short term and a vision for a possible build up of the CERN programme as the study moves from the IDR phase into the preparation of the IDR.

5.1 Request for additional CERN contributions to the IDS-NF in the short term

In the short term, CERN should make an additional 2 to 3 staff years of effort available strategically targeted at four key areas that are well matched to CERN's expertise and maximise the potential for CERN to play a leading role in the preparation of the RDR. Specifically:

- ***Safety consultancy:*** (perhaps at the level of 0.5 staff years per year)

  The baseline Neutrino Factory accelerator complex contains a number of systems, such as the pion production target, the cooling channel and decay rings, for which the safety analysis will be critical. It will be critical to demonstrate a detailed and robust approach to safety in order for a future proposal to initiate the Neutrino Factory project to be taken seriously. The safety consultancy envisaged here is one in which CERN personnel engage with the leaders of the various design tasks and guide them in their consideration of the safety issues;
- ***Cost and schedule consultancy:*** (perhaps at the level of 0.5 staff years per year)

  Along with a robust approach to safety, it will be crucial to demonstrate a competent and robust approach to the analysis of the cost of the Neutrino Factory and the schedule on which it could be implemented. CERN has a unique role to play in this area since the Neutrino Factory, if it is built, is most likely to be built by the sort of international partnership that CERN has an established track record of managing effectively. As in the case of the proposed safety consultancy, the cost and schedule consultant would not be expected to carry out the full cost and schedule analysis, rather the consultant would engage with the task and sub-task conveners to advise on best practice and to provide a reality check;
- ***Development of the SPL as a proton driver for the Neutrino Factory*** (1 staff year per year)

  A bunch stacking and compressor scheme has been developed that would in principle allow the SPL to provide the bunch structure required to serve the Neutrino Factory. For SPL to serve the Neutrino Factory requires that the 4 MW option is developed and that the issues relating to the delivery of the high-power beam to the pion production target are analysed properly. It is important that this work be pursued, perhaps in collaboration with those developing Project-X at

FNAL, to ensure that the development of the accelerator facility within the IDS-NF maintains the option for CERN to host the facility; and

- ***RF and magnet engineering for the muon front end and muon RLA systems***
  (1 staff year per year)

  Alongside the development of the conceptual design for the muon front end and the muon RLA systems there is a need to consider the engineering constraints in some detail. The principal risk to the present cooling channel design, for example, is that the proposed 201 MHz cavities can-not be made to reach the design gradient of 15 MV/m in the presence of the focusing magnetic field. The investment of effort in the front end and RLA systems would be well matched to CERN's responsibilities within EUROnu.

5.2 Opportunities to develop the CERN role as the IDS-NF begins preparation of the RDR

Making the targeted additional investment in the areas listed above gives CERN the opportunity to play a decisive role in the development of the RDR:

- By establishing the Project Office at CERN or, if a distributed model is eventually adopted, providing one or more of the key personnel who will make up the Project Office;
- By maintaining the option for the SPL to deliver a 4 MW proton beam with the bunch structure required by the Neutrino Factory, CERN will become established as a highly competitive host site;
- Through engagement with appropriate industries across Europe, CERN has the opportunity to establish robust, reproducible, and efficient manufacturing techniques for the high-gradient, superconducting and warm RF and high-field magnets that will be required in the muon front end and the muon acceleration systems.

For CERN to play the role that is commensurate with its breadth of expertise and track record, a build up to around 7 to 8 staff working on, or leading, aspects of the IDS-NF in the run up to the preparation of the RDR would seem to be desirable. Such a level of effort would ensure that the options considered and the designs produced would be compatible with CERN eventually hosting the facility. The table below shows a possible profile for the build-up of the additional effort.

Additional effort requested from CERN. The effort is in addition to that already identified through EUROnu and that presently directed at Neutrino Factory R&D by CERN. The staff effort recorded is the total additional effort, i.e. it is proposed that the team grows by 3 this year, 2 in financial year 2010/11 and 2011/12, and 1 in financial year 2012/13.

Financial year	***2009/10***	***2010/11***	***2011/12***	***2012/13***
Additional staff request (total wrt present complement)	3	5	7	8

References

1. IDS-NF-001, 'Principal objectives', 17 January 2007, https://www.ids-nf.org/wiki/FrontPage/Documentation?action=AttachFile&do=view&target=IDS-NF-001-v1.0.pdf
2. http://council-strategygroup.web.cern.ch/council-strategygroup/Strategy_Statement.pdf
3. https://www.ids-nf.org/wiki/FrontPage
4. https://www.ids-nf.org/wiki/FrontPage/Organisation/SteeringGroup/Representation

5. IDS-NF-004, 'IDS-NF: initial division of responsibilities within the Accelerator Working Group', https://www.ids-nf.org/wiki/FrontPage/Documentation?action=AttachFile&do=view&target=IDS-NF-004-v1.0.pdf
6. IDS-NF-DWG-001, 'IDS-NF: initial division of responsibilities within the Physics and Performance Evaluation Group', https://www.ids-nf.org/wiki/FrontPage/Detector/Documentation?action=AttachFile&do=view&target=IDS-NF-DWG-001.doc
7. IDS-NF-006, 'IDS-NF: initial division of responsibilities within the Physics and Performance Evaluation Group', https://www.ids-nf.org/wiki/FrontPage/Documentation?action=AttachFile&do=view&target=IDS-NF-006-v1.0.pdf

Table 1: Summary of resources available to carry out the IDS-NF. The resources identified in the table are predominantly directed at the accelerator study.

Resources presently available to carry out the International Design Study for the Neutrino Factory					
			Institute	***SY/year***	***Comments***
Europe					
	EUROnu	Neutrino Factory (work package 3)	CERN	1.54	
			CNRS	0.25	EUROnu provides resources for the period September 2008 to August 2011. The staff year per year (SY/year) recorded corresponds to the average effort over the four-year duration of EUROnu.
			Imperial College London	1.75	
			Oxford University	0.13	
			STFC	1.63	
			Warwick	0.58	
	UKNF	Accelerator design effort not accounted in EUROnu		1.80	
North America					
US	NFMCC	Present effort in support of the IDS-NF		3.00	Estimate of effort for the present financial year.
		Effort requested in the NFMCC 'Five year plan'		3.00	Average effort over the five year period.
Canada		Effort at TRIUMF in support of target development and at York and elsewhere in support of the development of a large liquid argon detector.		0.50	Rough estimate, to be revised.
Asia					
India	INO	Contributions to detector study		1.00	Estimate, to be revised.
Japan	NuFact-J	Contributions to accelerator and physics study		0.50	Contributing to FFAG design, front-end
Total				***15.68***	

Table 2: IDS-NF Steering Group and working group conveners

IDS-NF Steering Group	
Committee	
A Blondel	Geneva
M Zisman	LBNL
Y Kuno	Osaka
K Long	Imperial (Chair)
Accelerator Conveners	
S Berg	BNL
Y. Mori	Kyoto
C. Prior	STFC
J. Pozimski	Imperial
Detector Conveners	
A Bross	FNAL
P Soler	Glasgow
N. Mondal	Mumbai
A. Cervera	Valencia
Physics and Performance Evaluation Group Conveners	
A Donini	Madrid
P. Huber	CERN
S. Pascoli	Durham University
W. Winter	Universität Würzburg
O. Yasuda	Tokyo Metropolitan University

Table 3: Conveners of systems and sub-systems are for the Accelerator Working Group of the IDS-NF [5]. Responsibility for the design of the various transfer lines required rests with the muon-acceleration system designers. A second convener for the storage ring task has yet to be defined.

System **Sub-system**	**Coordinators**
Target	C.Densham (RAL), H.Kirk (BNL)
Muon front-end	
Capture ***Bunching and phase rotation*** ***Cooling***	C.Rogers (ASTeC), D.Neuffer (FNAL)
Acceleration	
Linear accelerators	A.Bogacz (JLab), J.Pozimski (ICL)
FFAG	S.Berg (BNL), S.Machida (RAL)
Storage ring	C.Prior (ASTeC), ANO

Table 4: Conveners of systems and sub-systems are for the Detector Working Group of the IDS-NF [5]. Discussions are in hand with a candidate for the second convener of the near detector task. The conveners for the beam monitoring in the storage ring task have yet to be defined. It is anticipated that a member of the INO collaboration will take on the joint coordination role in the 'Software and analysis framework' task.

System	**Coordinators**
Software and analysis framework	A. Cervera (IFIC, Valencia) TBD
MIND	N. Mondal (TIFR, Mumbai) P. Soler (Glasgow)
TASD	A. Bross (FNAL) M. Ellis (Brunel)
Lar	G. Barker (Warwick) S. Menary (York)
Near detector	R. Tsenov (Sophia) TBD
Beam monitoring in storage rings	TBD TBD

Table 5: Estimate of resources required to carry out the work required in the preparation of the Accelerator Reference Design Report. It has been assumed that three example sites for the accelerator facility will be considered, perhaps CERN, FNAL, and RAL. The effort required to deliver the proton driver section of the report at the example site has been assumed to be sufficiently site dependent that a local core team will be required at each site.

Accelerator Study: indicative estimate of effort in preparation of Reference Design Report				
System	***Expertise***	***Number of staff***		
Sub-system		***Per system***	***Number of site-specific studies***	***Total per system***
Proton driver	Core team	3.5	3	10.5
Target	Core team	3.5	1	5
Safety specific engineering	Chemical engineer	0.5		
	Radiation safety engineer	0.5		
	Magnet engineer	0.5		
Muon front end				
Capture	Core team	3.5	1	11
Bunching and phase rotation	Core team	3.5		
Cooling	Core team	3.5		
	Magnet engineer	0.5		
Acceleration				
Linacs	Core team	3.5	1	8.5
	Superconducting RF expert	0.5		
	Magnet engineer	0.5		
FFAGs	Core team	3.5		
	Magnet engineer	0.5		
Storage rings	Core team	3.5	1	4
	Civil/mining engineer	0.5		
Project officee	Costing and schedule coordination	2.0	1	2.5
	Safety coordinator	0.5		
Total		***34.5***		***41.5***

Table 6: Estimate of resources required to carry out the work required in the preparation of the Detector Reference Design Report. It has been assumed that the 2 candidate sites for each of the intermediate and far detectors will be considered and that a mining engineer with knowledge of the local conditions will be required.

Detector Study: indicative estimate of effort in preparation of Reference Design Report				
System	***Expertise***	***Number of staff***		
		Per system	***Number of site-specific studies***	***Total per system***
Far (7000--8000 km) detector	Core team	5.0		6
	Mining engineer	0.5	2	
Intermediate (3000--5000 km) detector	Core team	5.0		6
	Mining engineer	0.5	2	
Near detector	Core team	5.0		8
	Detector specialists	3.0		
Storage ring instrumentation	Core team	4.0		4
Project officee	Costing and schedule coordination	2.0		3
	Safety coordinator	1.0		
Total		***26.0***		***27***