



Test Infrastructure and Accelerator Research Area

Status Report

Needs for Accelerator Scientists Report

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28 February 2013

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Test Infrastructure and Accelerator Research Area

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Content

EXECUTIVE SUMMARY 4

1. INTRODUCTION 5

2. RESEARCH INSTITUTES 6

2.1 PERSONNEL NUMBERS 6

2.2 PERSONNEL QUALIFICATION LEVELS 8

2.3 RECRUITMENT 9

2.4. PERSONNEL TRAINING 12

3. COMPANIES 13

3.1 PERSONNEL NUMBERS 13

3.2 PERSONNEL QUALIFICATION LEVELS 15

3.3 RECRUITMENT 16

3.4. PERSONNEL TRAINING 19

4. HOSPITALS 20

5. HADRON THERAPY FACILITIES 21

6. IMPROVING THE SUPPLY OF TRAINED PERSONNEL 21

7. SUMMARY OF MAIN FINDINGS 22

8. OUTLOOK 23

REFERENCES 23

ACKNOWLEDGEMENTS 23

APPENDIXES 24

APPENDIX 1: Survey spreadsheet 24

APPENDIX 2: Responding research institutes and contact persons	25
Denmark.....	25
Finland.....	25
France.....	25
Germany.....	25
Italy	26
Norway	26
Poland	26
Spain.....	26
Sweden.....	26
Switzerland.....	27
United Kingdom	27
APPENDIX 3: Country-specific analysis.....	27
France: Research institutes	28
Germany: Research institutes	31
Italy: Research institutes.....	34
Italy: Companies.....	38
The Nordic Countries	41
Poland: Research Institutes and Technical Universities.....	45
Spain: Research institutes	46
Spain: Companies.....	50
Switzerland: Research institutes	53
United Kingdom: Research institutes.....	57

EXECUTIVE SUMMARY

- 70 research institutes, and 44 companies, from Denmark, Finland, France, Germany, Italy, Norway, Poland, Spain, Sweden, Switzerland and the United Kingdom completed the TIARA survey on market needs for personnel trained in accelerator science. A total of 3638 personnel at the institutes, and 993 at the companies, are engaged in accelerator-related activities.
- In all the countries surveyed a growth in total accelerator-related personnel at research institutes is projected over the next 5 years. The biggest increases are for Germany (+24%), Italy (+55%) and the Nordic countries (+68%), where there are large ongoing (or planned) accelerator facility construction projects. Overall the growth is projected to be 18%. The companies project a corresponding growth of 20% in total accelerator-related personnel over the next 5 years.
- All categories of accelerator personnel are expected to grow in number, but the increase is proportionally larger for engineers and technicians, which presumably reflects the need for technical staff for construction of the new accelerator projects.
- Physicists typically have at least master's or PhD degrees; engineers typically have master's or bachelor's degrees, with fewer having PhDs; technicians typically have, at most, a bachelor's degree. A greater proportion of personnel have PhDs in research institutes than in companies.
- 61 research institutes and 43 companies reported on personnel recruitment. The overall annual recruitment rate is approximately 9% for research institutes, and 18% for companies. The majority of institutes and companies reported difficulties in recruiting appropriate personnel; in particular, roughly 70% have difficulty recruiting engineers for accelerator-related work.
- Skills shortages were reported in a number of key areas. The most critical areas of shortage are in RF systems, beam dynamics, instrumentation and control, and vacuum systems.
- 68 research institutes and 40 companies reported on personnel training in accelerator science. 94% of research institutes and 75% of companies require training for their personnel. Although most training is provided 'on-the-job', there is a significant need for training provided by external bodies.
- The growth of accelerator-based techniques in medicine will require a significant increase in the number of suitably qualified personnel. For example, the number of personnel required to operate hadron therapy facilities is likely to double over the next 5-10 years.

1. INTRODUCTION

A survey of the ‘market needs’ for personnel trained in accelerator science and engineering was performed between July and December 2012. Research institutes, companies, and other interested organisations were contacted in the TIARA member states: Denmark, Finland, France, Germany, Italy, Norway, Poland, Spain, Sweden, Switzerland and the United Kingdom. A total of 70 research institutes and 44 companies provided data for the survey.

A spreadsheet-based survey was conducted. A representative of each organisation contacted was requested to provide responses to straightforward questions concerning the needs for personnel working in accelerator science and engineering at her/his organisation. Information was requested about the organisation and the number and type of personnel engaged in accelerator projects, the qualification level of personnel, the recruitment of personnel, the need for personnel training, and areas of skills shortages. The survey spreadsheet is shown in Appendix 1.

In each country the survey was targeted at research institutes, companies and organisations known to be engaged in accelerator-related activities. The numbers of responses by country are summarised in Table 1. The response rate of research institutes was very high (almost 90%) and we believe that we have captured an almost ‘complete’ dataset among the countries surveyed. The response from companies was generally patchy, due, understandably, partly to concerns regarding the provision of potentially commercially-sensitive information. Nevertheless, despite being far from comprehensive, the company data indicate some clear trends and here we report relevant statistics on the received dataset. We also present information gathered from the medical sector concerning personnel related to operation of accelerator-related medical systems and facilities.

	Research institutes		Companies	
	No staff	No staff	No staff	No staff
France	16	562	2 ¹	87
Germany	5	809	1	10
Italy	12	412	10	95
Nordic countries	10	142	1	90
Poland	2	64	1	504
Spain	9	161	27	137
Switzerland	2	1247	1	45
United Kingdom	16	242	1	25
Total	70	3638	44	993

Table 1. Number of responding research institutes and companies by country

¹ Note that this survey includes an answer from a company that is located in a neighbouring country that is not a member of TIARA, but which plays an important role in the accelerator domain.

2. RESEARCH INSTITUTES

The set of universities and accelerator-related laboratories contacted in our previous survey on education and training [1] was used as the basis for the current survey. 70 institutes responded and provided data. These research institutes and respective contact-persons are listed in Appendix 2.

2.1 PERSONNEL NUMBERS

The total number of personnel reported as being currently engaged in accelerator science and technology activities, summed over the responding research institutes, is 3638 (Figure 2.1). The breakdown is shown by country in Figure 2.2. Several countries have large national accelerator-related laboratories, most notably France, Germany and Switzerland (which, for these purposes is defined to include CERN). The number of personnel expected 5 years from now is also shown in Figures 2.1 and 2.2. The projection is for an increase of 660 (18%) in total staff within the next 5 years. Most countries project at least a modest increase. The biggest increases are for Germany (+24%), Italy (+55%) and the Nordic countries (+68%), where several large accelerator projects are either under, or projected to be under, construction: XFEL and FAIR (Germany); a new facility (formerly SuperB) near Frascati (Italy); MAX IV and ESS (Sweden).

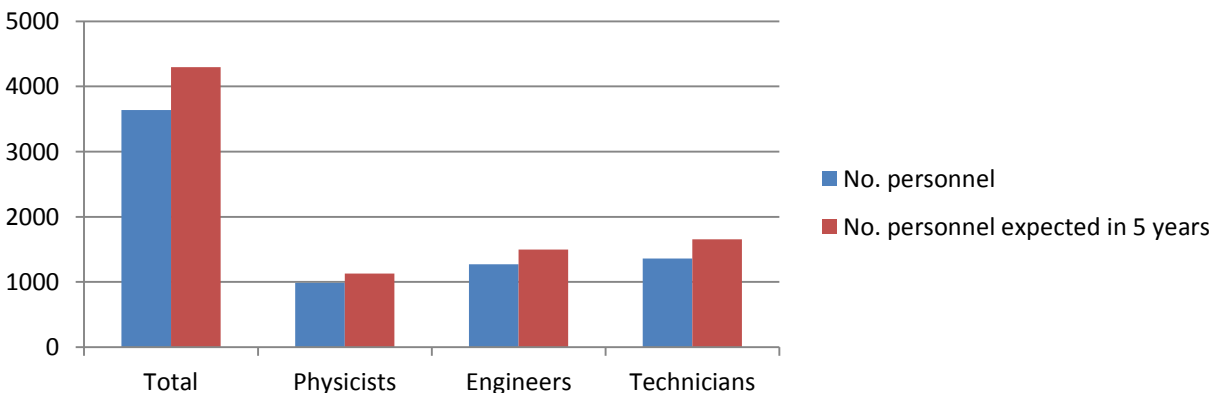


Figure 2.1: Total number of current personnel (blue) engaged in accelerator science activities at research institutes. The number of personnel expected in 5 years is shown in red.

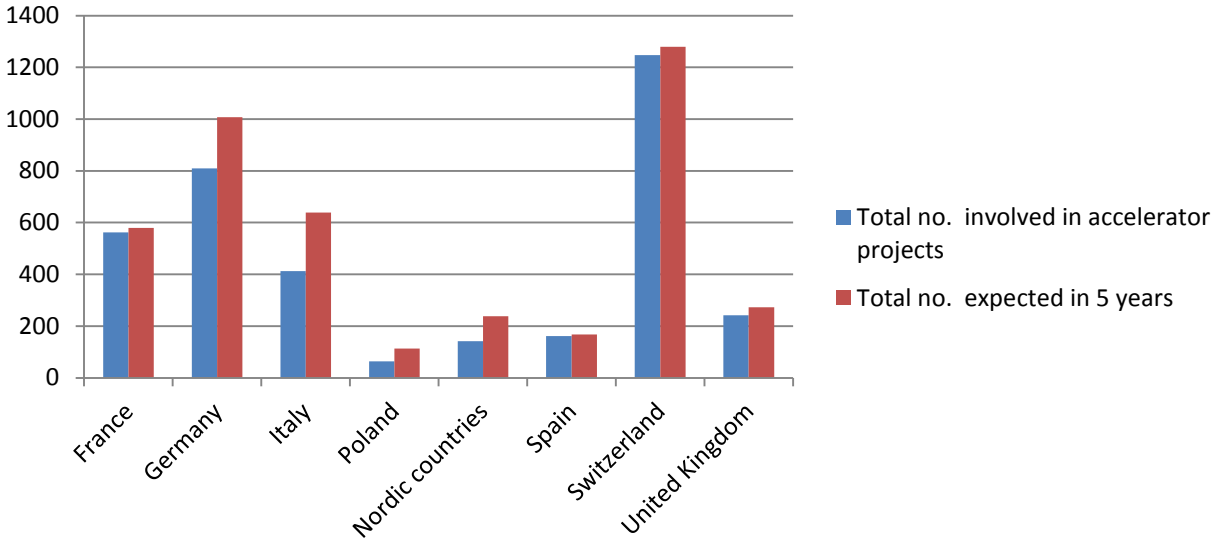


Figure 2.2: Distribution of the total number of personnel engaged in accelerator science and engineering at research institutes per country. Current number (blue) and projected number in 5 years (red).

Also shown are the numbers (Figure 2.1) and percentages (Figure 2.3) of personnel reported as being of type physicists, engineers or technicians. The breakdown of personnel is roughly even, with 27% currently reported as physicists, 35% as engineers, and 38% as technicians. Over the next 5 years there is a projected increase in all categories of accelerator personnel (Figure 2.1): physicists (+15%), engineers (+18%) and technicians (+21%), but the increase is proportionally larger for the engineers and technicians, which presumably reflects the need for technical staff for construction of new projects on this timescale.

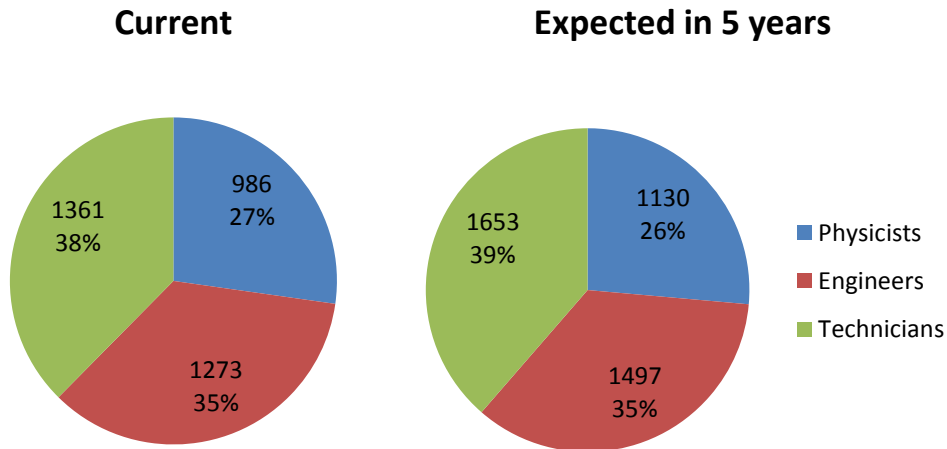


Figure 2.3: Reported breakdown of personnel engaged in accelerator science and engineering at research institutes currently (left), and expected in 5 years (right).

2.2 PERSONNEL QUALIFICATION LEVELS

Of the 70 responding institutes, 59 reported on the highest level of qualification, of their personnel; these data are presented in Figure 2.4. The majority of physicists (69%) were reported as having a PhD. For engineers there is a more event distribution, with the largest proportion (46%) having a master’s degree, 31% having a bachelor’s degree, and 23% a PhD. The vast majority of technicians were not reported as having a university-level qualification; this is not surprising, since technicians traditionally receive vocational training of a technical nature. Of those that do have university-level qualifications, 88% were reported as having a bachelor’s degree.

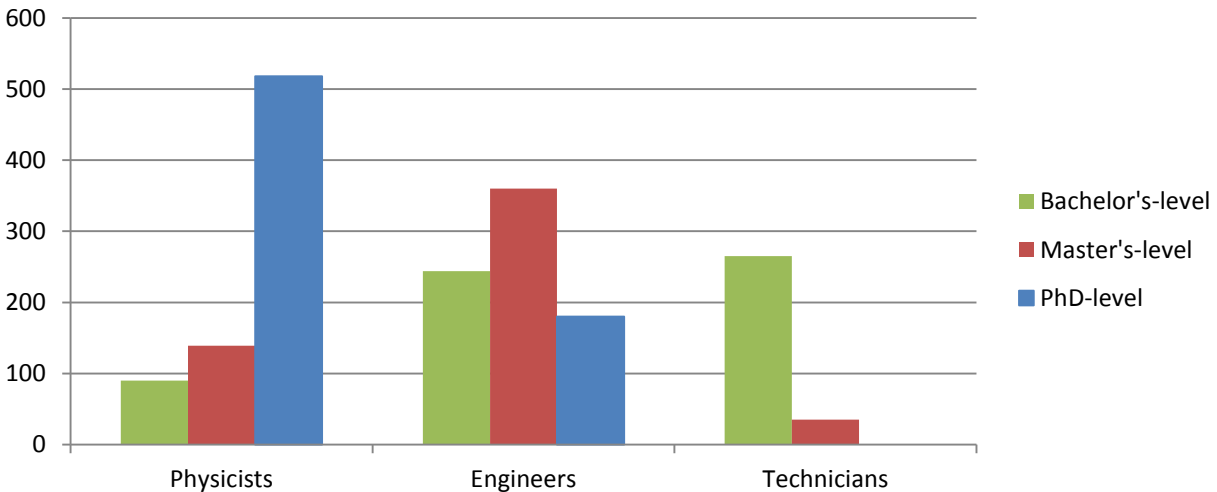


Figure 2.4: Reported highest qualification level that includes accelerator science and technology of current personnel engaged in accelerator activities at research institutes.

68 institutes gave some information on the highest level of qualification including accelerator science and technology that is *required* for new personnel; the percentage of institutes requiring a highest qualification is shown by type of personnel in Figure 2.5. For physicists the majority of institutes that reported (63%) require a PhD. For engineers there is a roughly equal percentage (approx. 28% each) requiring Master’s and PhD degrees; for technicians, 25% of institutes require a bachelor’s degree. Comparing Figures 2.4 and 2.5 there is a tendency for the required qualification level for new personnel to be slightly higher than the level for existing personnel.

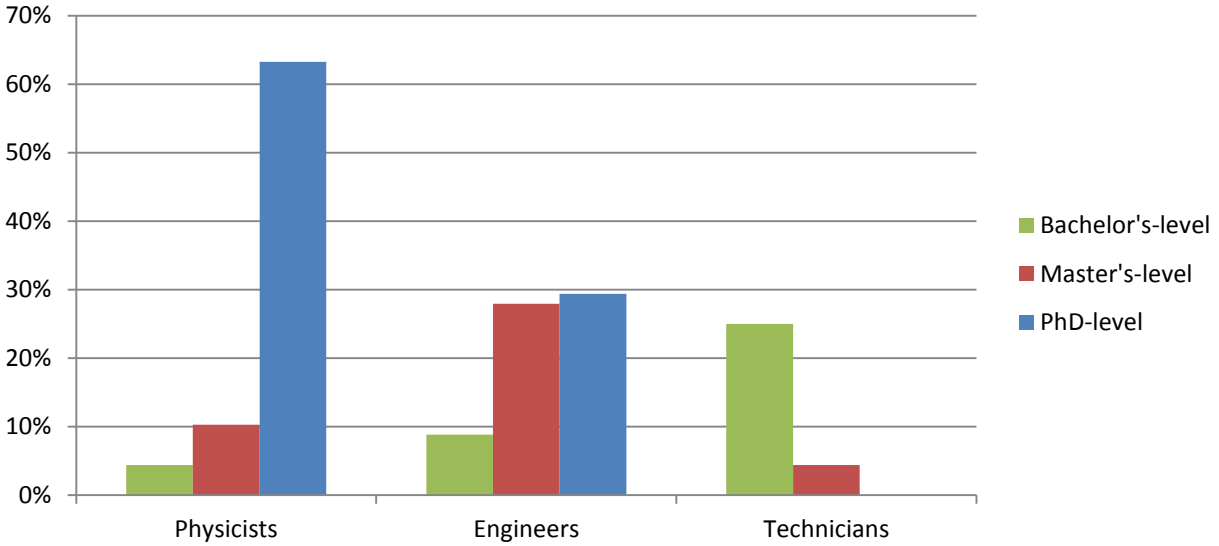


Figure 2.5: Reported required highest qualification level that includes accelerator science and technology (percentage of reporting institutes) for new personnel engaged in accelerator activities at research institutes.

2.3 RECRUITMENT

61 responding institutes reported on typical current annual recruitment numbers. The total numbers of accelerator-related personnel recruited annually are shown in Figure 2.6. The breakdown of the annual recruitment numbers between personnel categories is shown in Figure 2.7; there is a roughly even split among the three categories, with slightly higher numbers of engineers and technicians being recruited than physicists. The same data are represented as a percentage of each respective category of personnel in Figure 2.8. The recruitment rate is approximately 9% for all personnel categories. The percentage of institutes that reported having difficulties in recruiting personnel is shown by personnel category in Figure 2.9. For all personnel categories a majority of institutes report difficulties in recruiting appropriate personnel; the most serious difficulties (70% of institutes) are for recruitment of engineers.

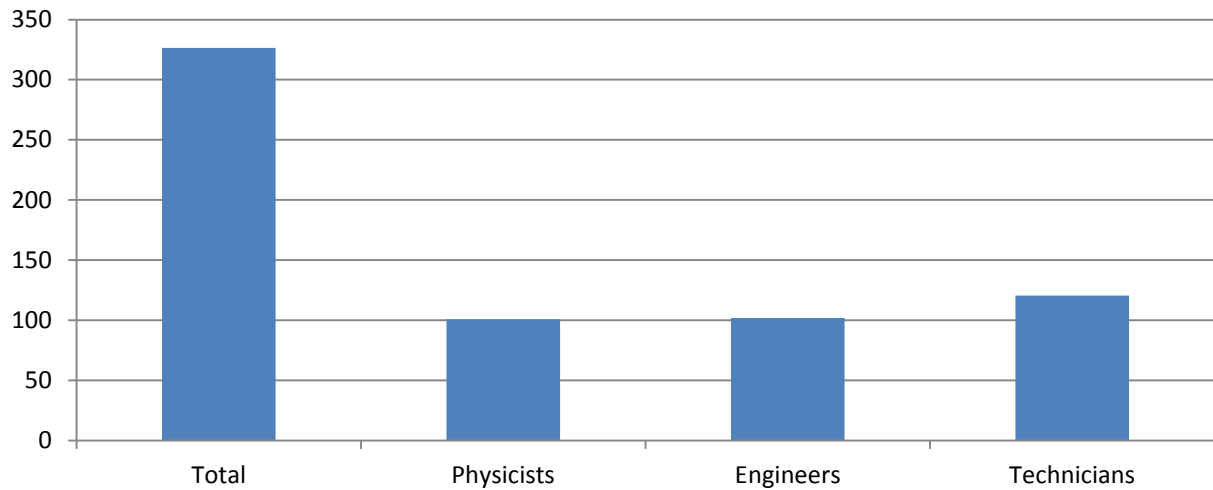


Figure 2.6: The number of accelerator-related personnel currently recruited annually.

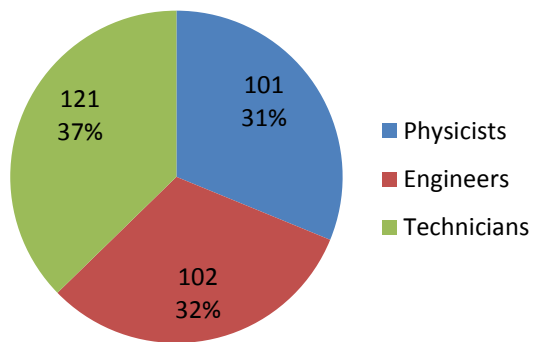


Figure 2.7: Percentage of the annual accelerator-related recruitment by category of personnel.

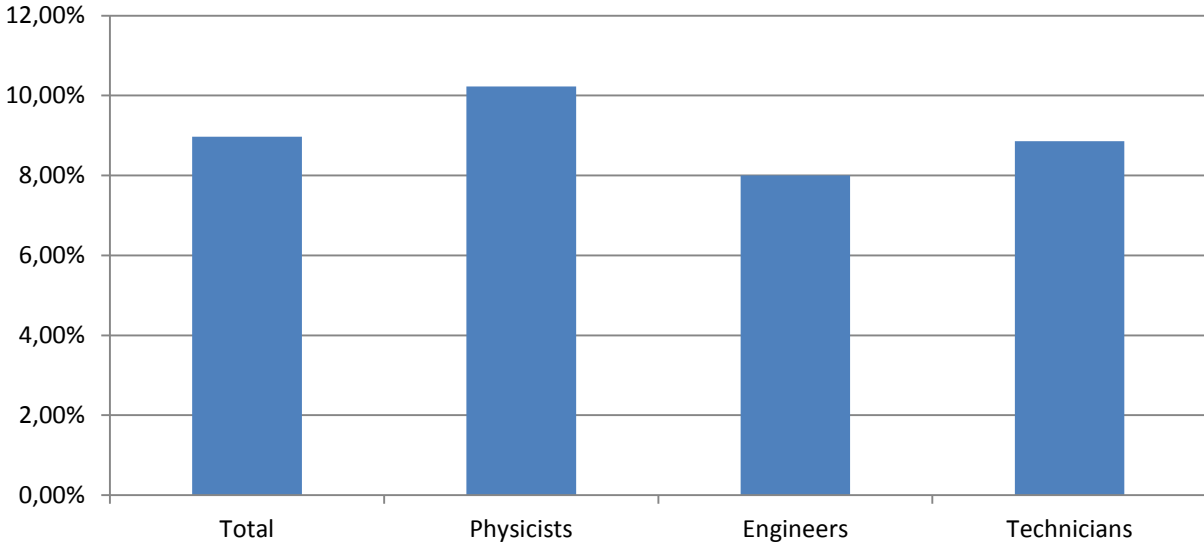


Figure 2.8: The percentage of each category of accelerator-related personnel currently recruited annually.

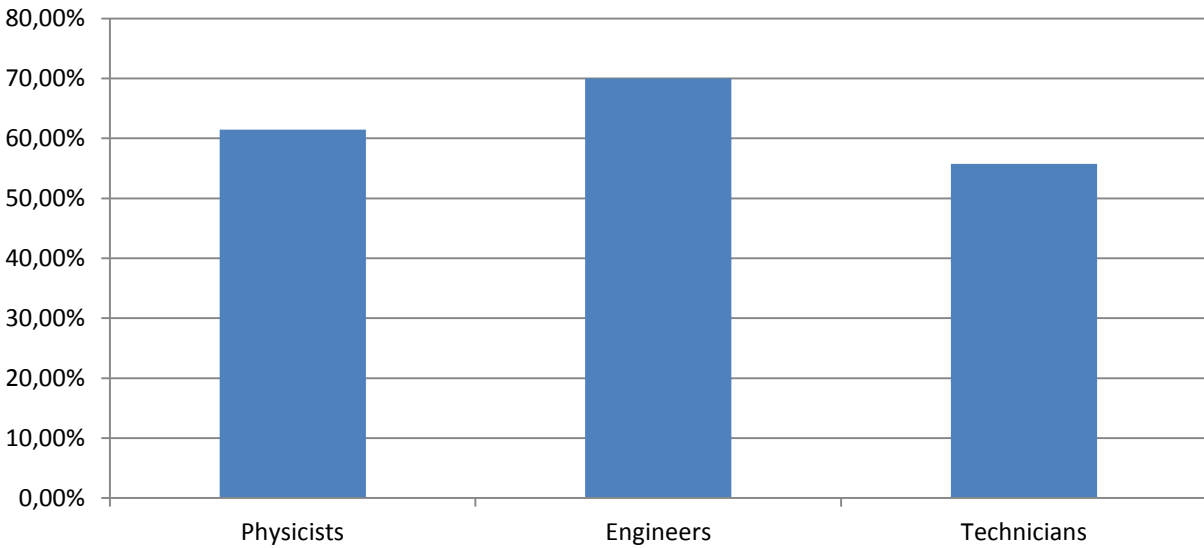


Figure 2.9: The percentage of institutes that reported difficulties in recruiting accelerator-related personnel, by personnel category.

Expertise shortages were reported in a number of areas; these are summarised in Figure 2.10. The most critical areas of shortage are in RF systems, beam dynamics, instrumentation and control, and vacuum systems.

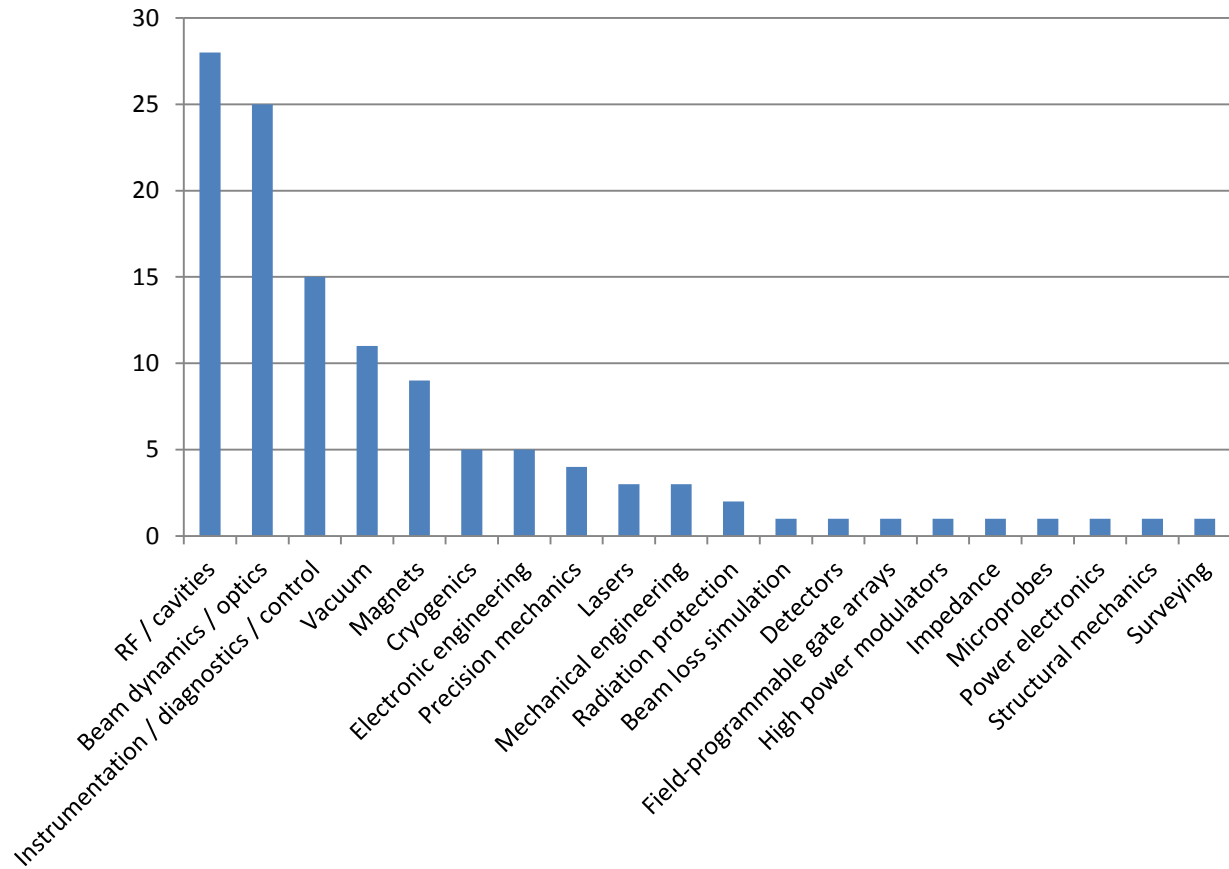


Figure 2.10: The number of institutes that reported lacking expertise vs. area of expertise.

2.4. PERSONNEL TRAINING

68 institutes reported on personnel training. The percentage of reporting institutes that require training in accelerator science and technology for their personnel is shown, by trainee type, in Figure 2.11. 94% of all institutes require training for personnel; 81% for physicists, 79% for engineers, and 66% for technicians. For all categories, the vast majority of training is provided ‘on the job’. However, in addition, 50% of all institutes require external training for physicists, 49% for engineers, and 31% for technicians. External training typically comprises attendance at an international or domestic accelerator school (see [1]).

In many European countries, there is a tendency at present to recruit non-permanent rather than permanent personnel. This tendency to avoid long-term investment in personnel may have a negative impact on hiring into the field.

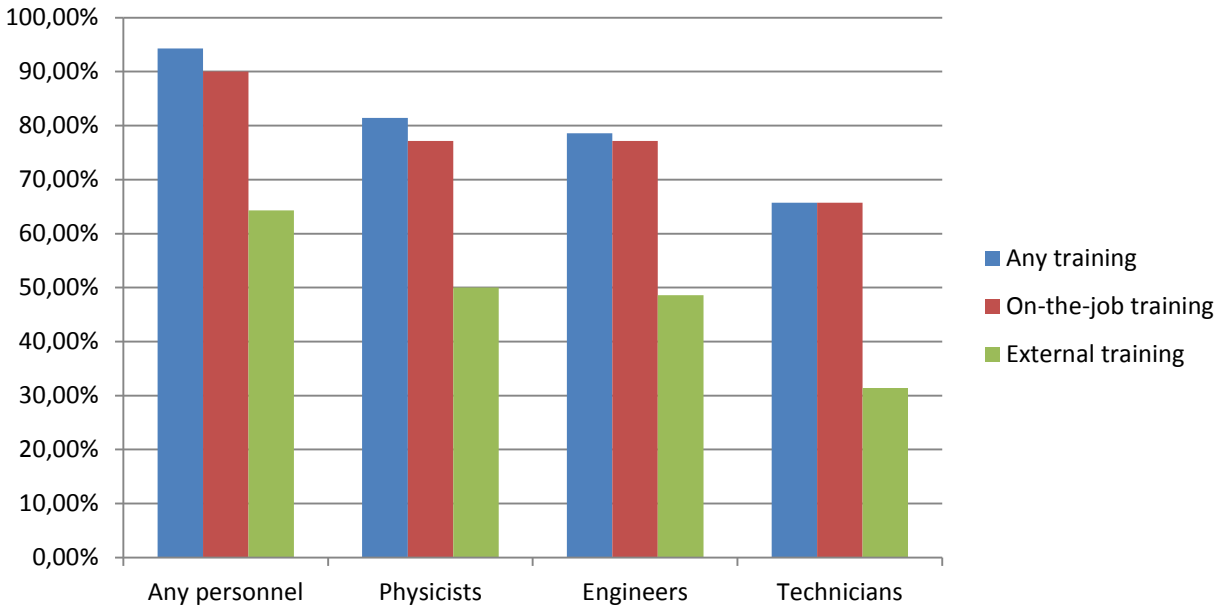


Figure 2.11: The percentage of all institutes that reported requiring training for their accelerator-related personnel, by personnel type.

3. COMPANIES

In each TIARA member country companies with known interests in the accelerator market were contacted. A company list gathered by TIARA Work Package 3 was used as input. A total of 44 companies responded (see Table 1). In general larger companies felt unable to share information, and the majority of responses were from smaller companies. In order to respect issues of commercial sensitivity, results from the gathered dataset are reported here without reference to particular companies or countries.

3.1 PERSONNEL NUMBERS

The total number of personnel reported as being currently engaged in accelerator-related activities, summed over the responding companies, is 993 (Figure 3.1); the number of personnel expected 5 years from now is also shown. The projection is for an increase of 197 (20%) in total accelerator-related personnel within the next 5 years. This large increase almost certainly reflects activity related to the construction of new major accelerator projects in Europe (see also Section 2.1).

Also shown are the numbers (Figure 3.1) and percentages (Figure 3.2) of accelerator-related personnel reported as being of type physicists, engineers or technicians. The breakdown of personnel is currently 17% reported as physicists, 48% as engineers, and 35% as technicians. This breakdown contrasts significantly with that for the research institutes, where a greater proportion of the accelerator personnel are physicists. The larger proportion of engineers and technicians in industry is not surprising, given the more immediate technical requirements of

delivering systems and products. Over the next 5 years there is a projected increase in all categories of accelerator personnel (Figure 3.1), but the increase is proportionally larger for the engineers and technicians (Figure 3.2). This is presumably a reflection of the industrial activity related to the construction of new major accelerator projects in Europe.

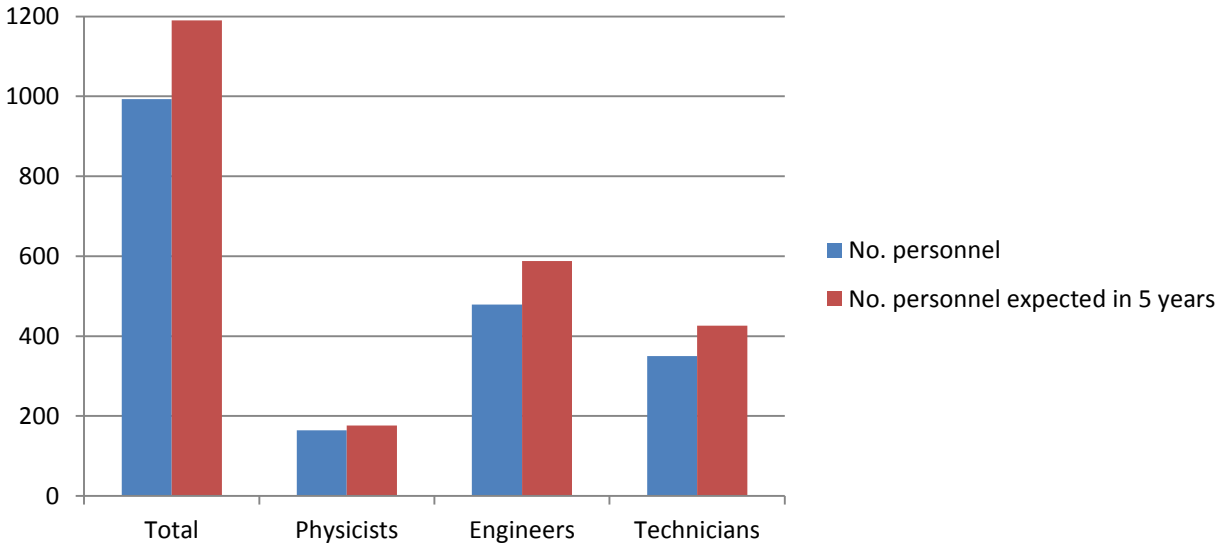


Figure 3.1: Total number of current personnel (blue) engaged in accelerator-related activities at companies. The number of personnel expected in 5 years is shown in red.

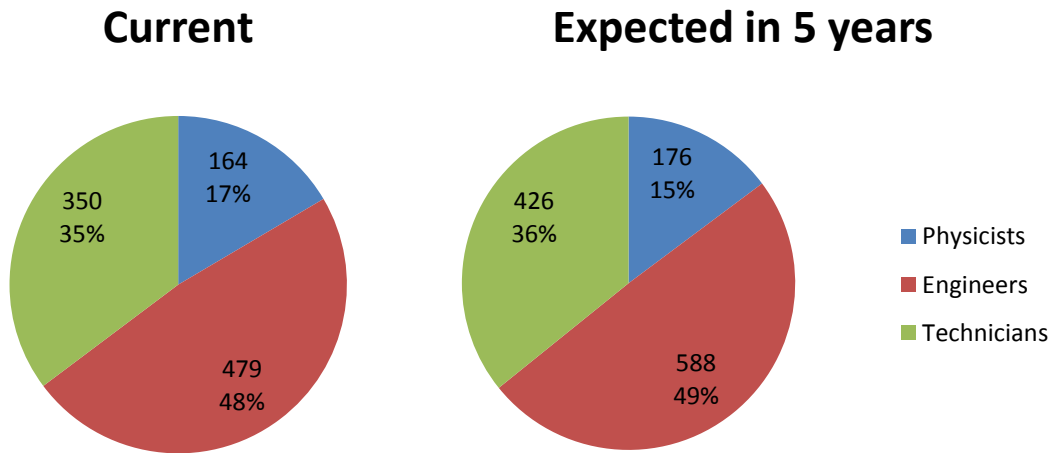


Figure 3.2: Reported breakdown of accelerator personnel currently (left) and expected in 5 years (right).

3.2 PERSONNEL QUALIFICATION LEVELS

Of the 44 responding companies, 29 provided information on the highest level of qualification of their personnel (Figure 3.3). The majority of physicists (55%) were reported as having a master's degree, with 41% having a PhD degree. The majority of engineers (69%) were reported as having a master's degree, with 24% having a bachelor's degree. As for the research institutes (Section 2.2), the vast majority of technicians were not reported as having a university-level qualification; of those that do have university-level qualifications, 76% were reported as having a bachelor's degree.

This pattern of qualifications for personnel types roughly mirrors that of staff at research institutes (Section 2.2): physicists tend to have at least master's or PhD degrees, although there are relatively fewer with PhDs in companies; engineers tend to have master's or bachelor's degrees, with few having PhDs; technicians tend to have, at most, a bachelor's degree, although relatively more have master's degrees in companies than in research institutes. Overall, as might be expected, a greater proportion of reported qualified personnel have PhDs in research institutes (38%) than in companies (12%).

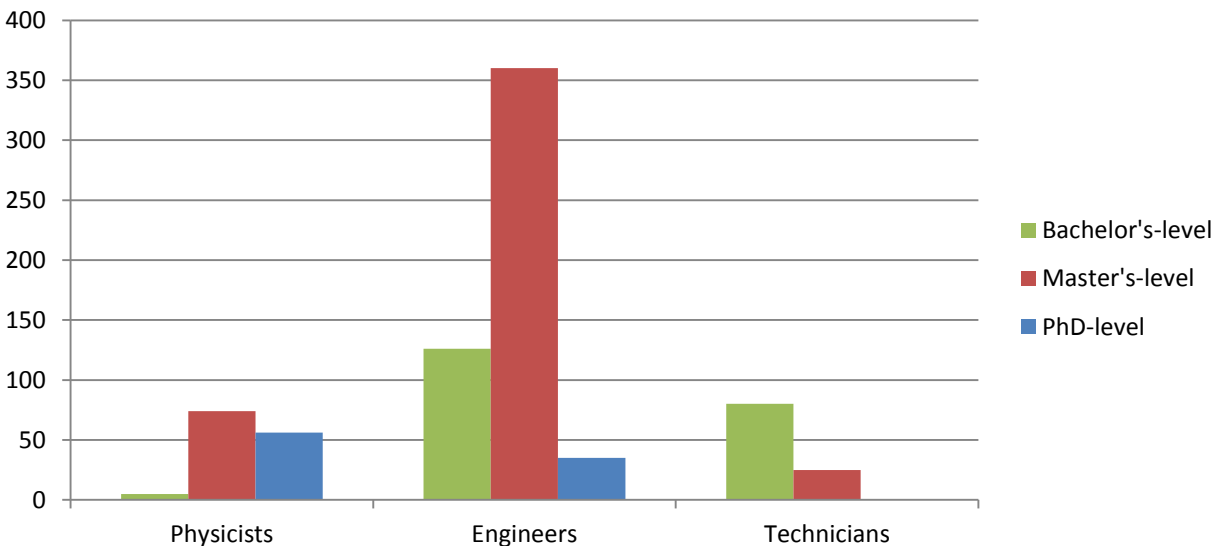


Figure 3.3: Reported highest qualification level that includes accelerator science and technology of current personnel engaged in accelerator activities at companies.

36 companies reported on the highest level of qualification *required* for new personnel; the percentage of companies requiring a highest qualification is shown by type of personnel in Figure 3.4. For physicists the largest reported percentage (25%) requires a PhD degree, with 19% requiring a master's. For engineers the largest percentage (42%) requires a master's degree, with 17% equally requiring either a bachelor's degree or a PhD. For technicians, 25% require a bachelor's degree and 9% a master's degree. Comparing Figures 3.3 and 3.4 there is a tendency for the required qualification level for new personnel to be slightly higher than the level for existing personnel.

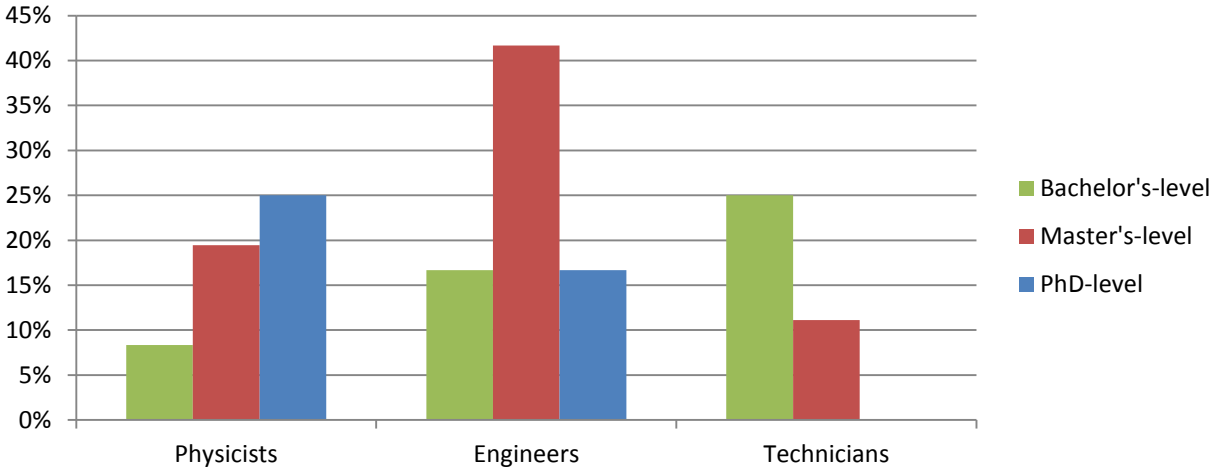


Figure 3.4: Reported highest qualification level required that includes accelerator science and technology (percentage of companies) for new personnel engaged in accelerator activities at companies.

The pattern of required qualifications for personnel in companies contrasts with that in research institutes (Section 2.2). A smaller percentage of companies vs. research institutes require physicists to have a PhD (25% vs. 63%); for engineers, the percentages are 17% vs. 29%. 25% of both reporting companies and research institutes require technicians to have a bachelor's degree, whereas to have a master's degree it is 11% vs. 4%. On average, as might be expected, physicists and engineers in research institutes are expected to have a higher qualification level than those in companies; for technicians the reported qualification requirement is slightly higher in companies than in research institutes, presumably reflecting the need for high-level manufacturing-related skills.

3.3 RECRUITMENT

43 responding companies reported on typical current annual recruitment numbers. The total numbers of personnel recruited annually are shown in Figure 3.5. The breakdown of the annual recruitment numbers between personnel categories is shown in Figure 3.6. Many more engineers and technicians are recruited than physicists, reflecting the personnel balance in favour of technical skills reported in Section 3.1. The same data are represented as a percentage of each respective category of personnel in Figure 3.7. The recruitment rate is just over 17% for all personnel categories. This is a significantly higher rate, by almost a factor of two, than that in the research institutes (Section 2.3), reflecting a higher degree of mobility, and commercial pressures, in the industrial sector.

The percentage of companies that reported having difficulties in recruiting accelerator-related personnel is shown by personnel category in Figure 3.8. The most serious difficulties are reported for recruitment of technical staff, with 70% of companies having difficulty recruiting engineers, and 50% having difficulty recruiting technicians. In contrast with the situation for research institutes, only 34% reported difficulty recruiting physicists.

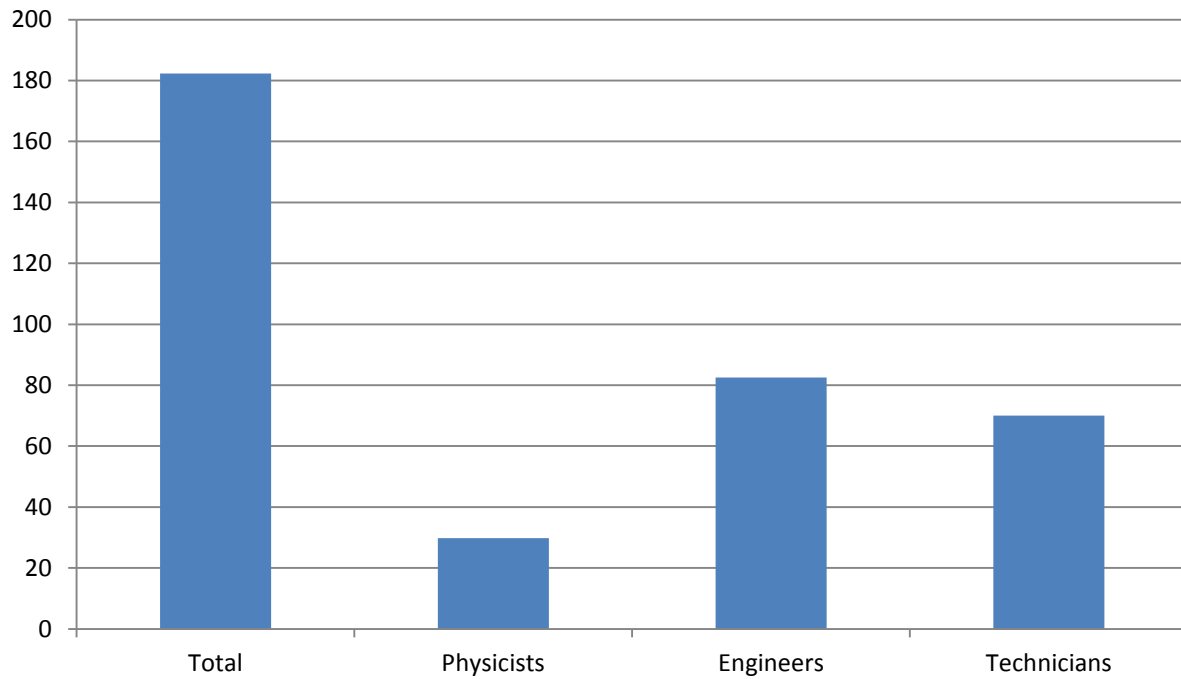


Figure 3.5: The number of accelerator-related personnel currently recruited annually.

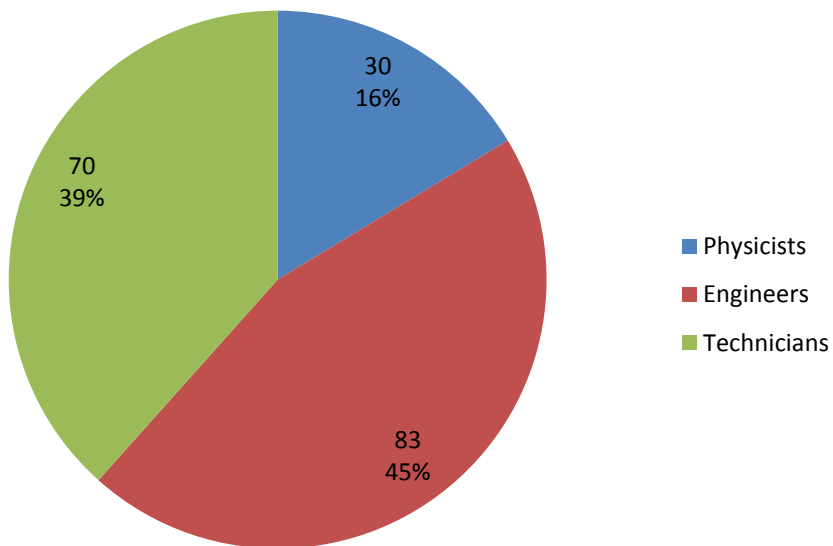


Figure 3.6: Percentage of the annual accelerator-related recruitment by category of personnel.

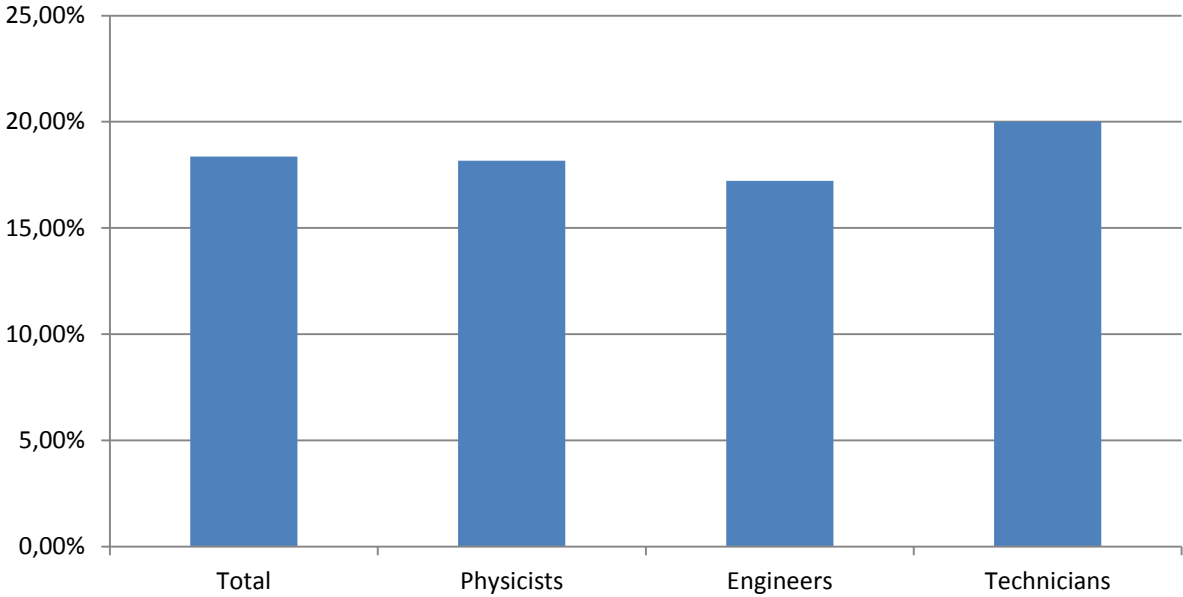


Figure 3.7: The percentage of each category of personnel currently recruited annually.

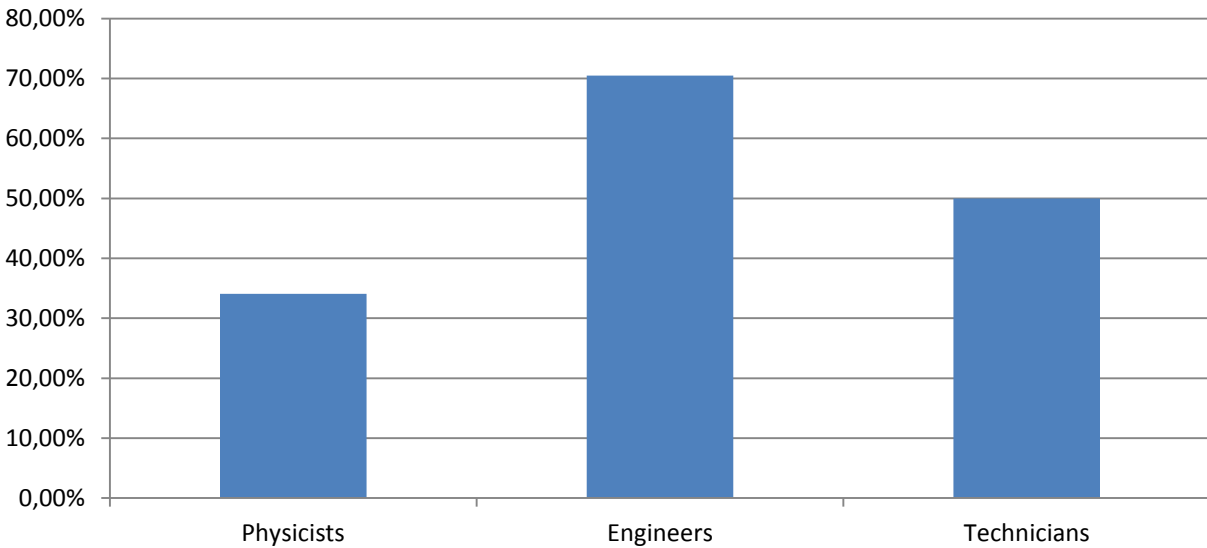


Figure 3.8: The percentage of all companies that reported difficulties in recruiting personnel, by personnel category.

Expertise shortages were reported in a number of areas; these are summarised in Figure 3.9. The most critical areas of shortage are in RF and vacuum systems, which were also noted by the research institutes (Section 2.3). In addition, both electronic and mechanical engineering were noted by companies as areas in which expertise is lacking.

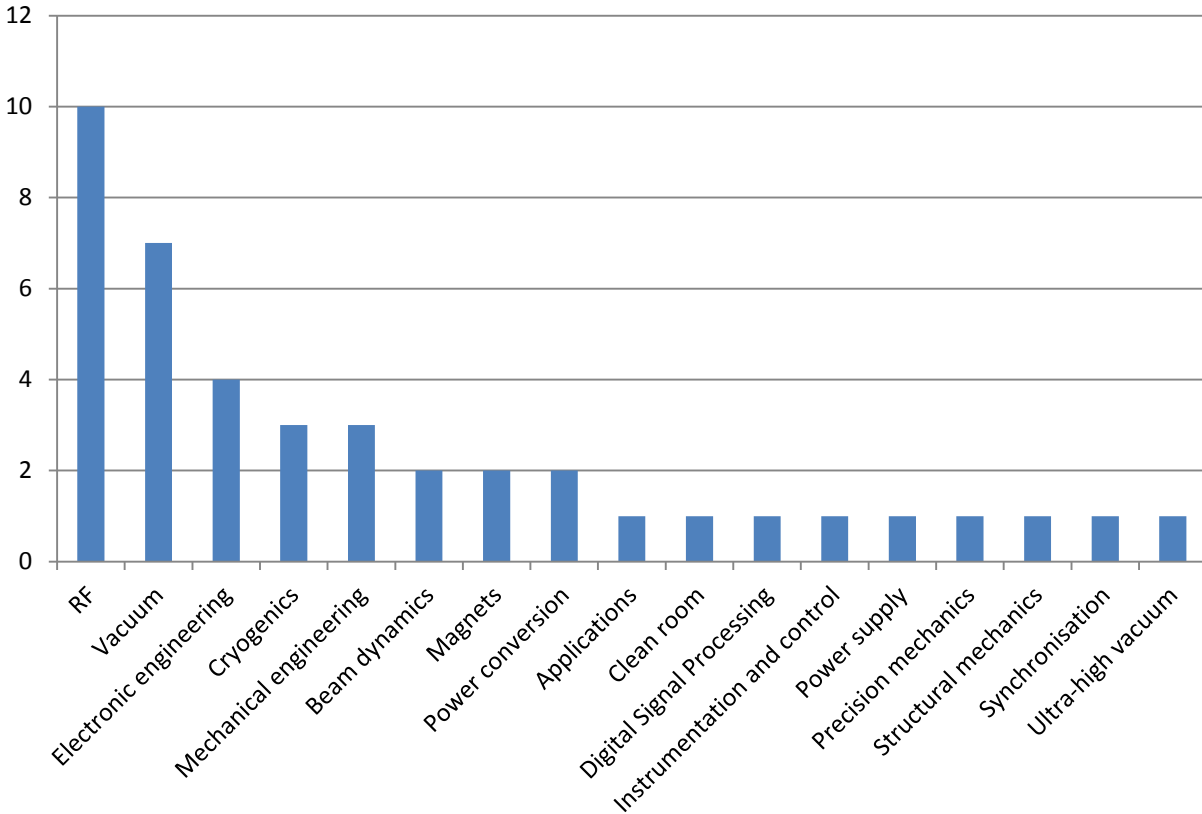


Figure 3.9: The number of companies that reported lacking expertise vs. area of expertise.

3.4. PERSONNEL TRAINING

40 companies reported on personnel training. The percentage of reporting companies that require training in accelerator science and technology for their personnel is shown, by trainee type, in Figure 3.10. 75% of all companies require training for personnel; 43% for physicists, 68% for engineers, and 55% for technicians. For all categories, the vast majority of training is provided ‘on the job’. However, in addition, 36% of all companies require external training for physicists, 48% for engineers, and 32% for technicians. Compared with research institutes, less training appears to be required, most notably for physicists. However, the needs for external training of engineers and technicians are similar in proportion to those in the research institutes (Section 2.4).

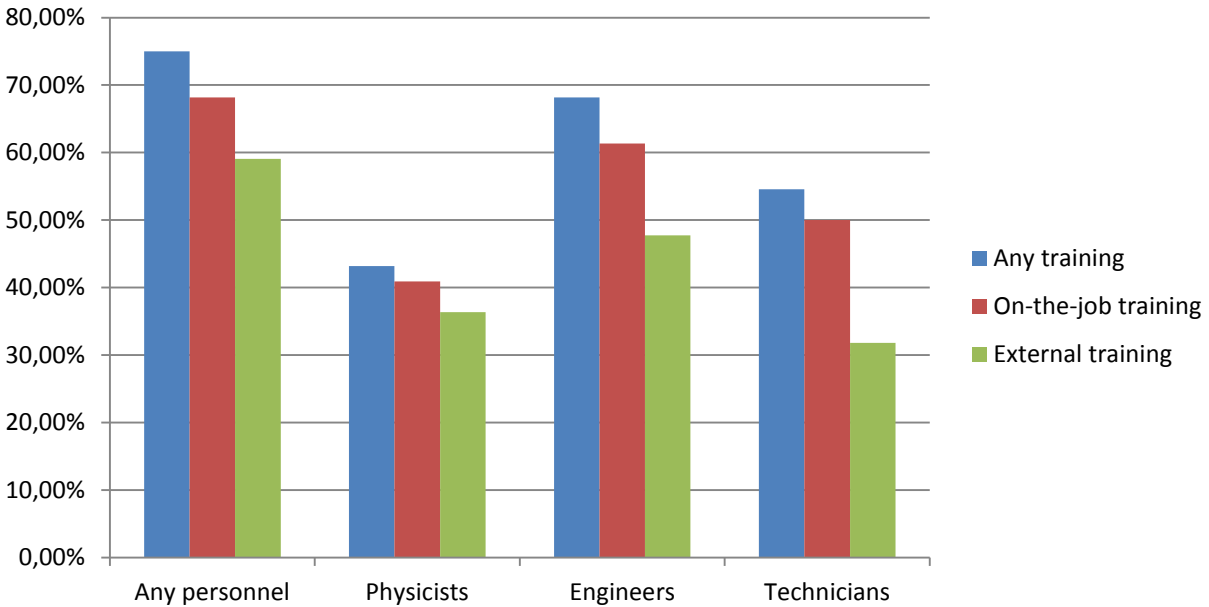


Figure 3.10: The percentage of all companies that reported requiring training for their personnel engaged in accelerator science, by personnel type.

4. HOSPITALS

A large number of trained physicists are employed in hospitals. In Europe measures of the number can be gauged from organisations such as ESTRO and EFOMP. ESTRO is the European Society for Radiotherapy and Oncology [2], covering radiation oncology professionals. Around one third of the 5000 members are physicists. EFOMP is the European Federation of Organisations in Medical Physics [3]; their current membership covers 35 national organisations and 3 affiliated national organisations which together represent more than 5000 physicists and engineers working in the field of medical physics. However, as discussed below, only a small fraction of them will be directly involved in the development of accelerator systems.

A large number of these physicists work in radiotherapy departments with accelerator systems; for example, in a 2011 UK workforce census, some 700 physicists were listed in 54 radiotherapy departments. A smaller number of physicists are also employed in PET-isotope producing accelerators; there are estimated to be more than 200 PET cyclotrons currently operating in the EU. The vast majority of such facilities are ‘turn-key’ systems provided by industry, requiring trained dedicated operators for normal practice and qualified staff for quality assurance and servicing. A substantial proportion of hospital-based physicists who work directly using accelerator technology require practical knowledge of the operation and maintenance of these systems. However, only very a small percentage will be involved in research and development of the accelerator systems, and such work as there is will be in close collaboration with (and typically led by) manufacturers. It is important to note that the planned particle therapy centres

(see below) in several countries, will expand the number of dedicated accelerator physicists in hospitals significantly.

5. HADRON THERAPY FACILITIES

Treatment of cancer and other diseases using charged hadron beams, typically protons, but also carbon ions, is a rapidly growing area of medicine. The particle beams are produced with accelerator systems. Currently there are 40 operating facilities worldwide [4], 12 of them in Europe. We estimate that a crew of between 10 and 15 highly-skilled and trained staff are required to operate and maintain the accelerator used in a modern hadron therapy facility. Typically several of the physicists and engineers have PhD-level training, and the remainder are degree-level engineers and technicians. The current ‘market’ for such accelerator-related personnel in Europe is hence in the range 120 – 180 people.

However, there is a rapid growth in this area, with 24 new facilities under construction worldwide [5], 9 of them in Europe, and a number of others (eg. 2 in the UK) planned for construction within the next decade. The ‘doubling time’ for the number of facilities is estimated to be about 8 years. Hence, looking ahead 5-10 years from now, the market for trained accelerator-related personnel is likely to be approaching 240 – 360 people. Training for new staff is likely to be a mix of ‘on the job’ training and training at other operating hadron therapy facilities.

6. IMPROVING THE SUPPLY OF TRAINED PERSONNEL

Respondents were invited to suggest methods for improving the supply of, and access to, trained personnel. In terms of *supply* of personnel, suggestions included:

- Encouragement of more universities to include accelerator science in their curricula.
- More dedicated accelerator science Master’s and PhD courses, including via the Inter-university Erasmus Mundus programme.
- Contacts and specialised accelerator-related courses within engineering faculties.
- More training courses at the post-doctoral level.
- Wider provision of grants and/or sponsorship for accelerator training.
- Increasing the number of university faculty positions in accelerator science.
- Greater provision of specialised courses in accelerator science, including summer schools and nationally-organised schools.
- Greater possibility of transition between research and engineering careers.
- Development of in-house training in relevant companies and hospitals.

Higher salaries, increased funding to allow more positions (both temporary and permanent, and improved public relations were also mentioned as being factors that could be addressed to improve supply.

In terms of *access* to qualified personnel, suggestions included:

- Greater collaboration between academia and industry.
- Dedicated campus recruitment activities, and university ‘job boards’.
- A pan-European database, or ‘professional register’, of accelerator-trained students and personnel.
- A website of accelerator-related jobs and opportunities.
- Improved access to large facilities.
- More industry/laboratory placements and internships.

These suggestions will be further explored and developed in our next report.

7. SUMMARY OF MAIN FINDINGS

- 70 research institutes, and 44 companies, from Denmark, Finland, France, Germany, Italy, Norway, Poland, Spain, Sweden, Switzerland and the United Kingdom completed the TIARA survey on market needs for personnel trained in accelerator science. A total of 3638 personnel at the institutes, and 993 at the companies, are engaged in accelerator-related activities.
- In all the countries surveyed a growth in total accelerator-related personnel at research institutes is projected over the next 5 years. The biggest increases are for Germany (+24%), Italy (+55%) and the Nordic countries (+68%), where there are large ongoing (or planned) accelerator facility construction projects. Overall the growth is projected to be 18%. The companies project a corresponding growth of 20% in total accelerator-related personnel over the next 5 years.
- All categories of accelerator personnel are expected to grow in number, but the increase is proportionally larger for engineers and technicians, which presumably reflects the need for technical staff for construction of the new accelerator projects.
- Physicists typically have at least master’s or PhD degrees; engineers typically have master’s or bachelor’s degrees, with fewer having PhDs; technicians typically have, at most, a bachelor’s degree. A greater proportion of personnel have PhDs in research institutes than in companies.
- 61 research institutes and 43 companies reported on personnel recruitment. The overall annual recruitment rate is approximately 9% for research institutes, and 18% for companies. The majority of institutes and companies reported difficulties in recruiting appropriate personnel; in particular, roughly 70% have difficulty recruiting engineers for accelerator-related work.
- Skills shortages were reported in a number of key areas. The most critical areas of shortage are in RF systems, beam dynamics, instrumentation and control, and vacuum systems.

- 68 research institutes and 40 companies reported on personnel training in accelerator science. 94% of research institutes and 75% of companies require training for their personnel. Although most training is provided ‘on-the-job’, there is a significant need for training provided by external bodies.
- The growth of accelerator-based techniques in medicine will require a significant increase in the number of suitably qualified personnel. For example, the number of personnel required to operate hadron therapy facilities is likely to double over the next 5-10 years.

8. OUTLOOK

The survey has provided a remarkable ‘snapshot’ of the market needs for accelerator science personnel within the participating European states. The response rate has been extremely high. It could well be appropriate to repeat the survey periodically in the future, in which case an attempt could be made to gather data on these points.

REFERENCES

[1] TIARA education and training survey results:

<http://tiara.physics.ox.ac.uk/database-of-survey-results/>

TIARA education and training survey report:

<http://cds.cern.ch/record/1442599>

[2] <http://www.estro.org>

[3] <http://www.efomp.org>

[4] <http://ptcog.web.psi.ch/ptcentres.html>

[5] <http://ptcog.web.psi.ch/newptcentres.html>

ACKNOWLEDGEMENTS

We are grateful to C. Timlin, M. Partridge and K. Peach for providing relevant information on hospitals and hadron therapy facilities.

APPENDIXES

APPENDIX 1: Survey spreadsheet

<u>SURVEY ON 'MARKET NEEDS' FOR TRAINED PERSONNEL IN ACCELERATOR SCIENCE & ENGINEERING</u>				
ALL DATA WILL BE TREATED IN STRICT CONFIDENCE AND ANONYMISED IN ANY STUDY				
You & your institution				
Your name				
Institution name				
Name of project (e.g. XFEL, ESS), OR institution (e.g. CERN) that you are reporting on here.				
Accelerator science & engineering personnel numbers				
	Physicists	Engineers	Technicians	Total
How many of the following personnel do you have who are engaged in accelerator projects?				
How many do you expect to have in 5 years?				
How many do you recruit in a typical year?				
For engineering personnel: specify the field of speciality (e.g. mechanical, electrical...)				
Is any qualification including accelerator science & engineering currently required at the level of:				
	Physicists	Engineers	Technicians	Total
Bachelor's (yes/no)				
Current number of Bachelors-level personnel (if known)				
Master's (yes/no)				
Current number of Master's-level personnel (if known)				
PhD (yes/no)				
Current number of PhD-level personnel (if known)				
Do you need to train your personnel in accelerator science & engineering? (yes/no)				
	Physicists	Engineers	Technicians	
If yes, by which means?				
On-the-job training (yes/no)				
Formal training/qualifications from an external source (yes/no)				
Do you have difficulty recruiting people with expertise in accelerators? (yes/no)				
	Physicists	Engineers	Technicians	
Are you short of people with relevant expertise? (please specify: e.g. beam dynamics, electronic engineering, vacuum, RF ...)				
Do you have suggestions for improving the supply of, or access to, suitably trained people?				
Any other comments				

APPENDIX 2: Responding research institutes and contact persons

Denmark

ISA, Aarhus University, Søren Pape Møller

Finland

Aalto University, Filip Tuomisto

Åbo Akademi University, Jan-Olof Lill

Department of Physics, University of Jyväskylä, Pauli Heikkinen

University of Helsinki, Jyrki Räsänen

France

C2RMF-FR3506, Claire Pacheco

CEA/INAC/SBT, Alain Girard

CEA/DSM/IRFU/SACM, Antoine Dael

CNRS/IN2P3/CENBG, Laurent Serani

CNRS/IN2P3/CSNSM, Cyril Bachelet

CNRS/IN2P3/IPN Orsay, Luc Perrot

CNRS/IN2P3/LAL Orsay, Alessandro Variola

CNRS/IN2P3/LAPP-Université de Savoie, Andrea Jeremie

CNRS/IN2P3/LLR- Ecole polytechnique, Arnd Specka

CNRS/IN2P3/LPSC, Maud Baylac

CNRS/IN2P3/SUBATECH-Université et Ecole des Mines de Nantes, Freddy Poirier

ENSTA-CNRS-Ecole polytechnique/LOA, Victor Malka

ESRF, Jean-luc Revol

GANIL-CEA-CNRS, Florent Staley, Marec Lewitowicz, Frederic Chautard

Synchrotron SOLEIL, Nadji Amor, Laurent Nadolski

Université Paris-Sud-CNRS/LCP, Jean Michel ORTEGA

Germany

DESY, Alexander Gamp

GSI Helmholtzzentrum für Schwerionenforschung GmbH, Oliver Kester

Helmholtz-Zentrum Berlin, Andreas Jankowiak

Institut für Kernphysik der Johannes Gutenberg-Universität Mainz, Kurt Aulenbacher

Institut für Kernphysik, FZ Jülich, Andreas Lehrach

Italy

ENEA, Luigi Picardi

Fondazione CNAO, Marco Pullia

INFN - Laboratori Nazionali del Sud, Luciano Calabretta

INFN - Laboratori Nazionali di Frascati, Andrea Ghigo

INFN - Laboratori Nazionali di Legnaro, Giovanni Bisoffi, Andrea Pisent

INFN - Milano & Università degli Studi di Milano, Paolo Pierini

Sincrotrone Trieste, Gerardo D'Auria

ESS - Italy c/o INFN - Laboratori Nazionali del Sud, Santo Gammino

IFMIF-Italy c/o INFN Laboratori Nazionali di Legnaro, Andrea Pisent

SuperB/SuperC – CabibboLab, Walter Scandale

INFN - Napoli & Università degli Studi di Napoli Federico II, Maria Rosaria Masullo

INFN - Pisa & Università degli Studi di Pisa, Franco Cervelli

Norway

University of Oslo, Steinar Stapnes

Poland

Institute of Nuclear Physics, Polish Academy of Sciences, Piotr Malecki

National Centre for Nuclear Research, Slawomir Wronka

Warsaw University of Technology, Ryszard S. Romaniuk

Spain

ALBA CELLS, Gaston Garcia

AMIT Cyclotron, CIEMAT, Fernando Toral

CLIC, CIEMAT, Fernando Toral

CMAM, Universidad Autónoma de Madrid, Ángel Muñoz-Martín.

CNA, Centro Nacional de Aceleradores, Joquin Gomez Camacho

CIEMAT, Centro de Investigaciones Energéticas Medioambientales y Tecnológicas. Marisa Marco

ESS Bilbao, European Spallation Source of Bilbao, FJ Bermejo

UPC, Technical University of Catalonia (Universitat Politecnica de Catalunya), Youri Kubyshin

Sweden

European Spallation Source ESS AB, Håkan Danared

Lund University/MAX-lab, Sverker Werin

Stockholm University, Ansgar Simonsson

The Svedberg Laboratory, Uppsala University, Björn Gålnander

Switzerland

CERN, Roger Bailey

Paul Scherrer Institut, Terence Garvey

United Kingdom

Diamond Light Source, Riccardo Bartolini

Dundee University, Allan Gillespie

Glasgow University, Paul Soler

Huddersfield University, Roger Barlow

Imperial College London, Juergen Pozimski

John Adams Institute, University of Oxford, Philip Burrows

John Adams Institute, Royal Holloway, University of London, Stewart Boogert

Lancaster University, Amos Dexter

Liverpool University, Andy Wolski

Manchester University, Roger Jones

Science and Technology Facilities Council, Greg Diakun

Sheffield University, Chris Booth

Strathclyde University, Alan Phelps

Surrey University, Karen Kirkby

Warwick University, Paul Harrison

University College London, Matthew Wing

APPENDIX 3: Country-specific analysis

In this appendix section we provide context and commentary on specific issues relating to individual countries, especially where there are different trends relative to the ‘average’ findings reported above.

France: Research institutes

For this survey, the laboratories have been contacted via the SFP, French Society of Physics (Société Française de Physique, Interdivision Physique des Accélérateurs et Technologies Associées). 16 of the 23 contacted laboratories provided information and it can be estimated that the main actors in accelerator have responded to the survey.

The landscape of French laboratories investigated has two characteristics:

- A part of the laboratories does mainly accelerator R&D and construction and tests of parts of accelerators, which are then sent elsewhere (e.g. SACM, IPN Orsay, LAL) whereas others are facilities for users (e.g. ESRF, Synchrotron Soleil, Arronax).
- There is a large discrepancy in number of personnel involved in accelerator science (from 3 to 170 employees). Laboratories can be roughly classified in 3 categories:
 - "Big" laboratories, with number of personnel working on accelerator projects up to 50: Ganil, Synchrotron Soleil, IPN Orsay, SACM, ESRF
 - "Intermediate" laboratories, number of personnel between 10 and 50: C2RMF, LPSC, LAL
 - "Small" laboratories, number of personnel less than 10: CLIO, CSNSM, Arronax, CENBG, LLR, LAPP. (It is worth noting that Arronax will significantly increase its personnel from 6 to 15 in next five years)

1. Evolution of personnel involved in accelerator science

First it should be noted that some of the laboratories, with activities in accelerator R&D mainly, expressed a difficulty to foresee the needs in personnel in 5 years.

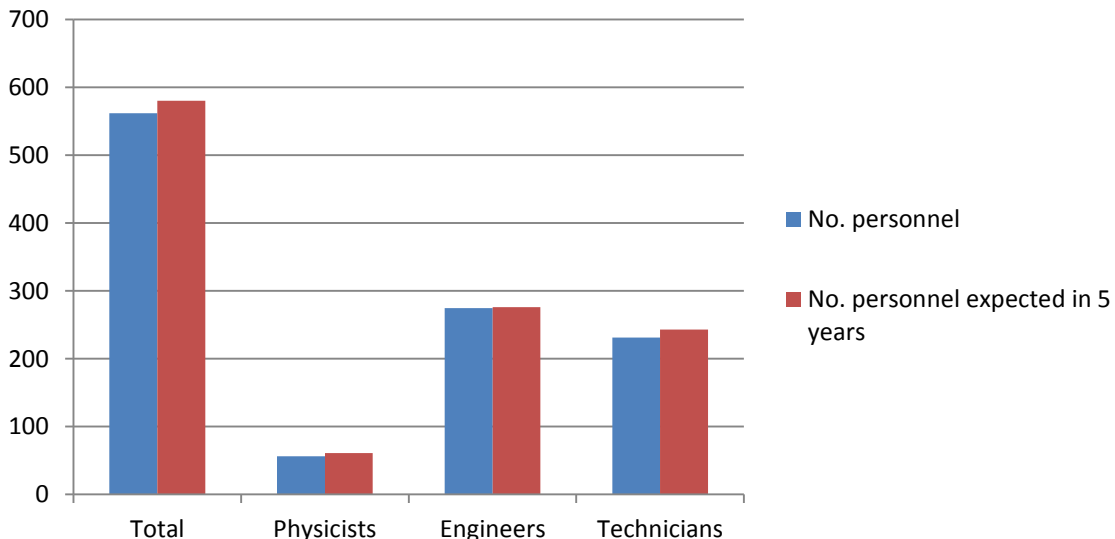


Figure 1: Total number of current personnel (blue) engaged in accelerator science activity at research institutes. The number of personnel expected in 5 years is shown in red.

Globally, French laboratories foresee a very small increase of their staff (3%), taking into account the natural renewal due to retirements and transfers. This increase is much lower than

the overall increase estimated in Europe (18%) and comes mainly from the “small” and “intermediary” laboratories. The "big" laboratories keep a constant number of personnel involved in accelerator science.

The reported breakdown of qualifications indicates that about 50 % are engineers, about 40 % are technicians and about 10 % are physicists. This proportion should remain stable within the coming 5 years. The low proportion of physicists (10%) in France compared to the average proportion in Europe (about 30%) can be explained by the following statement: In France, the distinction Physicist/Engineer is not made officially in some of the institutes (called EPIC²). For this survey, Ganil, which represents 31% of the total number of personnel, considered all the non-technician personnel as engineers.

2. Personnel qualification levels

Generally, the correspondence between category and degree is:

- For a physicist, a PhD is mandatory.
- For an engineer, a PhD or Master degree is required. Most of the engineer degrees are not delivered by university but by engineering school and are equivalent to a Master degree.
- For a technician, the BTS (Brevet de Technicien Supérieur) is required in most cases, which can be awarded 2 years after the Baccalaureat, to be compared to a Bachelor degree which can be awarded 3 years after the Baccalaureat.

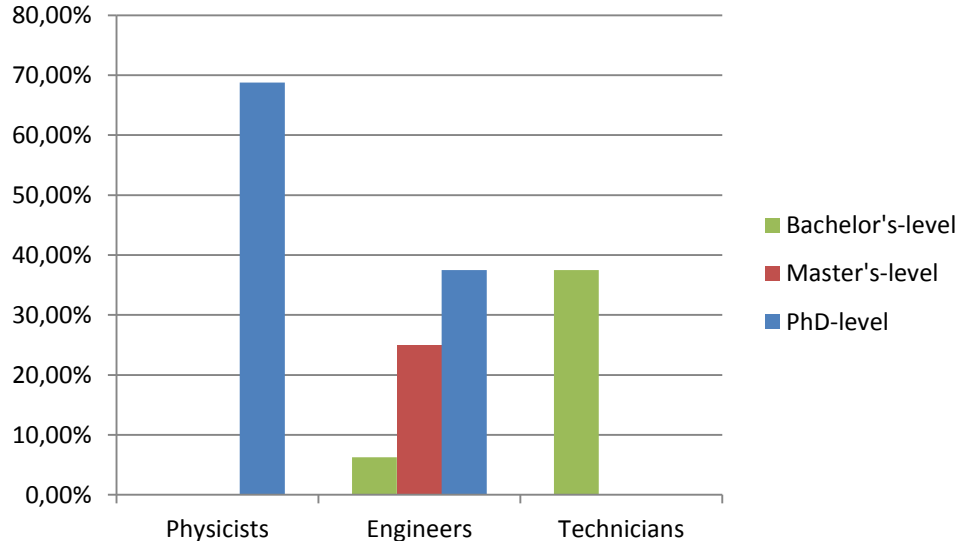


Figure 2: Reported highest qualification level required in accelerator science (percentage of all institutes) for new personnel in accelerator science activities at research institutes.

Most French institutions report that their physicists have to hold a PhD including accelerator science and engineering. For engineers, the requirement in accelerator science knowledge is slightly qualified according to their level of qualification (or diploma). On the contrary, that is

² EPIC means Public Institution of Industrial and Commercial nature. Ganil, CEA are EPIC.

not mandatory for technicians because specific accelerator training does not exist at bachelor's level. Moreover, some professions in accelerator projects (e.g. mechanical) do not require any qualification in accelerator science. Thus some laboratories were reluctant to give a clear answer "yes" or no" and would have preferred to qualify their answer.

3. Recruitment

It is reported by the responding institutes that about 20 personnel are recruited in accelerator science and engineering in a typical year. The recruitment rate for each category is shown below.

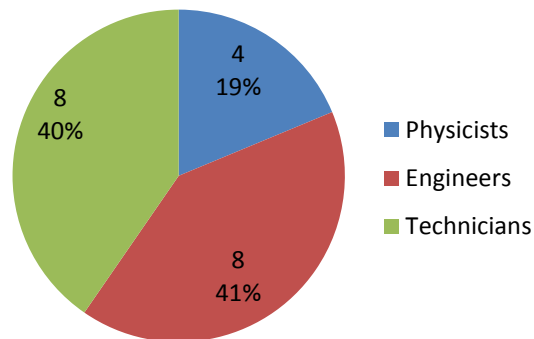


Figure 3: the relative proportions of the categories of personnel currently recruited annually

As a majority of European institutes, the French institutes reported difficulties in recruiting. Some explanation is given below depending on qualification levels:

- For engineers and technicians, the field seems to be not enough attractive for students. Another reason very often mentioned is that accelerator classes appear too late in the curriculum, only at Master 2's level, instead of Bachelor's level as it should be.
- For technicians, low salary and poor career opportunities are the main obstacles.

4. Personnel training

Most institutions reported a need for training their staff, either 'on the job' but also with external training, especially for engineers and technicians. This statement is in good agreement with the fact that these personnel are mainly recruited without specific accelerator qualification. The main reason is that up to these levels of qualifications, few French schools provide training in the field of accelerator technologies.

Germany: Research institutes

The German data includes information from DESY with the international project XFEL and from GSI with the international project FAIR. Information from the national institutes Helmholtz-Zentrum Berlin (BESSY) and Juelich as well as from the University of Mainz completes the German survey of the marked needs for scientific-technical personnel defined as physicists, engineers, and technicians. The scientific-technical personnel engaged today and expected in 5 years in German accelerator research institutes is shown in Figure 1. The expected high increase of personnel, especially compared to other TIARA member states, can be explained by the FAIR project at GSI. GSI expected to hire about 120 engineers and technicians in the next years for planning, order, construction and future operation of the accelerators and storage rings. All other reporting German institutes will hold or increase moderately their number of personnel.

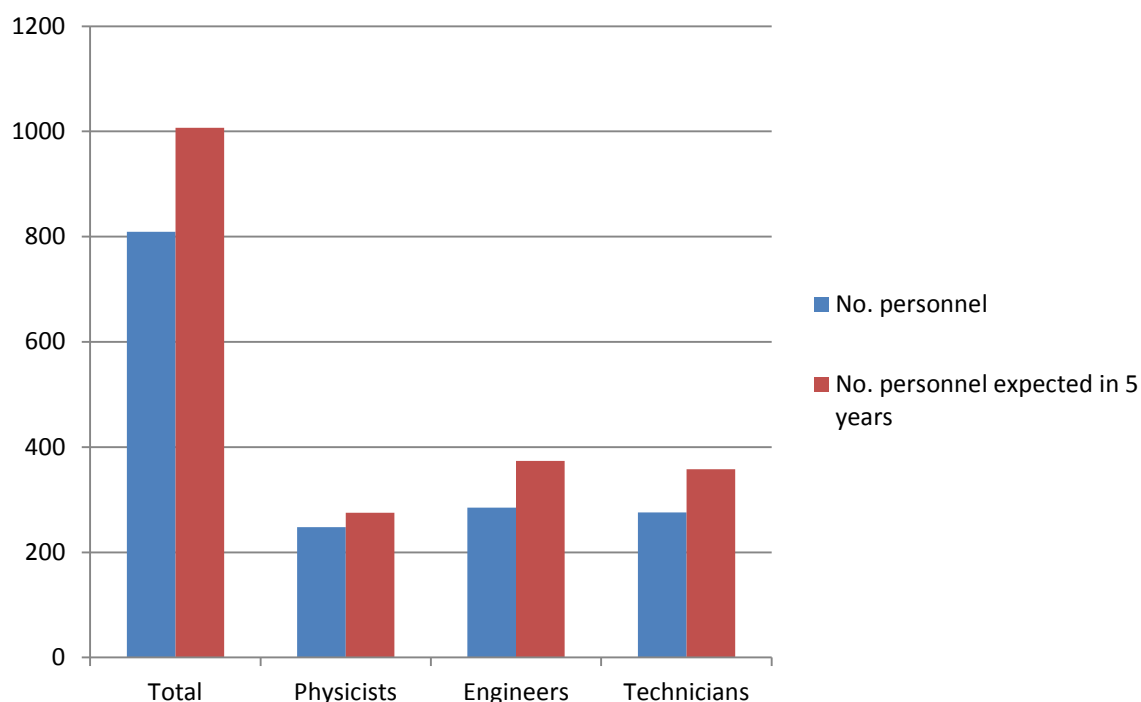


Figure 1: Total number of personnel engaged today (blue) and expected in 5 years (red) in German institutes.

Figure 1a shows the reported qualification level of personnel in German accelerator research institutes. 193 Physicist hold a PhD as highest degree and only 32 physicists a master's degree. 116 engineers hold a master's degree and 162 a bachelor's degree. The highest degree for technicians is the bachelor's degree.

Before the introduction of the bachelor's and master's degree in Germany, the standard degree was the German diploma (Diplom) and could be obtained at university and university of applied sciences (Fachhochschule). For the comparison to the other TIARA member, a diploma degree from a university is considered as master's degree and a university of applied sciences as bachelor degree. Most technicians do not hold a university bachelor degree but obtained comparable skills by 'on the job' training (Berufsausbildung). During the three years of

apprenticeship, the apprentices spend about 50-70% of their time in companies and the rest in formal education in vocational school. Normally the candidates for apprenticeships are young people under 22 with a second school degree. The German accelerator research institutes offer apprenticeships for technicians such as electricians, industrial mechanics and engineering draftsmen.

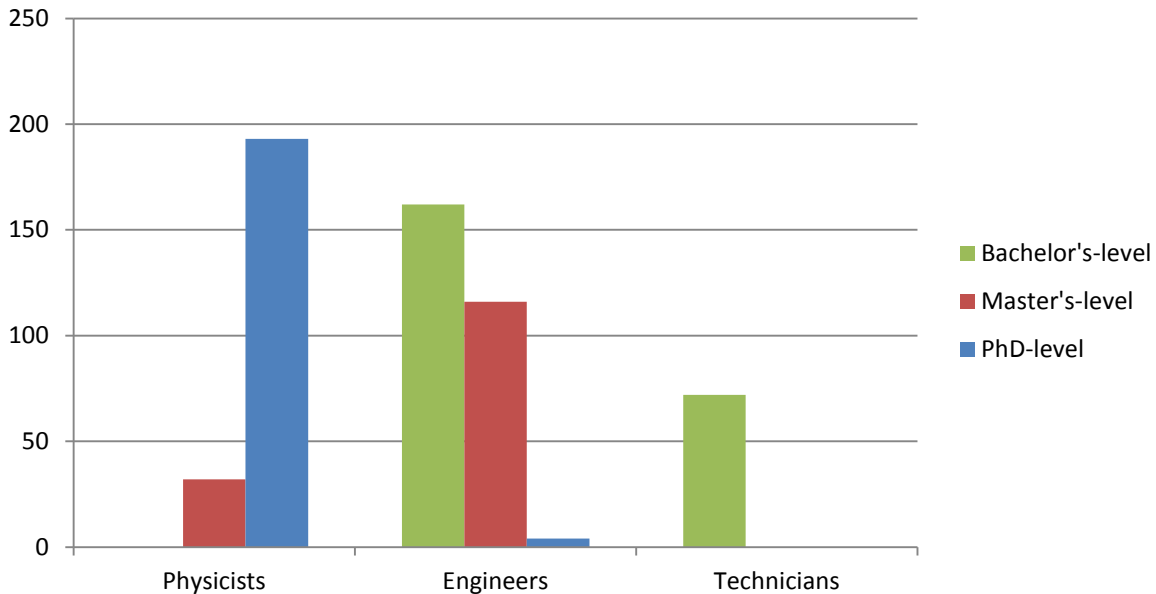


Figure 1a: Reported qualification level of personnel in German accelerator research institutes breakdown to the highest degree hold by the employee.

Figure 2 shows the percentage of all institutes requiring qualifications in accelerator science. All German institutes require from their employed physicists qualification in accelerator science and technology. 60 % of the reporting German institutes require from their employed engineers a qualification in accelerator science and technology. From the employed technicians, no specific qualification in accelerator science is required.

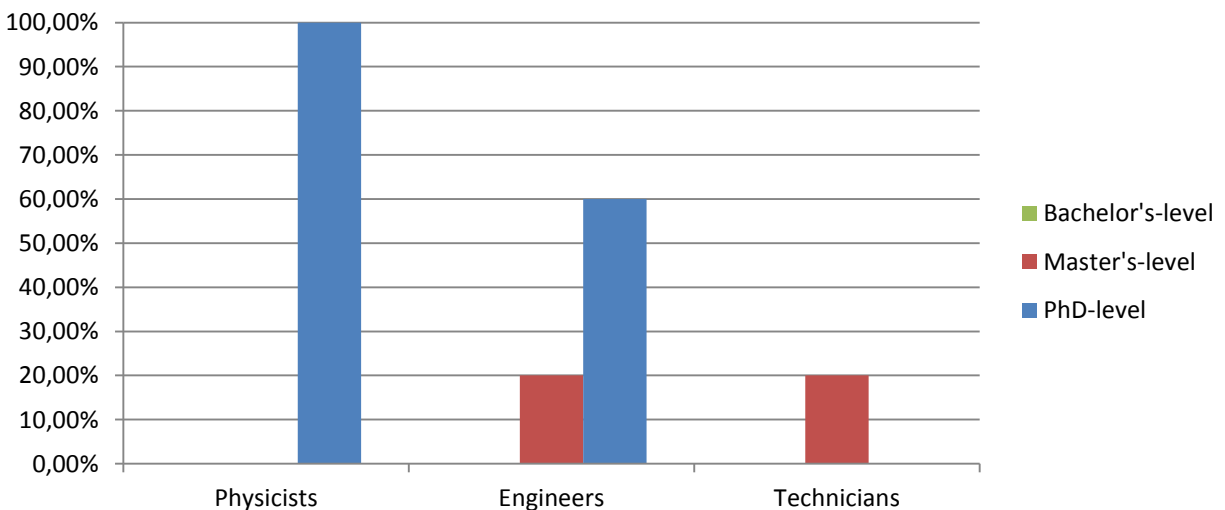


Figure 2: Percentage of all institutes requiring qualification in accelerator science.

German institutes recruited in a typical year about 50 new employees, thereof one third are physicists, one third are engineers and one third are technicians (See figure 3).

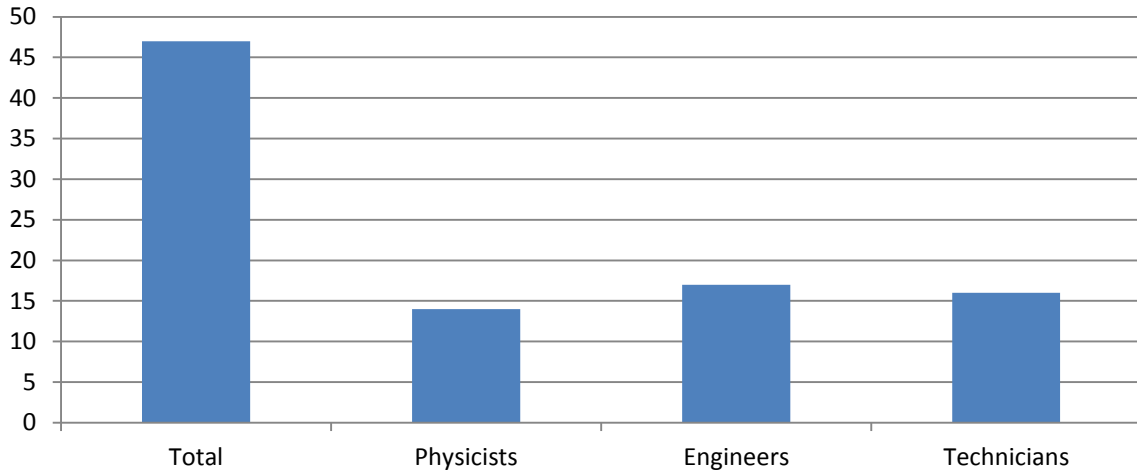


Figure 3: Typical number of personnel recruited each year

All German institutes requiring on-the-job training as well as external in accelerator physics and technology for their employees shown in Figure 4.

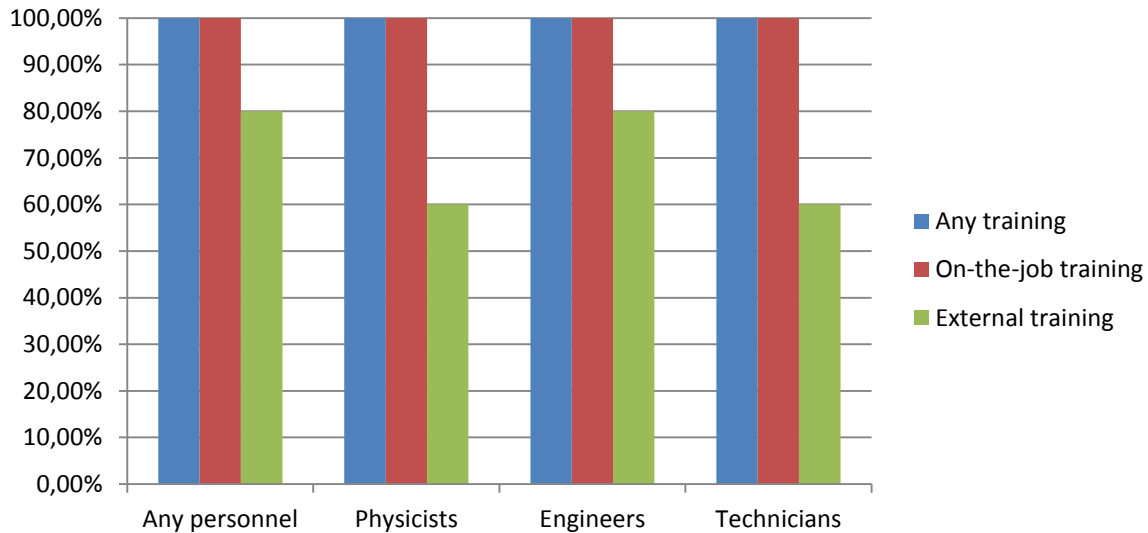


Figure 4: Percentage of all German institutes requiring training

Figure 5 shows that all German institutes had difficulties to recruit engineers and technicians due to the low payment and poor career opportunities in the public system as well as due to the shortage of skilled professionals in German (Fachkräftemangel). The situation for recruiting physicists is better, especially for the German research institutes with close contacts to universities, with accelerator physics courses.

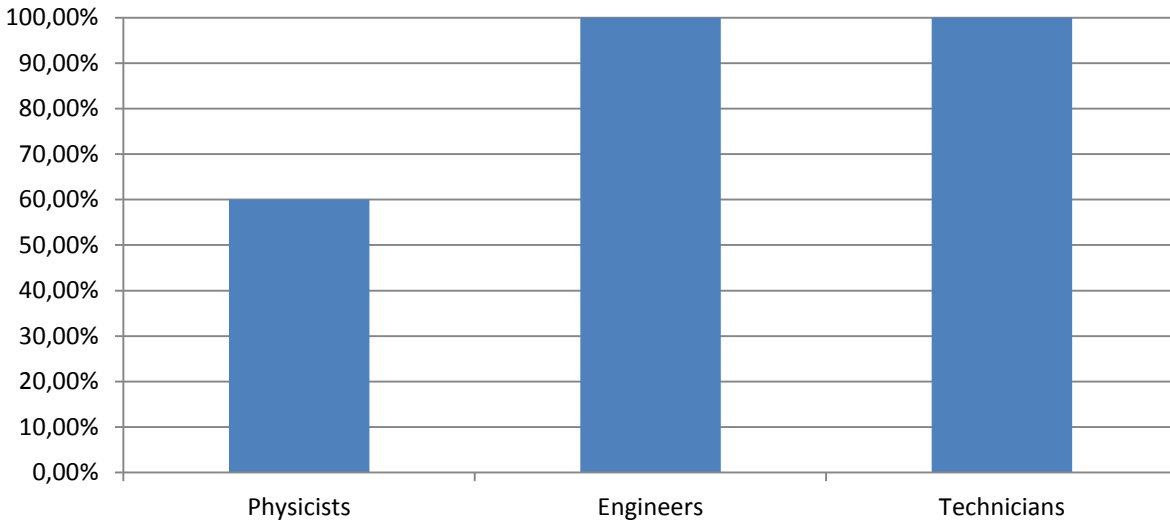


Figure 5: Percentage of all institutes having difficulty-recruiting personnel.

Italy: Research institutes

7 Italian laboratories answered our survey on the market needs for accelerator-trained personnel, together with the Italian groups collaborating with the ESS and the IFMIF international projects, and the SuperB project.

The present number of employed personnel, together with the 5-year projection is shown in Figure 1. The spectacular increase (almost 50 %) in personnel, much higher than the general trend in Europe, is mainly due to the forecoming project of building a Super Flavour Factory in Frascati. In spite of the recent government decision of turning the SuperB project into a much smaller budget project, the rescaling to a SuperC (Tau Charm Factory) should not imply a decrease in the need of new personnel. Nevertheless, as the final decision is not taken yet at the moment of writing this report, the projection should be taken with some caution. Furthermore, some groups have foreseen some expansion in their personnel only based on their needs for their on-going projects without taking into account the constraints given by the spending reviews going on in the Italian public administration. Due to these uncertainties, the 5 years expected personnel given in Figure 1 should be considered as an optimistic upper limit.

Two universities answered the survey, but, as it is usually the case also in the other Italian universities, training in accelerator physics or engineering is not a requirement for recruitment, therefore they have not been included in this analysis.

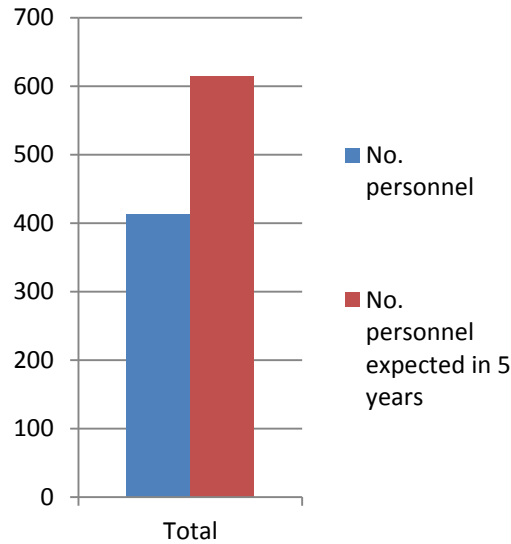


Figure 1: Total number of current personnel (blue) engaged in accelerator science activities at research institutes. The number of personnel expected in 5 years is shown in red.

The breakdown of present personnel is shown in Figure 2a. We observe that, whilst the percentage of physicists in Italy is comparable with Europe, in percentage in Italy there are many more technicians than engineers. Indeed in Italy an engineer normally owns a master's degree, and very often also a PhD. Therefore, from the academic point of view, he/she has the same qualification as a physicist, which is generally not the case in Europe. This is why in Italy most of the personnel that are counted as engineers in Europe fall into the category of technicians.

It has to be pointed out that in Italy the Bologna Declaration of 1999 has been applied only formally in most of the engineering faculties: the original 5 year university program was split into 3 and 2 year programs, without any change in the single subject programs. Therefore, as the course programs have not changed, the objective of the reform, that the undergraduate level of higher education should lead to a professional qualification 'relevant for the labour market', is not attained and students are obliged to continue their studies for at least another 2 years.

This Italian peculiarity is also reflected in the qualification required for new engineering positions (Figure 4): only 1 in 10 institutes requires a bachelor's level for an engineer, whilst 2 institutes even ask for a PhD. A similar situation can be found in the qualification required by the Italian companies (see later, Figure 9), for 1 in 9 of them a bachelor's degree is sufficient, while 1 in 9 requires a PhD.

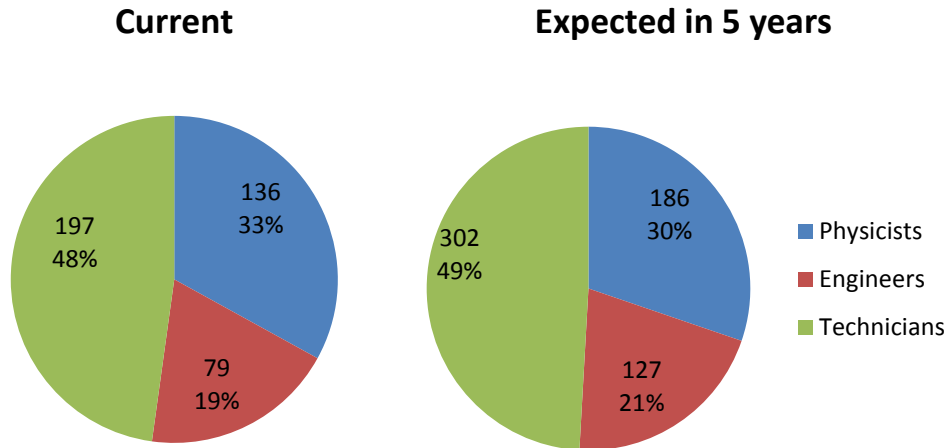


Figure 2: Reported breakdown of personnel engaged in accelerator science and engineering at research institutes currently (left, a), and expected in 5 years (right, b).

The proportion among the three categories will not vary much in 5 years from now (Figure 2b); there will be only a small increase in the relative number of engineers and technicians with respect to physicists, reflecting the passage from the project phase to the construction phase of the new accelerator.

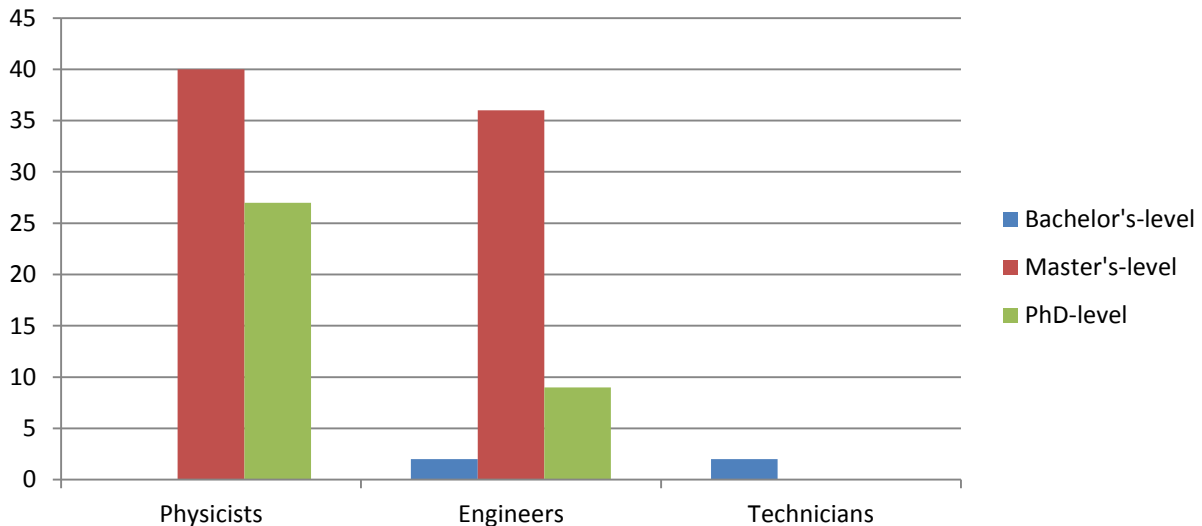


Figure 3: Reported highest qualification level of current personnel engaged in accelerator science activities at research institutes.

The qualification of the presently employed personnel is shown in Figure 3. The information is rather incomplete as it accounts only for about 28 % of the total number of employees, and this is most probably due to the fact that very often the person who answered the questionnaire was not aware of the full education history of all other members of the personnel. Nevertheless, we have a large enough sample to be representative of the whole community.

Unlike Europe, most physicists and engineers in the present staff own a master degree, fewer own a PhD. This can be explained with the fact that until 1984, when the PhD program was started, the ‘Laurea’, which is now considered equivalent to a master level degree, was the highest education level in Italy. The PhD programs only went to regime around 1990, but having a PhD was not a strict requirement for research positions until very recently. Consequently, people over 50 only quite seldom own a PhD, and they are almost the majority. Indeed, it should be pointed out that in Italy the average age of researchers is getting higher and higher - just below 50 in the INFN - because very little recruitment was possible in the last several years due to the economic situation.

The qualification required nowadays for the different positions is shown in Figure 4. For physicists a PhD is preferred, while for engineers 7 institutes over 10 only require a master’s degree. We should point out, though, that in Italy there exists neither a degree nor a PhD program labelled ‘accelerator physics’; only very recently a PhD program in Accelerator Physics has been started in Roma “La Sapienza”. Usually a general academic title of a certain level is required, and this is what is reported in Figure 4, plus some specific experience in the field, which has been most often gained either hands-on or in preparation of a master’s or a PhD exam or during a postdoctoral fellowship.

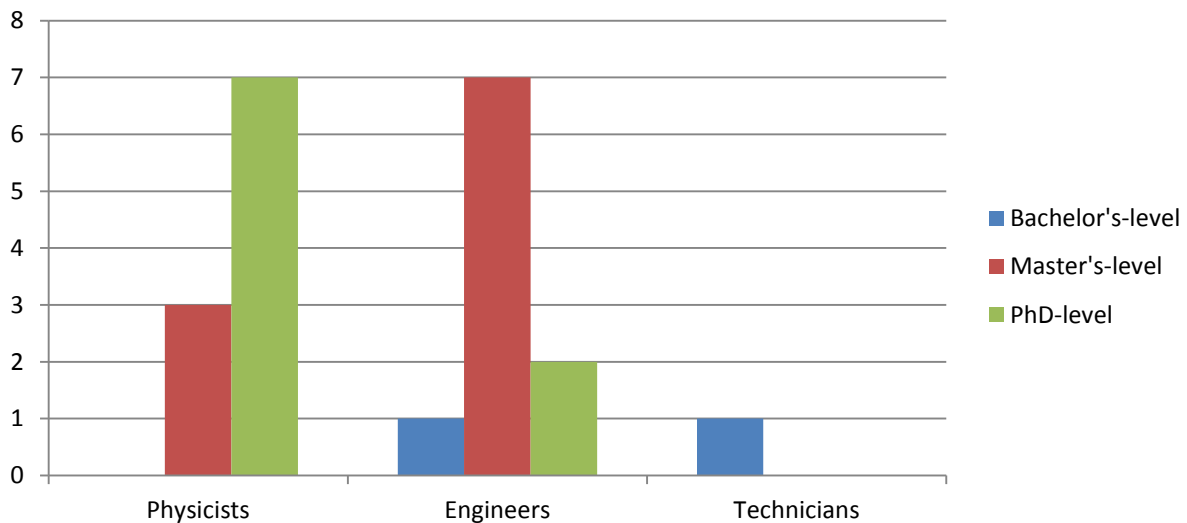


Figure 4: Reported highest qualification level required in accelerator science (number of institutes) for new personnel in accelerator science activities at research institutes

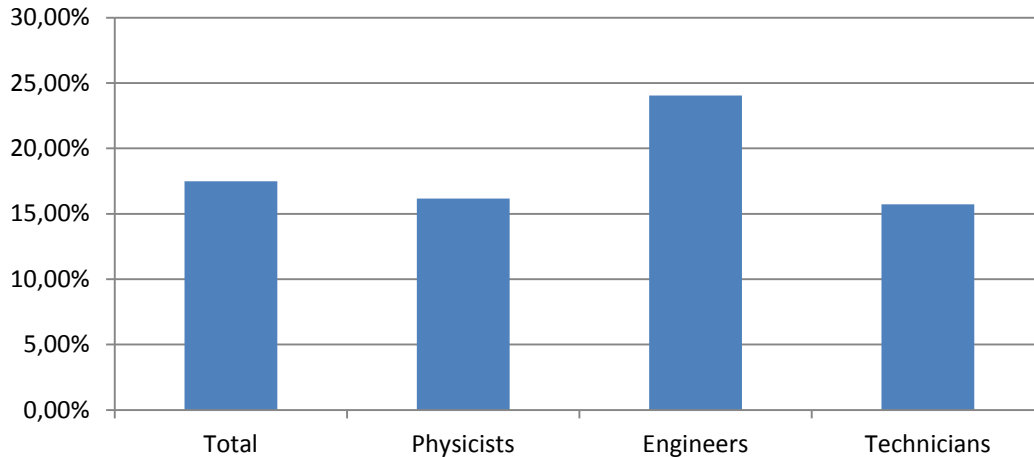


Figure 5: The percentage of each category of personnel currently recruited annually

The percentage of people recruited each year with respect to the total number of staff members as shown in Figure 5 is based on the projection of personnel at 5 years from now. It is clear that this very high rate of recruitments is due to the start of the Super Flavour Machine construction in Frascati; such a high rate will not be sustained other than for very few years from now.

Italy: Companies

10 Italian companies answered our survey on the labour market. They are quite small companies with an average number of staff members around 20.

No company in Italy is building whole accelerators. They mainly produce components, often even based on design studies performed in research canters, like CERN or INFN, so that they only take care of the industrialization and mass production.

In the following we refer to the personnel that is involved in building accelerator related components, but that not necessarily has experience in the specific accelerator field.

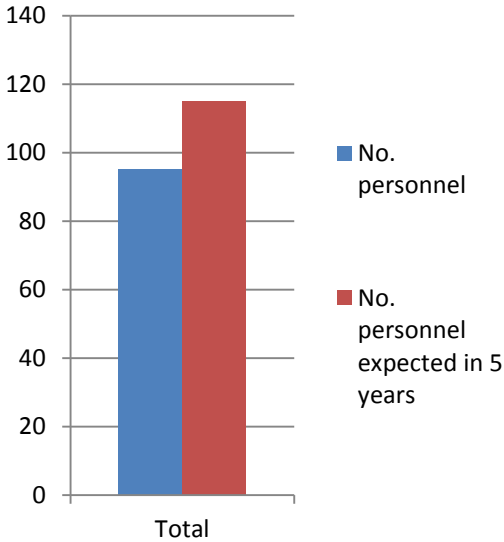


Figure 6: Total number of current personnel (blue) engaged in accelerator science activities at companies. The number of personnel expected in 5 years is shown in red.

The total number of personnel employed in Italian companies now, and as estimated in 5 year from now is shown in Figure 6. Actually, some companies found it quite difficult to foresee how many people they will be able to be hiring in a range of time longer than 3 years; the reason is that they mainly work on contract, mostly with non-permanent personnel, and they are not able to guess job orders for the future. As already said, the big project of a particle Factory has not been finalized yet and no call for tenders has been made yet. It should be expected that some Italian companies would receive orders for its components, thus allowing for some more recruitments. The breakdown of the present personnel in the three categories (Figure 7) shows quite a small percentage of physicists (10%), which is a sign that not much study is performed at the companies themselves.

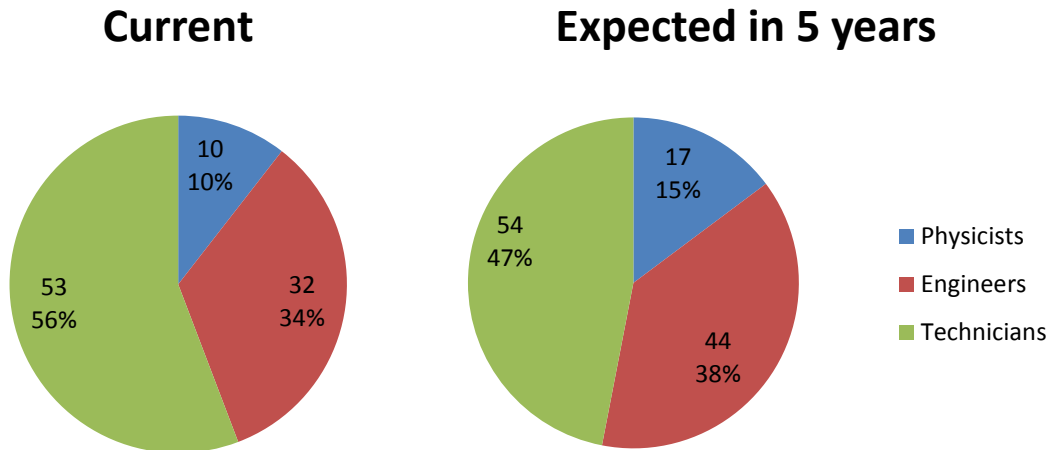


Figure 7: Reported breakdown of personnel engaged in accelerator science and engineering currently (left), and expected in 5 years (right).

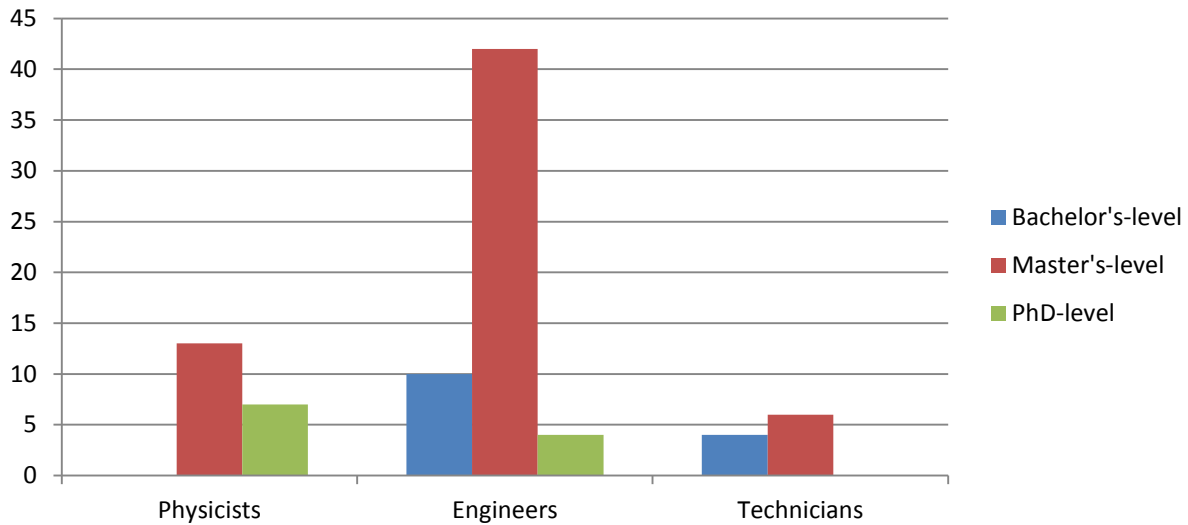


Figure 8: Reported highest qualification level of current personnel engaged in accelerator science activities at companies.

The reported qualification level of the present personnel is shown in Figure 8. This chart shows more or less the same distribution as the personnel in the research institutes (Figure 3). The required qualification levels for new recruitments (Figure 9) have already been commented on (see the discussion of Figure 2a).

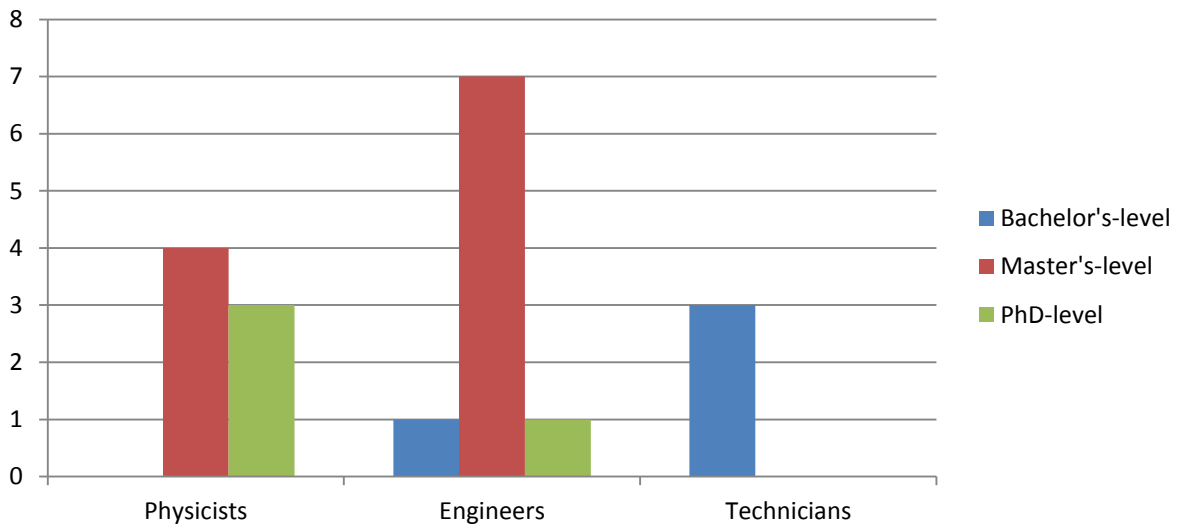


Figure 9: Reported highest qualification level required (number of companies) for new personnel in accelerator science activities at companies

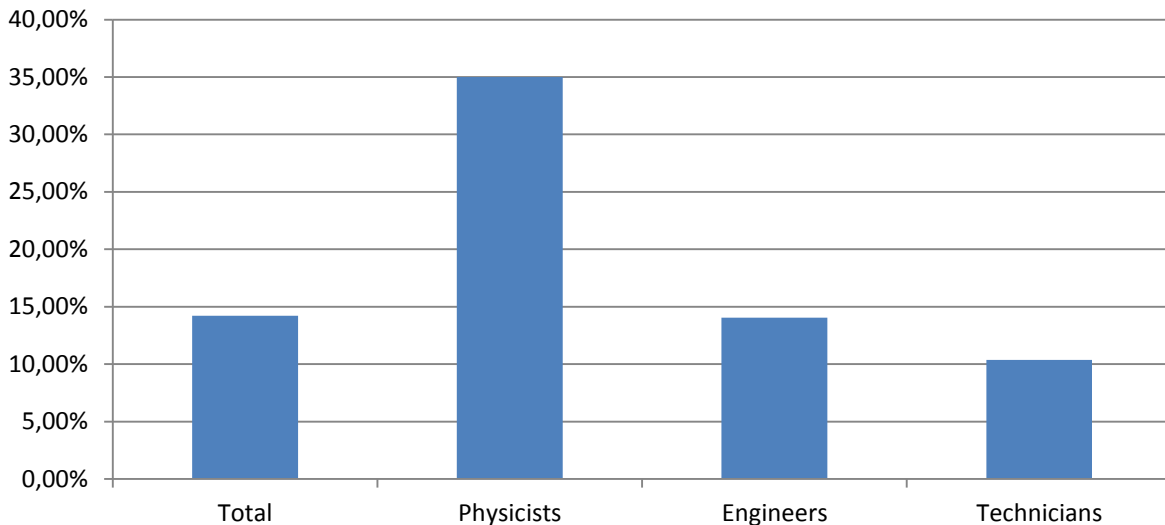


Figure 10: The percentage of each category of personnel currently recruited annually.

Also in the case of the companies there is quite some high recruitment rate (Figure 10), in this case it is mainly due to the turn over of the temporary staff.

The Nordic Countries

The **Nordic countries**, consisting of Norway, Sweden, Finland and Denmark, include accelerator laboratories mainly at Universities, although there also are a couple of international laboratories with international funding and user communities. We will in the present appendix describe briefly these laboratories country by country.

Denmark has only one laboratory with any significant research and development in accelerator physics, namely ISA at Aarhus University. Several accelerators and storage rings are used in various stages of their lifecycle. In addition, the group has and is collaborating with several external laboratories on various accelerator projects like the European Spallation Source (ESS), and with industry and hospitals.

One major company within accelerators exists in Denmark. The company staff includes close to one hundred accelerator physicists, engineers and technicians with most of the production at subcontractors. The firm expects a very significant staff increase in the coming 5 year period, up to 50 %.

A large number of trained physicists are employed in hospitals, and a large fraction is working with and at accelerators, mainly with cancer radio therapy but also with isotope producing accelerators for PET. Only a small fraction of these physicists are working with accelerator R&D, but a planned particle therapy center in Denmark will expand the number of accelerator physicists significantly.

Finland includes Aalto University, Åbo Akademi, the University of Turku PET Centre, University of Helsinki and University of Jyväskylä. The University of Jyväskylä has the largest accelerator in, a 130 MeV cyclotron, supplying beams for nuclear physics to an international user community. It has been in operation for many years and has some accelerator development. Accelerator research at Aalto University comprises of low-energy positron physics, hardly what is called accelerator physics in the ordinary sense. At Åbo Akademi, we believe there are no accelerators, only they use the University of Turku PET center, with its 3 cyclotrons. Helsinki University has a tandem accelerator and a low energy implanter with limited accelerator R&D.

In **Norway**, the only major accelerator is an older 35 MeV cyclotron at the Department of Physics at University of Oslo.

In **Sweden**, the major accelerator laboratories include the MSL laboratory at Stockholm University, the Svedberg laboratory at Uppsala University, the MaxLab (now MAX IV) in Lund and finally the upcoming major laboratory, ESS, also outside Lund. MSL housed an ion synchrotron/storage ring, presently being relocated to GSI, and now the laboratory only includes a low-energy electrostatic cryogenic storage ring. Uppsala University comprises a 180 MeV proton cyclotron previously also used as an injector for a now decommissioned high energy storage ring. A commercial proton cyclotron for cancer therapy is presently being built. At MAXLAB at Lund University, several synchrotron radiation light sources have been built, MAX I, II and III, and operated for many years. Presently, the world's brightest light source, the 3 GeV MAX IV accelerator, is being built outside Lund, and will in a few years replace the 3 existing machines. The laboratory has during many years been very active and successful in accelerator research and developments. Also just outside Lund, the European Spallation Source (ESS) is presently being designed and built to deliver first neutrons in 2019 and be fully operational in 2025. A major component of the facility is a superconducting high-power 2.5 GeV proton linear accelerator delivering a record beam power of 5 MW. Already now ESS is a major accelerator laboratory and the organization will grow to more than 100 accelerator engineers and physicists in a few years.

Quantitative analysis of the survey of the Nordic countries

The total number of accelerator scientists and engineers is relatively low in the Nordic region as a whole, with a total of about 250 persons identified in this survey. A large fraction of this staff works at the Max IV laboratory, ESS in Lund or in industry. The Scandinavian Research Institutes and universities estimate to hire about 100 persons over the next five years. Most of these persons are foreseen to work for ESS, which will start the construction of its new accelerator in a few years' time.

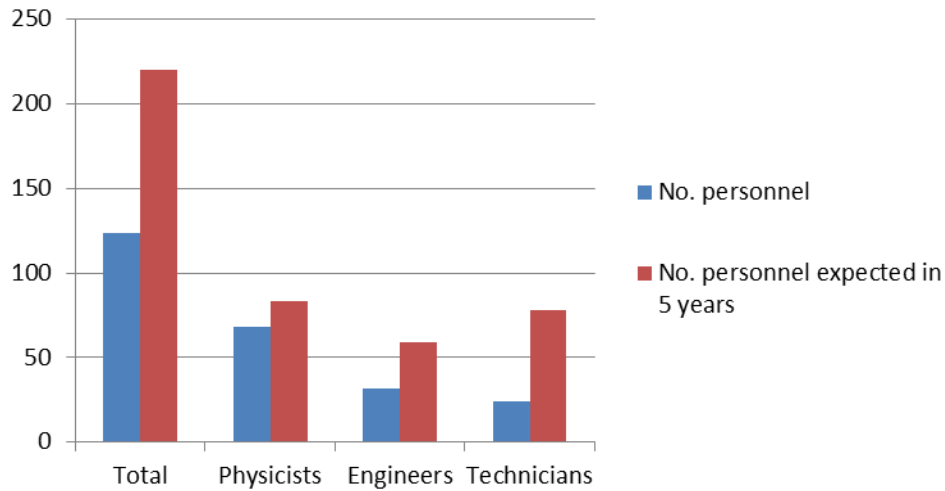


Figure 1: Total number of current personnel (blue) engaged in accelerator science activities at research institutes. The number of personnel expected in 5 years is shown in red.

Today most of the personnel at ESS are physicists but during the construction phase and the operation phase of the machine, most of the people hired will either be engineers or technicians. This explains the big change in profiles needed for the Nordic research institutes in the next five years.

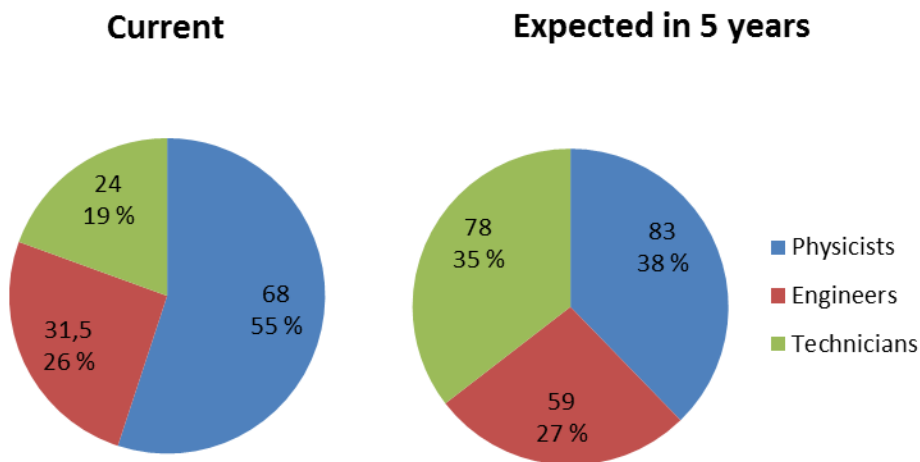


Figure 2: Reported breakdown of accelerator personnel (a) currently, and (b) expected in 5 years.

The Scandinavian Research Institutes and universities report that most of its personnel working with accelerators have a Doctoral degree.

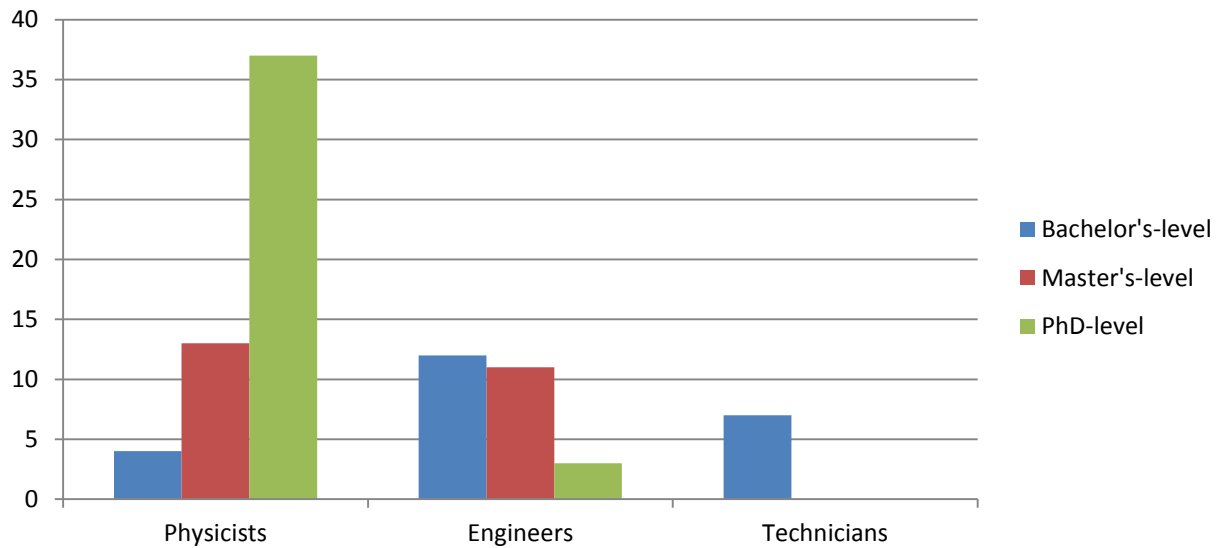


Figure 3: Reported highest qualification level of current personnel engaged in accelerator activities at research institutes.

Roughly 40% of the Research Institutes and universities report that they have difficulties recruiting accelerator physicists, engineers and technicians.

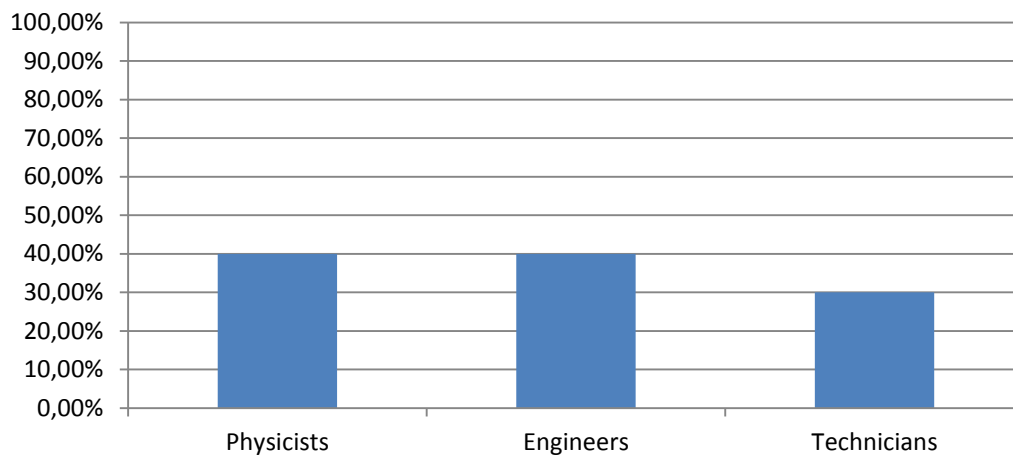


Figure 4: The percentage of institutes that reported difficulties in recruiting personnel, by personnel category.

Poland: Research Institutes and Technical Universities

Research and development as well as some production activities in the area of physics and techniques of acceleration concentrate in Poland in two large research institutes and in several technical universities.

An outstanding feature of Polish activities in that domain is presence of well trained groups of engineers and technicians with substantial experience gained during the installation of the LHC machine and participation in largest accelerator projects in Europe. Thanks to their skills they can be of great help in any accelerator intervention all over the world. The scale and importance of such services illustrate e.g. fact that the team of over 70 engineers and technicians from IFJ PAN is booked for LHC, XFEL, ESS and other large projects several years in advance. Similar services are provided by team from the University of Science and Technology - AGH.

A small scale production of medical and industrial accelerators, the precision electron accelerators, in particular accelerators used by oncology therapists takes place in the Department of Nuclear Equipment HITEC NCBJ, a unit integrated into the NCBJ - National Centre for Nuclear Research, located in Swierk about 30 km from Warsaw. This Department also continue to supply CERN with various unique devices.

Technical Universities participate in several key accelerator research areas, such as sources and injectors, RF structures and systems, superconducting as well as conventional magnet systems, cryogenics, alignment and stabilization, diagnostics and instrumentation, electronics and software.

Groups of experts from Cracow, Lodz, Warsaw and Wroclaw have been actively involved in many accelerator projects in Europe, being responsible for modeling, design and production of many accelerator components as well as delivery, assembly and starting up on-site. Thanks to close cooperation with industry, the production capabilities include: warm cavities and whole accelerating structures, electron guns, RF chains, warm magnets (solenoids, dipoles, quadrupoles), beam lines, advanced mechanics, cryogenic components including super-fluid helium transfer lines and cryostats.

The main projects are: FAIR (cryogenics components delivery), LHC upgrade (warm cavities' production for Linac4), ITER (components delivery), XFEL (design and production of HOM couplers and absorbers, helium transfer line and super-fluid helium cryostats design and production), Wendelstein 7-X stellarator (components design and delivery), SuperB (control systems). Another example of our participation in the development of future facilities is ESS where our groups work on radiation protection, beam dynamics, beam optics and collimators calculations.

Spain: Introduction

The science industry comprises a series of goods and services that are supplied to large scientific facilities and which include instrumentation, electronics, power electronics and precision, control and sensory mechanics. Spain has a long history of participation in science facilities and their related international organizations. These infrastructures provide the most advanced facilities, which are indispensable for raising the quality of our research and technological development results and which, due to the high cost involved, could not be undertaken on an individual basis. This sector is very horizontal, where scientific and technological centers at Universities, Public Research Centers and Technological Centers are working for international projects as FAIR, XFEL, CLIC, IFMIF-EVEDA, ITER, etc.

The Spanish commitment to the national accelerator infrastructures and its development has been an intense and lengthy effort in the past decade. It has culminated on the current on-line facilities of ALBA CELLS (third generation Synchrotron Light Facility, 3GeV), CMAM (Tandem 5MV, Crockcroft-walton), CNA (Tandem 3MV Peletron, and 1MV Crockcoft-Walton). Much effort has been focused into various projects, to develop and construct two superconducting Linacs in Bilbao and Huelva, a superconducting cyclotron in CIEMAT, and an electron race-track microtron (6, 8, 10, 12 MeV) in UPC.

The Spanish CENIT program, National Strategic Technological Research Consortium, was created to stimulate R&D and innovation collaboration amongst companies, universities, public research bodies and technological centers. It finances key long-term scientific and technological initiatives, developed together by private and public entities. An example of a CENIT Programme related to accelerator technology is the AMIT project. The AMIT consortium, (*Advanced Molecular Imaging Technologies*), consists of 10 companies and 13 public research organizations that have partnered with the goal of overcoming technological barriers in the technology sector to support the benefit of Molecular Imaging in Medicine and Biomedicine.

The numerous applications of industrial accelerators cover a broad range of business segments from low beam energy electron beam systems for welding, machining, and product irradiation to medium energy cyclotrons for medical isotope production and high energy accelerators for medical therapy. These systems have a significant impact on people's lives and the world's economy. Wide scale industrial use of many of these processing tools has resulted in the growth of the number of Spanish companies which are involved in these areas.

Therefore, an adequate number of personnel with the necessary qualifications and experience are needed to cover all the needs of industry and research.

Spain: Research institutes

Spain has made a great effort in recent years in training in this field. And even with the crisis forecasts of these centers is to maintain and increase the personnel involved in these activities.

The number of scientific-technical personnel defined as physicist, engineers, and technicians engaged today and expected in 5 years in Spain accelerator research institutes is shown in Figure 1.

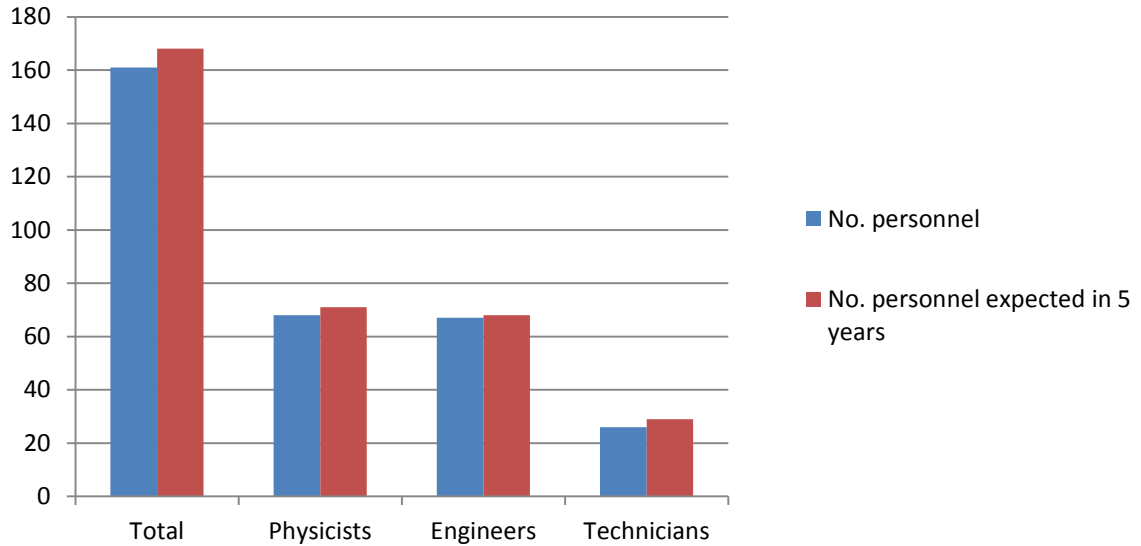


Figure 1: Total number of personnel engaged today (blue) and expected in 5 years (red) in Spain.

The number of staff for the next five years in the Spanish research institutes is stable, with a small increase due to the consolidation of existing projects.

Figure 1a shows the reported qualification level of personnel in Spain accelerator research institutes. Most physicists engaged in research have a PhD level, but not for Engineers that is Master's level.

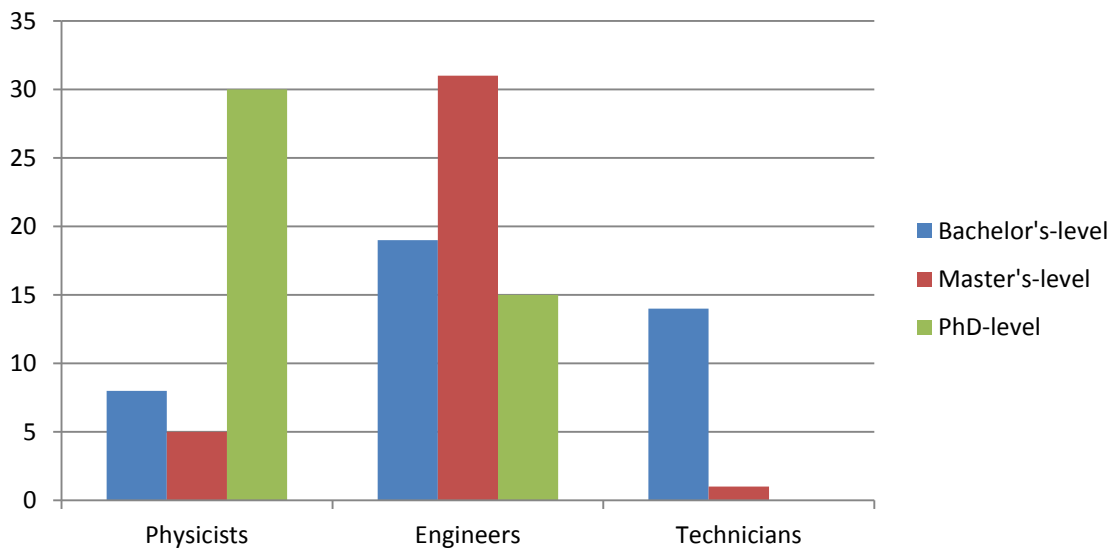


Figure 1a: Reported qualification level of personnel in Spain.

Figure 2 shows the percentage of all institutes requiring qualifications in accelerator science. Approximately 30% of the research institutes require PhD level for physicists, however as shown in Figure 1a, more than 50% of those hired have that level of qualification.

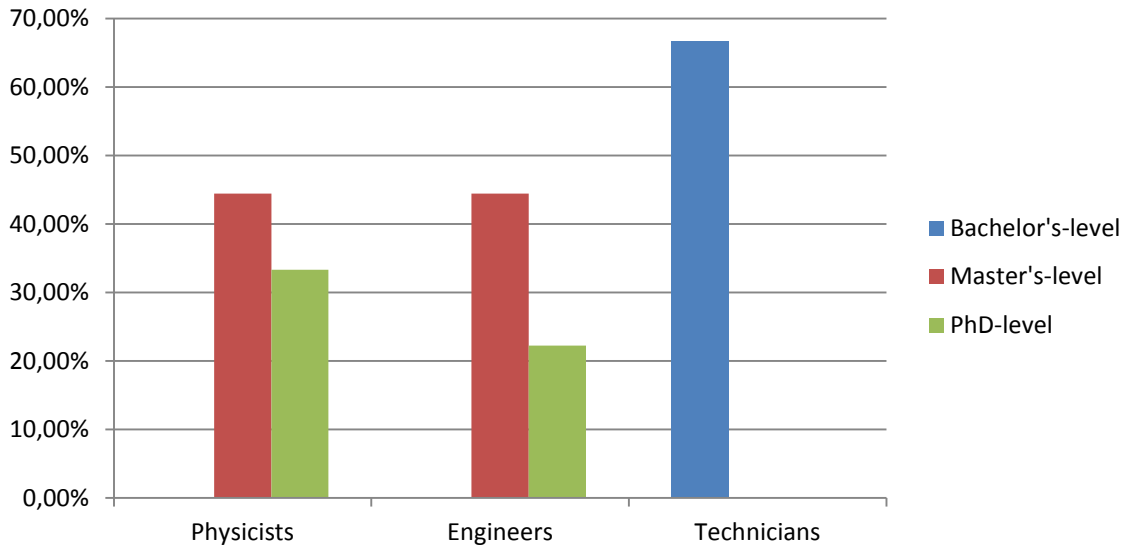


Figure 2: Percentage of all institutes requiring qualification in accelerator science.

Spain institutes recruited in a typical year around 30 employees, thereof one third are physicists, one third are engineers and one third is technicians (See figure 3).

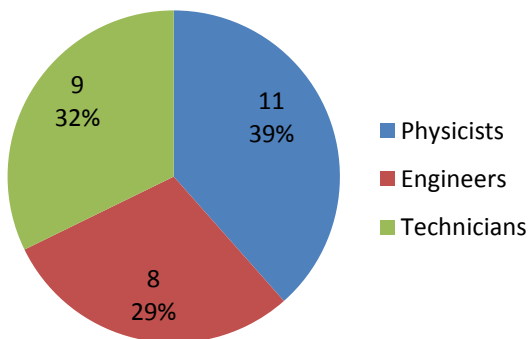


Figure 3: Typical number & Percentage of personnel recruited each year.

All Spanish institutes require on-the-job training as well as external training in some interesting accelerator physics topics. Typically this training is made in the framework of the CERN accelerators schools. See Figure 4.

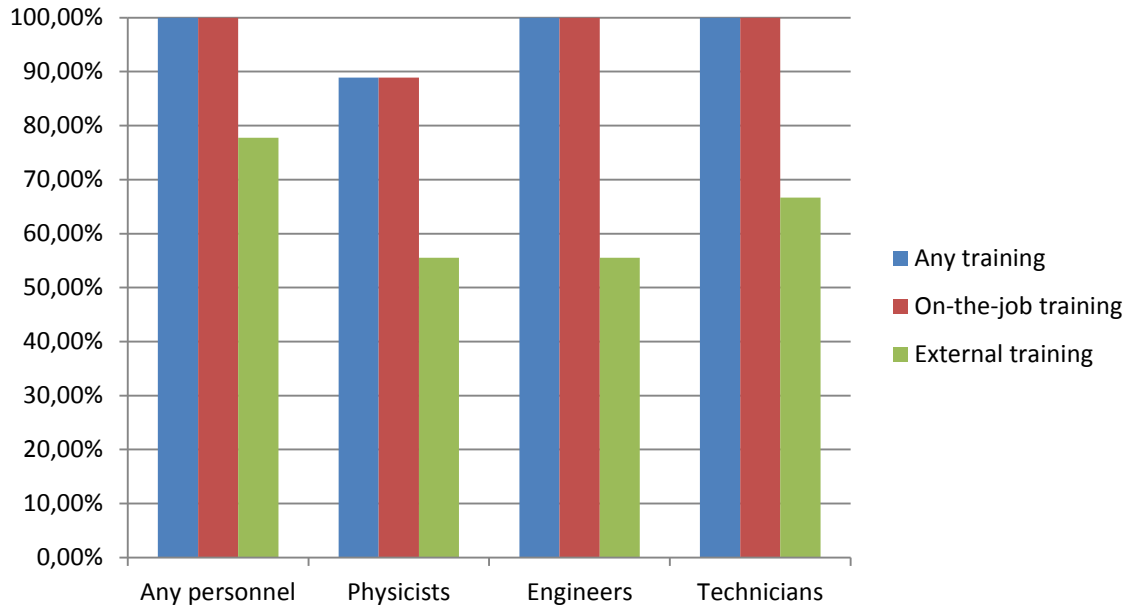


Figure 4: Percentage of all institutes requiring training

Figure 5 shows that all Spanish institutes had difficulties to recruit highly qualified physicists, engineers and technicians.

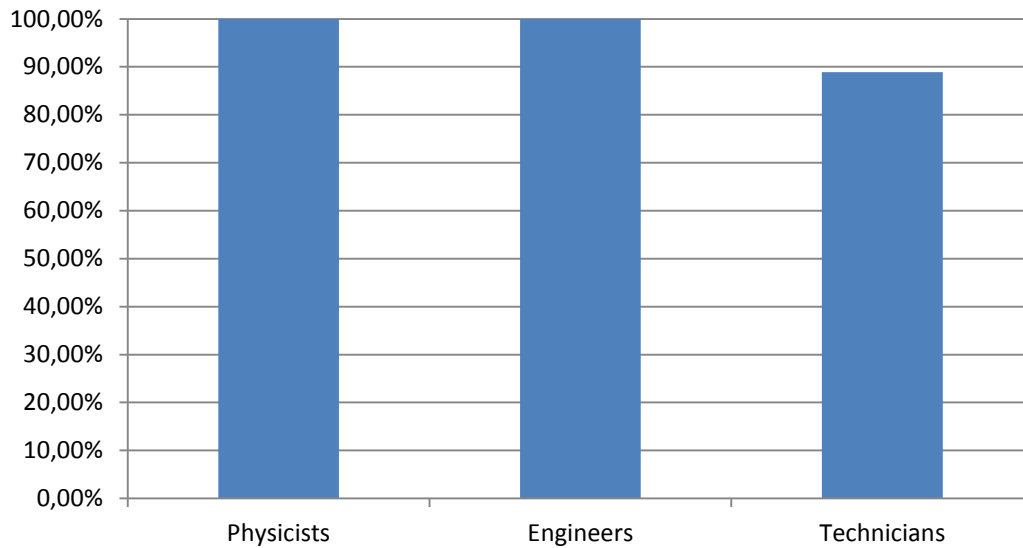


Figure 5: Percentage of all institutes having difficulty-recruiting personnel.

The development of structures and mechanisms that allow the recruitment and training of scientific and staff highly qualified is an essential ingredient in the development of the science of accelerators.

Spain: Companies

Technological change means that jobs change. Employees' skills must be updated through education and training so that technological advances are successfully integrated into the companies. We have contacted 93 companies known to be engaged in accelerator-related activities to survey their skill requirements, training needs and different levels of training. We had a response of about 30, mostly companies that have few staff dedicated to these activities, between 5 and 10 employees, only one third of the total having a large number of staff on these issues, i.e. about a total of 140 people, a low number for the Spanish population. The forecast for the next five years is to increase to 250 employees.

The majority requires qualified technicians and engineers, and the number of physicists needed is very small, because the main activities of Spanish companies that replied are mechanics, mechatronics, & electrical systems.

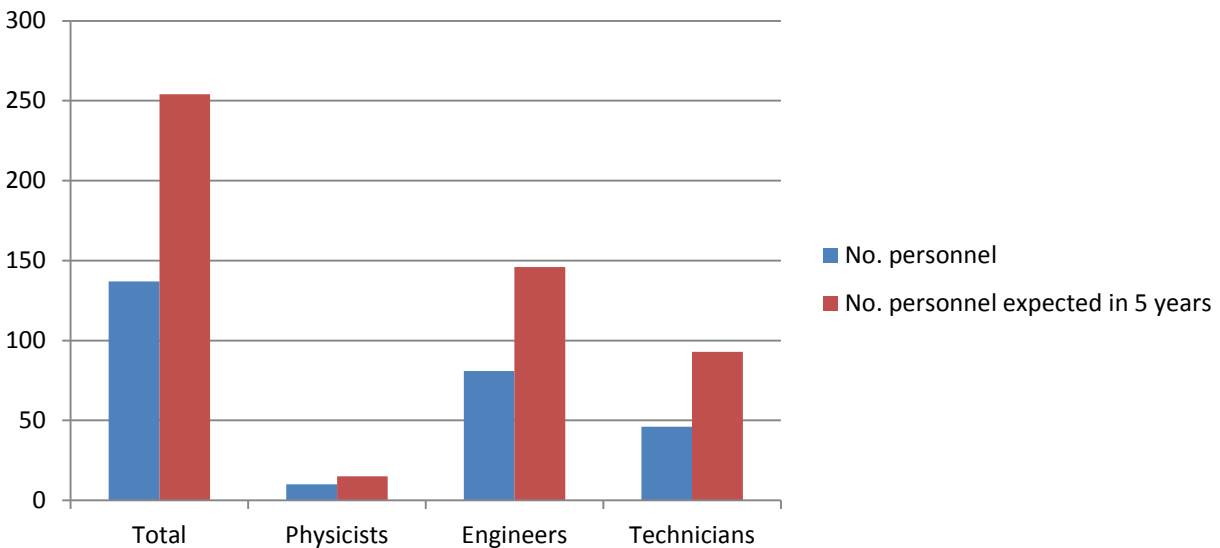


Figure 6: Total number of personnel engaged today (blue) and expected in 5 years (red) in Spain.

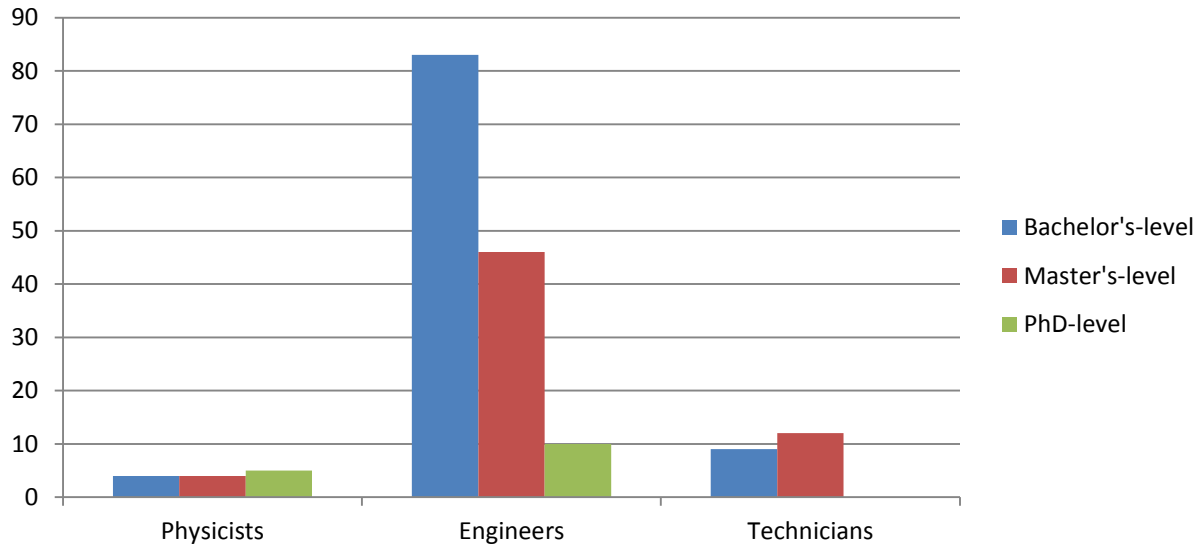


Figure 7: Reported qualification level of personnel in Spain.

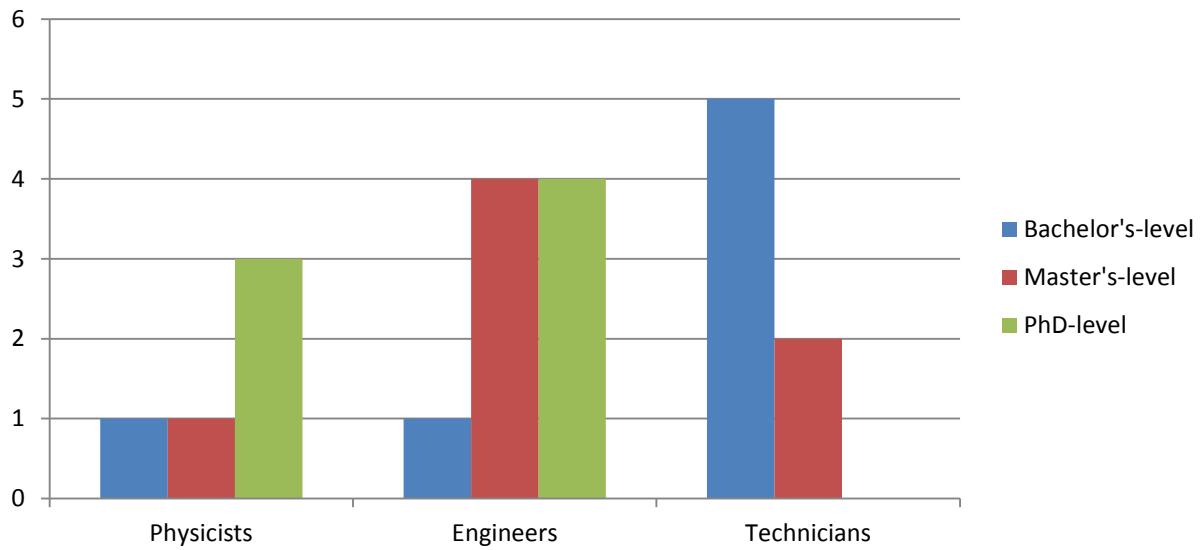


Figure 8: Number of companies where qualification is required in accelerator science.

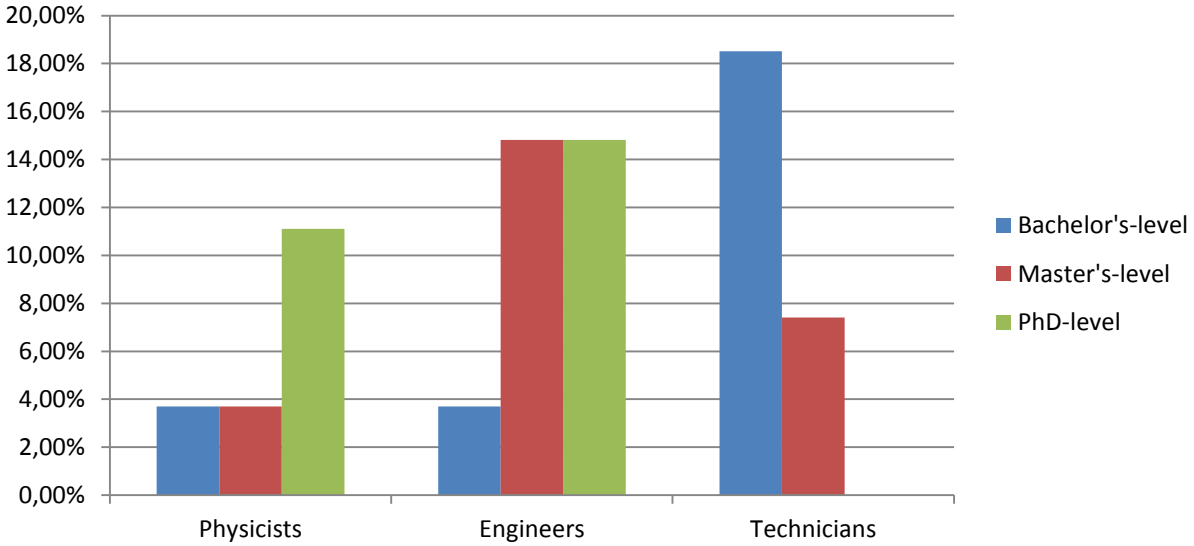


Figure 9: Percentage of all Spanish companies requiring qualification in accelerator science.

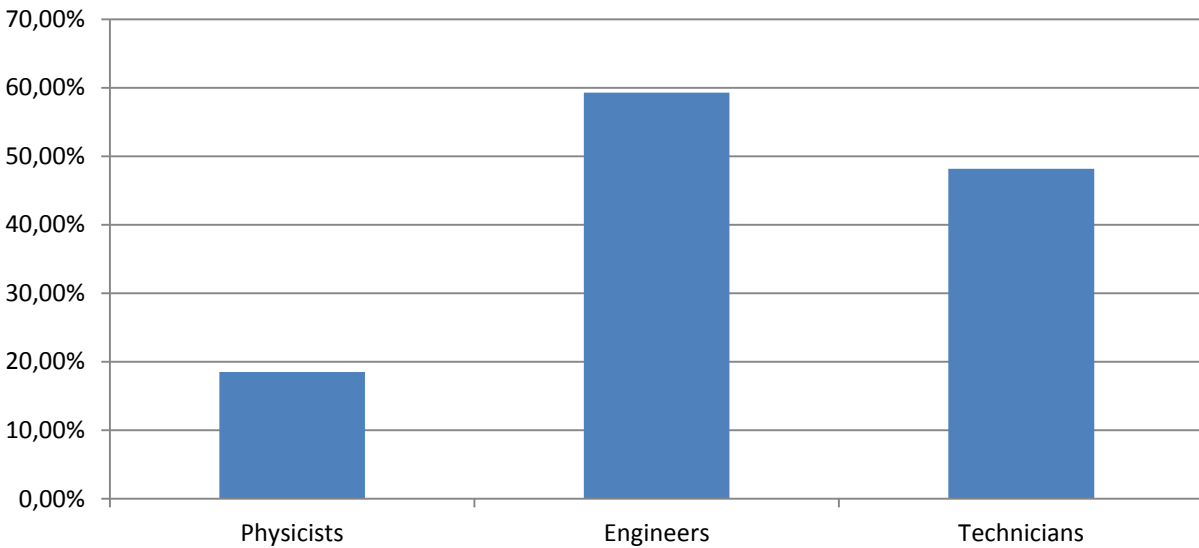


Figure 10: Percentage of companies having difficulty recruiting.

We would like to thank the Spanish Science Industry Association, INEUSTAR, (www.ineustar.com), for providing the list of Spanish companies whose activities are related to the area accelerator science.

Switzerland: Research institutes

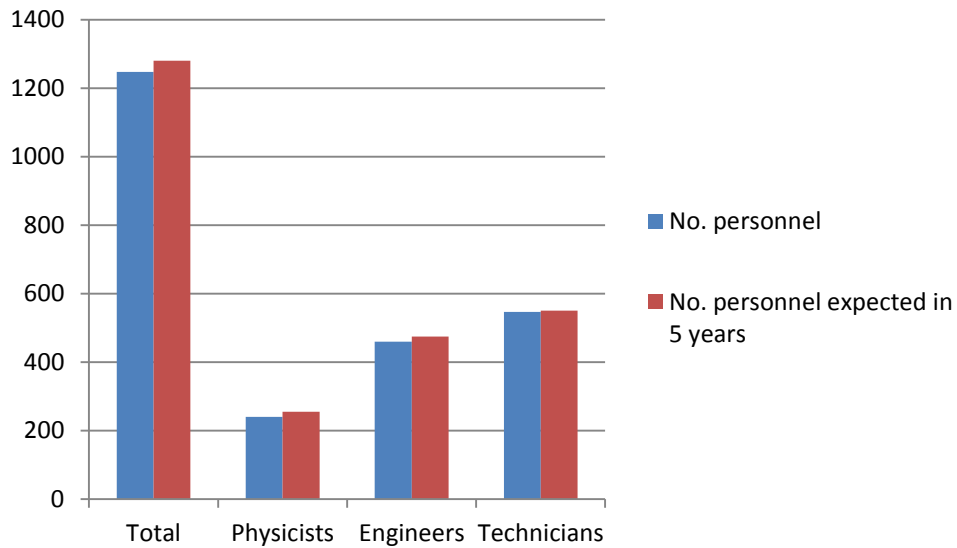


Figure 1: Total number of current personnel (blue) engaged in accelerator science activities at research institutes. The number of personnel expected in 5 years is shown in red.

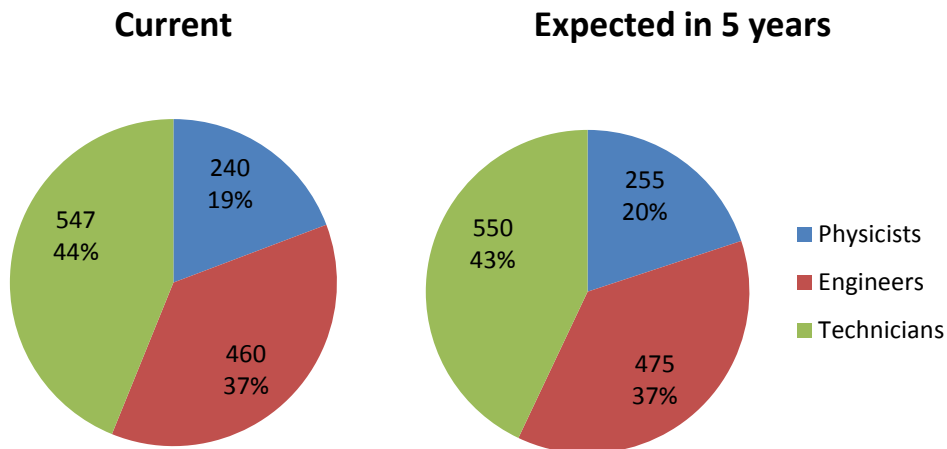


Figure 2: Reported breakdown of accelerator personnel (left) currently, and (right) expected in 5 years.

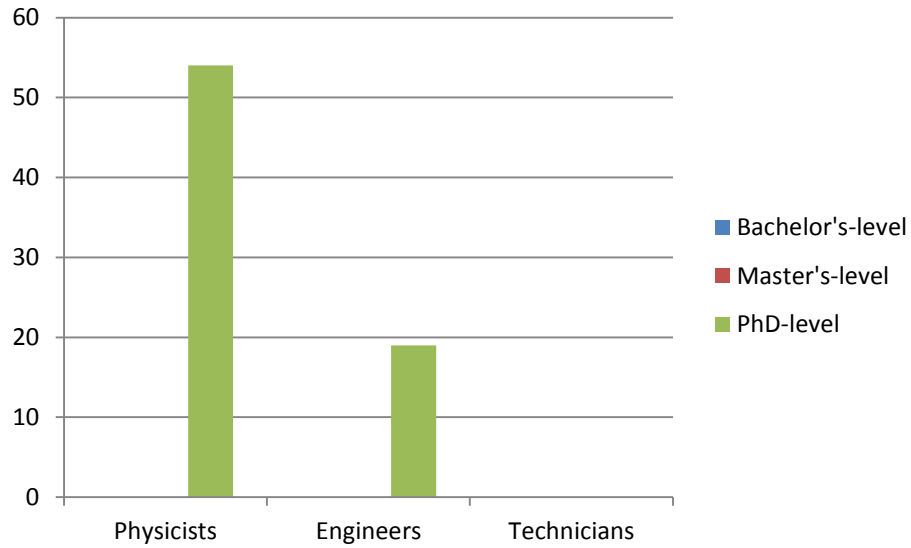


Figure 3: Reported highest qualification level of current personnel engaged in accelerator activities at research institutes.

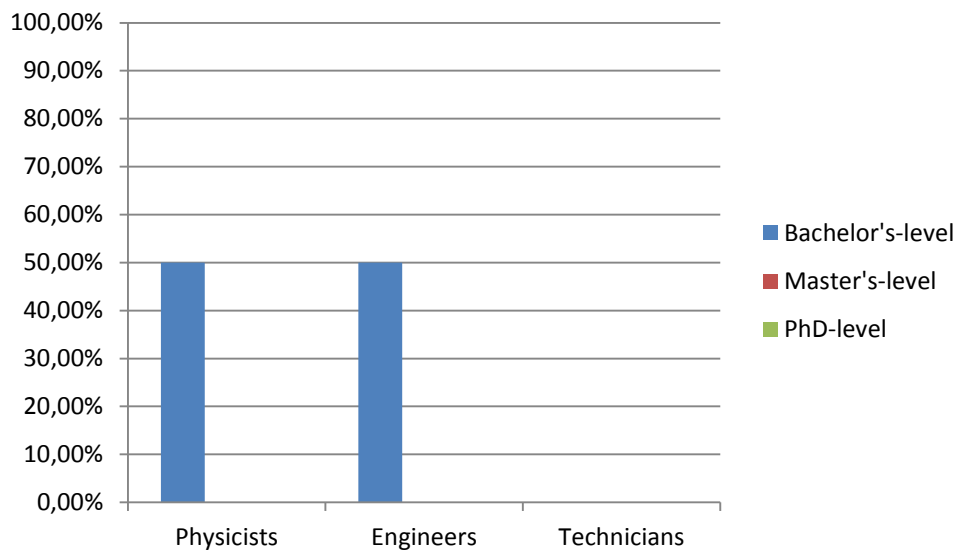


Figure 4: Reported highest qualification level required in accelerator science (percentage of reporting institutes) for new personnel engaged in accelerator activities at research institutes.

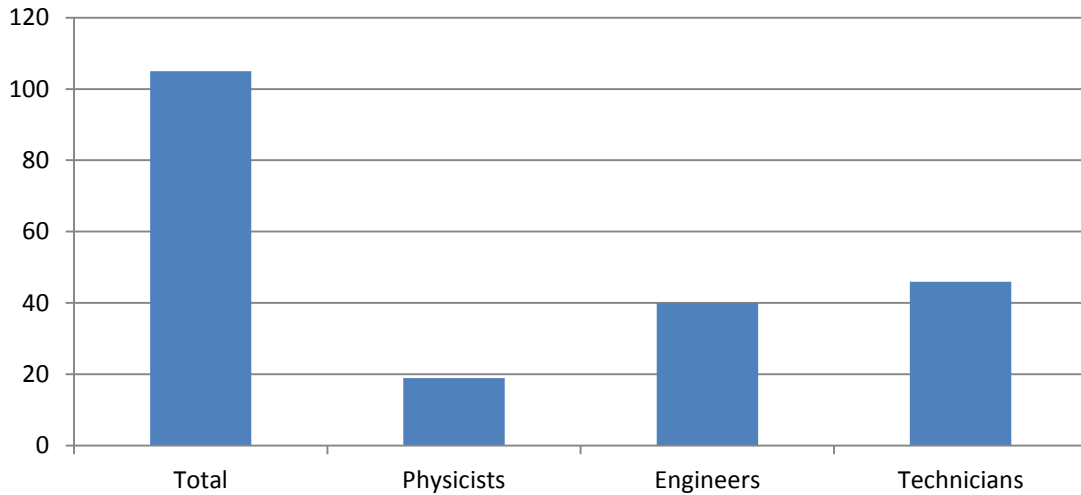


Figure 5: The number of personnel currently recruited annually.

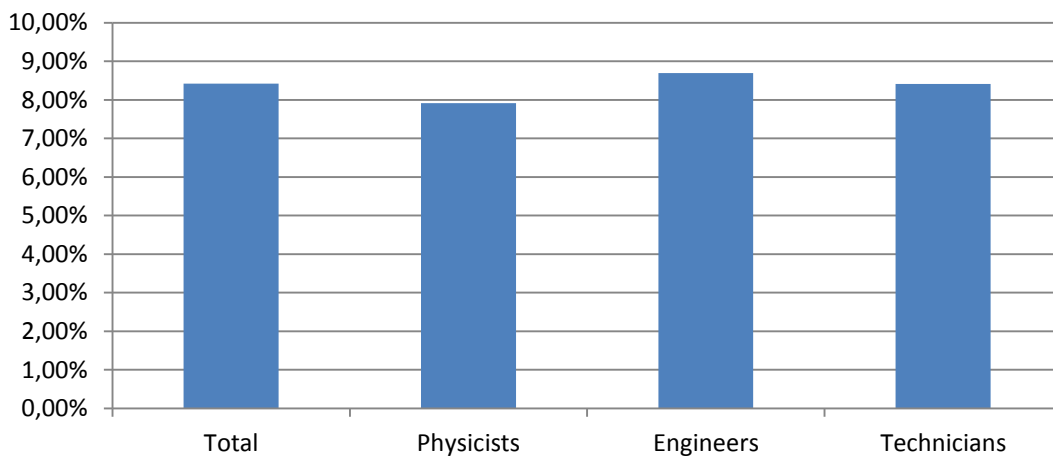


Figure 6: Percentage of the annual recruitment by category of personnel.

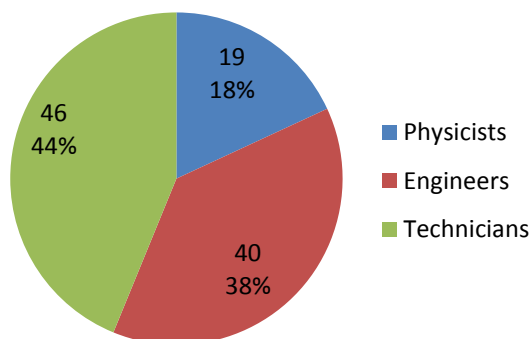


Figure 7: The percentage of each category of personnel currently recruited annually.

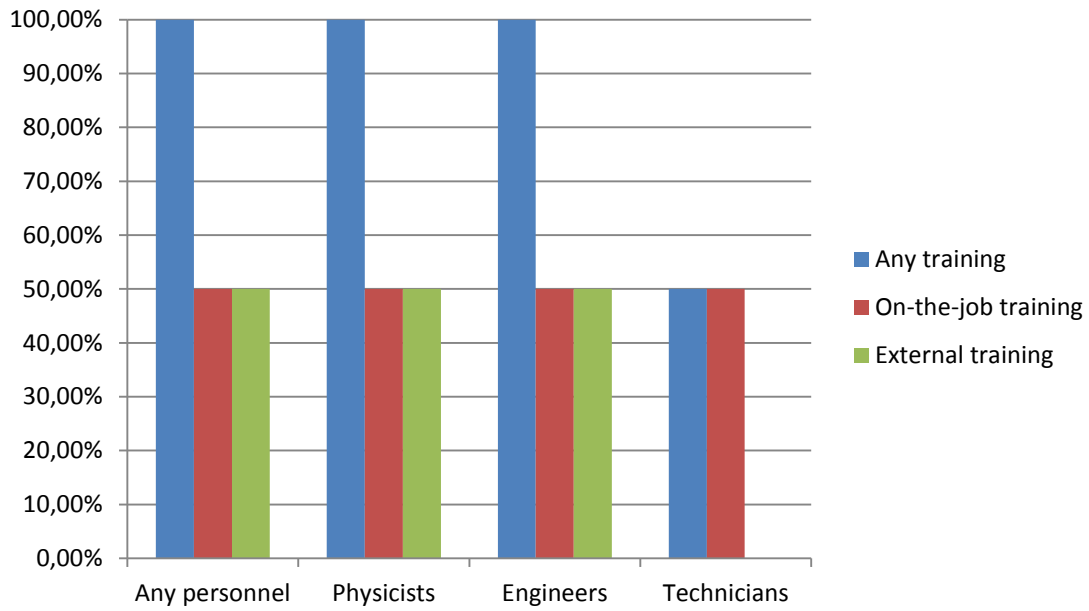


Figure 8: The percentage of all institutes that reported requiring training for their personnel engaged in accelerator science, by personnel type.

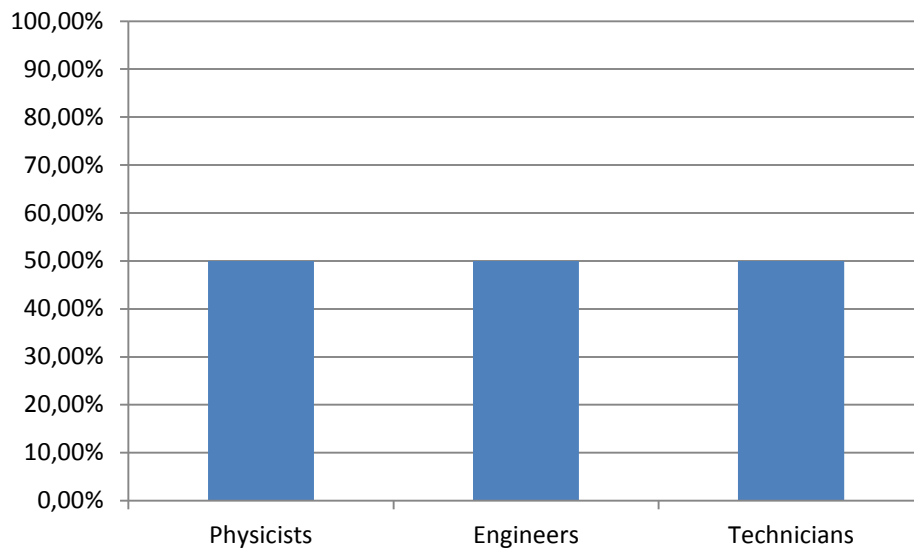


Figure 9: The percentage of institutes that reported difficulties in recruiting personnel, by personnel category.

United Kingdom: Research institutes

The United Kingdom operates large accelerator facilities at the Rutherford Appleton Laboratory and Daresbury Laboratory sites. The largest of the facilities are the ISIS spallation neutron source and the Diamond Light Source. Several universities also have local accelerator R&D facilities. Nevertheless the UK number of accelerator-related personnel is significantly smaller than in comparably-sized countries (i.e. Germany, France and Italy) which operate several large accelerator facilities.

A major new national initiative in accelerator science was launched approximately 10 years ago, and this has dramatically increased the numbers of UK-trained accelerator physicists, although many of these are engaged in overseas accelerator R&D projects, eg. at CERN, SLAC and KEK. The result is that, in contrast with the global European picture, the UK personnel breakdown (Figure 1) is dominated by physicists, rather than engineers and technicians who would typically operate and maintain facilities. A modest increase in total personnel, of roughly 11%, is projected over the next 5 years.

A large fraction of (typically) physicists are employed on short-term (typically 3-year) ‘research associate’ contracts. Because of this, although the total recruitment rate, at about 10%, is in line with that across Europe, the personnel recruitment pattern is somewhat different (Figure 2). Recruitment is dominated by the physicists, with an extremely low turnover of engineers and technicians. There is a strong, widely-held view that talented engineers and technicians are extremely valuable, and more difficult to attract than physicists, and therefore should be retained in permanent staff posts.

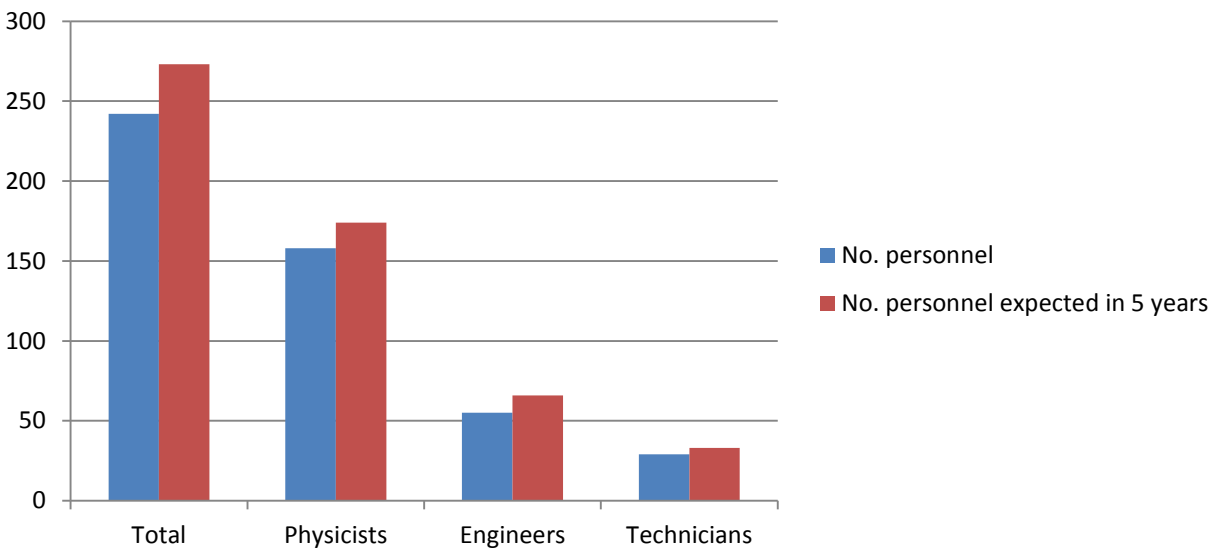


Figure 1: Total number of UK personnel engaged today (blue) and expected in 5 years (red).

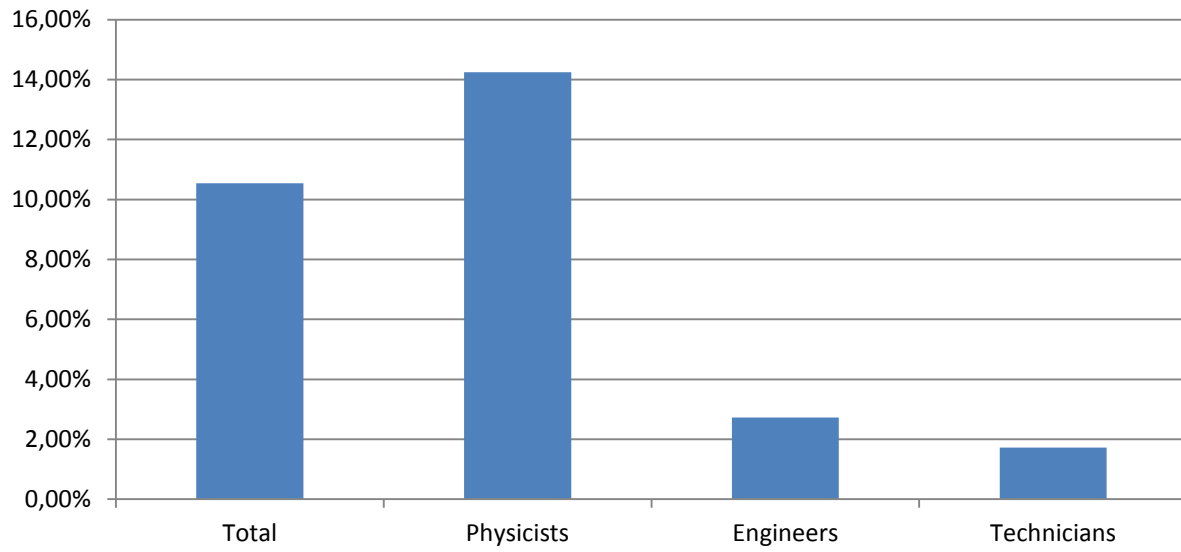


Figure 2: The percentage of each category of UK personnel currently recruited annually.