

# Report of the Committee for Nuclear Energy Competence in Finland

Publications of the Ministry of Employment  
and the Economy  
Energy and the Climate  
14/2012



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MINISTRY OF EMPLOYMENT AND THE ECONOMY

# Report of the Committee for Nuclear Energy Competence in Finland

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<b>Julkaisun nimi   Titel   Title</b> Report of the Committee for Nuclear Energy Competence in Finland		
<b>Tiivistelmä   Referat   Abstract</b> <p>In October 2010, the Ministry of Employment and the Economy set up a committee to examine the long-term competence needs of the nuclear energy sector. The study was implemented by a group of experts ensuring extensive representation of the nuclear energy sector. One of the key conclusions was that comprehensive high-standard national competence is needed by nuclear sector companies and research institutes, as well as by authorities. Training of experts and sector-specific research activities call for long-term investments and cooperation, both among national actors and on an international scale.</p> <p>Competence needs in Finland's nuclear energy sector are growing. The nuclear power plant units presently in operation, as well as the Olkiluoto 3 unit under construction, require a competent labour force on a continuous basis. Posiva must have readiness for commencing final disposal of spent fuel by 2020. The new nuclear power projects – TVO's Olkiluoto 4 and Fennovoima's nuclear power plant, which were given favourable decisions-in-principle by the Government in 2010 – will particularly increase the need for experts.</p> <p>In its statement when ratifying these decisions-in-principle on 1 July 2010 Parliament required that the Government will, for its own part, create the preconditions for utilising Finnish labour, knowledge and business life as far as possible in nuclear power projects. The appointment letter of 27 October 2010 assigns the following duties to the Committee for Nuclear Energy Competence: 1) to survey the present personnel resources of nuclear actors; 2) to conduct an extensive review of the need for Finnish basic higher education, postgraduate education, further education and supplementary training; 3) to investigate the opportunities for Finnish participation in the forthcoming major nuclear power plant projects; 4) to survey the research infrastructure available to nuclear actors and research; 5) to examine Finnish research activities and participation in international research activities; and 6) to review the situation regarding VTT Technical Research Centre of Finland's research reactor.</p> <p>The work was carried out in six divisions which were also in charge of writing the texts for the report. A survey was implemented in order to acquire background material, and sent to some 300 organisations within the sector. The results of the survey are presented extensively in this report, which will be published both in Finnish and English. The committee included representatives from the Ministry of Employment and the Economy, the Ministry of the Environment, the Ministry of Social Affairs and Health, the Ministry of Education and Culture, the Radiation and Nuclear Safety Authority Finland (STUK), VTT Technical Research Centre of Finland, Aalto University, the universities of Jyväskylä, Oulu and Helsinki, and Lappeenranta University of Technology. The power companies involved were Fennovoima, Fortum, TVO, Posiva and the industrial association FinNuclear. In addition, several other organisations participated in the work of various divisions, and the number of people involved in the writing process of the report was more than 150. The report presents a large number of recommendations for long-term development of competence in the nuclear energy sector in Finland.</p> <p>Contact person at the Ministry of Employment and the Economy: Energy Department/Jorma Aurela, tel. +358 50 5922109 or +358 29 506 4832 (from 14 June 2012)</p>		
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# Preface

On 1 July 2010 the Finnish Parliament ratified the Government's decisions-in-principle in favour of projects for new nuclear facilities. In its statement given in this context, Parliament required that the Government will, for its own part, create the preconditions for utilising Finnish labour, knowledge and business life as far as possible in nuclear power projects.

As a whole, safe and reliable operation of nuclear facilities calls for development and maintenance of a solid competence base. Extensive national competence is essential owing to the special nature of the nuclear power sector. The Fukushima Daiichi nuclear power plant accident resulting from the natural disasters in Japan in March 2011 was a timely reminder of the importance of relevant competence and a robust safety culture.

On 27 October 2010 the Ministry of Employment and the Economy set up a committee to prepare steps for ensuring sufficient nuclear sector competence. The committee's duty was to

- survey the present personnel resources of nuclear actors;
- conduct an extensive review of the need for Finnish basic, further and supplementary education and training;
- investigate the opportunities for Finnish participation in the forthcoming major projects for nuclear facilities;
- survey the research infrastructure available to the nuclear actors;
- explore Finnish participation in international research activities; and
- review the situation regarding VTT Technical Research Centre of Finland's research reactor.

In addition, on the basis of surveys conducted, the committee was to give recommendations for steps to be taken until the 2020s.

Members invited to the committee included representatives from ministries, Radiation and Nuclear Safety Authority Finland (STUK), universities, research institutes and companies operating within the industry. Industrial Counsellor Riku Huttunen from the Ministry of Employment and the Economy (Director General of the Energy Market Authority from 1 August 2011) was appointed chair of the committee, Senior Engineer Jorma Aurela acted as its secretary general, and Senior Adviser Jaana Avolahti and Senior Inspector Eriika Melkas from the Ministry of Employment and the Economy acted as recording secretaries. In accordance with the committee's duties, six divisions were established to work under the committee. A large number of other experts were also invited to participate in the work of the committee and the divisions. The members of these bodies, together with the experts who participated in their work, are listed in appendix 1. Jukka Laaksonen, Director General of the Radiation and Nuclear Safety Authority (STUK), was heard separately by the committee.

The committee worked in a good cooperative spirit, and the responsibility for writing the report was also shared by a large number of people. I therefore want to thank the whole team of experts for their contribution. Jarmo Ala-Heikkilä, Juhani Hyvärinen, Heikki Purhonen, Eija Karita Puska, Jorma Aurela and Jaana Avolahti, who were in charge of chairing the divisions and compiling the different parts of the report, deserve special thanks.

RIKU HUTTUNEN  
*Chair of the committee*

Press Conference on 26 March 2012 where the report of the Competence Committee was handed over to Minister of Economy Jyri Häkämies, on the left. On the right, the chairman of the Committee Riku Huttunen, Director General, Energy Market Authority.



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# 1 Introduction

## 1.1 General Situation in the Nuclear Energy Sector

There are now four nuclear power plant units in operation in Finland, and a fifth under construction. In addition, Parliament in July 2010 ratified the Government's decisions-in-principle concerning two new units. Fennovoima Oy's plant site Pyhäjoki is a totally new location for a nuclear power plant. Posiva Oy is expected to submit an application to the Ministry of Employment and the Economy by the end of 2012 for a construction licence relating to a nuclear waste final disposal repository.

Most of the duties within the nuclear energy sector are such that persons with suitable technological or scientific education can be further trained to their duties by the companies and other organisations using nuclear power. However, this kind of further training and qualification process typically takes several years. Every person involved with nuclear power and nuclear facilities must also receive training on the safety culture relating to the use of nuclear energy, in addition to the professional competence within his or her own competence area. This requires a special kind of diligence and ethics, which includes acknowledgement of the fact that nuclear safety is also the first priority in normal everyday work. In practice, employment relationships in nuclear power facilities have been long-lasting, and the working atmosphere good.

Certain areas of the nuclear energy sector require lengthy, even multi-year special training on top of the higher education degree. Such areas include certain fields of reactor physics and thermal hydraulics. Within such fields the competence is often built up through participation in research activities and later transfer to other organisations within the sector. The contributions of VTT Technical Research Centre of Finland, Lappeenranta University of Technology (LUT) and Aalto University in particular within these areas are significant. However, one must note that in Finland there are currently only two nuclear-energy-specific professorships (in Lappeenranta and Otaniemi, Espoo), and one professorship of radiochemistry at the University of Helsinki.

In 2000 the Ministry of Trade and Industry published the report "Toimenpiteitä ydinenergia-alan tietämyksen säilyttämiseksi" (in Finnish; "Steps for Maintenance of Nuclear Energy Sector Knowledge in Finland"), in which the committee tasked with examining the issue proposed steps for the development and maintenance of competencies within the sector. The committee came to the conclusion that, generally speaking, the standard of competence and the availability of services in Finland were at least at a satisfactory level. However, the committee pointed out that in many fields the resource base was comparatively narrow. The committee considered it

important that Finland continue national nuclear safety research, development of training and education and, particularly, participation in international training and research. As part of the study, it was calculated that in 2000 there were some 500 nuclear safety experts in Finland.

The decision-in-principle of 2000-2001 relating to building a final disposal facility for spent nuclear fuel, and the decision-in-principle concerning construction of the fifth nuclear power plant unit approved by Parliament a year later, significantly changed the situation described above. The need for competent labour increased substantially; on the other hand, there was also enhanced motivation among those working within the sector and an increase in the number of those seeking related jobs or training. In 2005, the Ministry of Trade and Industry made a rough estimate that at that point there were approximately 700 experts with equivalent competence to that calculated for the more thorough study of 2000.

Following the nuclear power decisions made in 2001-2002 the sector recognised the strong need for supplementary training, especially for persons with a few years' experience within the nuclear energy sector. In 2004 the Radiation and Nuclear Safety Authority (STUK), the Ministry of Trade and Industry (the present Ministry of Employment and the Economy), Lappeenranta University of Technology (LUT), Helsinki University of Technology (TKK, present Aalto University), VTT Technical Research Centre of Finland and power companies launched so-called 'YK' courses, or national training courses in nuclear safety. The model for the course was sought from the International Atomic Energy Agency (IAEA). The course that initially lasted six weeks was tailored for Finnish needs and has been developed continuously to meet the latest developments within the sector.

The ninth YK course in 2011-12, and today a total of over 500 nuclear sector experts have passed the course. The tenth YK course will begin in autumn 2012. Lappeenranta University of Technology is currently in charge of arranging the course. Tuition, however, is still provided by a group of almost 100 teachers assembled from all nuclear sector organisations, who place their best competence at the course's disposal without separate compensation. A similar national pilot course has also been arranged within the field of nuclear waste management.

**Figure 1.1.** The eighth YK course about to begin in October 2010. In the front row, fourth from left, Professor Riitta Kyrki-Rajamäki, the principal of the course. Other people in the photo are students or instructors on the course. By spring 2012, a total of more than 500 people have already passed the YK course. Photo: Timo Mikkola



Extensive use of Finnish labour for the nuclear power projects is dependent on the project structure and arrangements of the company building the power plant (licence holder), on the availability of competent labour, and on how attractive the industry and other actors find the potential subcontracting projects and tasks. Activating the Finnish business sector at the earliest possible stage of the process enhances its opportunities for participating in the projects. On the other hand, it must be noted that European Union regulation prevents any kind of favourable treatment of national industry by government in the internal market. Furthermore, procurement decisions are made by the company responsible for the project. Naturally, it is clear that the stipulations of Finnish laws and labour market regulations must be adhered to in all nuclear power projects.

The party in charge of activating Finnish industry has been an association by the name of FinNuclear (registered association from 2010), formed by several industrial organisations, which aims to develop Finnish nuclear industry in such a manner that it would be capable of fully effective participation in the new nuclear power projects. The work in the FinNuclear conglomerate is conducted by employees of the development company Prizztech Oy.

All key nuclear industry actors are involved in the FinNuclear activities. In 2010 FinNuclear launched supplementary training courses tailored to Finnish industry for the purpose of assisting preparation for potential new projects. Both the present licence holders and FinNuclear have also organised several events bringing together potential nuclear power plant suppliers and Finnish industry representatives.

In addition, the Federation of Finnish Technology Industries established a branch group in 2009–2010 for nuclear related businesses, the “Finnish Nuclear Suppliers’ Group”, the purpose of which is to promote the competencies of Finnish industry in nuclear power projects. Today, the business group has already some 70 members.

Any country using nuclear power is required to have sufficient infrastructure that, in addition to operator and supervisory organisations for the facilities, and to nuclear waste management, also covers relevant training, research and expert services. The construction of Olkiluoto 3 and potential new nuclear power plant units will increase the need for nuclear sector experts in Finland. At the same time, the retirement of existing experts continues, especially among those who were involved in the design and construction of Finland’s first four nuclear power plant units. All this combined increases the need for training and education, in which active research into nuclear safety plays a crucial role.

Any kind of applied research into nuclear safety would not be possible without foundations built upon the continuous existence and development of basic research within the field. Such research is carried out at various universities (LUT, Aalto, and the universities of Helsinki and Jyväskylä) – with funding from, for instance, the Academy of Finland and the EU – as well as at VTT Technical Research Centre of Finland and the Radiation and Nuclear Safety Authority (STUK).

Participation in international research within the sector also plays a vital role. Important cooperation organisations include the Nordic Nuclear Safety Research Programme (NKS), the fission research programme of the EU i.e. the European Atomic Energy Community (Euratom), the programmes of OECD’s Nuclear Energy Agency (NEA), and the IAEA research programmes. Partly due to the Olkiluoto 3 project, Finns have held a strong position in nuclear safety research, and particularly in cooperation among the authorities of different countries.

The starting point for the coordinated national research programmes of nuclear safety, initiated as early as the end of the 1980s, was that they create preconditions for continuing the safe use of nuclear power; maintenance of knowledge needed for management of nuclear waste; development of new knowledge; and participation in international cooperation. National programmes are funded by the key organisations operating within the nuclear energy sector. The State Nuclear Waste Management Fund (VYR) has acted as a significant provider of funding for national nuclear safety research since the beginning of 2004. In accordance with the amendment to the Nuclear Energy Act that entered into force that year, funds are collected in two separate funds that are kept apart from the other assets of the Fund. From power companies the contributions are collected according to their nuclear power capacity, and from those responsible for nuclear waste management according to their assessed liability. Each year, the funds available for allocation are used for financing research projects that form a project entity supporting the purpose for which the funds are collected.

Internal research conducted by nuclear power companies, or authorities that fall within the scope of supervision or licensing of existing or new facilities or nuclear waste management, have been excluded from among the research programmes eligible for funding on the basis of the Nuclear Energy Act. The organisations practising public research within the sector have developed into an important resource, which various ministries, the Radiation and Nuclear Safety Authority (STUK) and power companies have been able to utilise.

In continuation of earlier similar research programmes, a four-year research programme entitled SAFIR2014 (Safety of nuclear power plants – Finnish national Research programme) was launched in 2011. The projects included in the SAFIR2014 programme can be related to such matters as ageing of nuclear facilities, technical reforms in various areas of technology, and organisational changes within the field. The programme is also to maintain know-how in those areas where no significant changes occur but in which dynamic research activities are the absolute precondition for safe use of nuclear power.

The new Finnish Research Programme on Nuclear Waste Management KYT2014 was also initiated in 2011. The programme provides funding for technical and scientific research, the purpose of which is to establish and ensure our country's general basic readiness for nuclear waste management solutions and their implementation. The key areas of research within this programme entity are research activities promoting long-term safety of geological final disposal of spent nuclear fuel, and analysis of alternatives for Posiva's present waste management programme.

For example, in 2011 the Fund had approximately 5.2 million euros available for financing the SAFIR2014 programme, when the overall funding of the programme amounted to some 10 million euros. The same year, the Fund had approximately 1.7 million euros to contribute to the KYT2014 programme. The overall funding base of the KYT programme in 2011 was some 2.8 million euros. Both approved decisions-in-principle of 2010 relating to additional nuclear power construction increased the annual funding by about one million euros each.

## 1.2 Objectives of the Committee's Work and Method of Implementation

The major increase over the past decade in the need for nuclear power competence, described above, forms the backcloth to the appointment of the Committee for Nuclear Energy Competence in Finland. Another background factor is the statement presented in 2010 by Parliament in connection with the ratification of the Government's decisions-in-principle concerning the nuclear power plant projects, requiring that "the Government will, for its own part, create the preconditions for utilising Finnish labour, knowledge and business life as far as possible in nuclear power projects".

On 27 October 2010, the Ministry of Employment and the Economy (MEE) set up a committee which came to be known as the Committee for Nuclear Energy Competence in Finland. The committee was given the task of assessing the nuclear expertise resources Finland would need over the next few decades. The committee was to examine the overall situation regarding nuclear energy sector competence, and outline the needs for further development of the relevant personnel resources. Furthermore, the committee was to estimate the needs for further development of the research infrastructure available to domestic nuclear safety research, and to give recommendations to actors within the sector.

The committee included representatives from the ministries with the highest level of involvement in the project: the Ministry of Employment and the Economy, the Ministry of the Environment, the Ministry of Social Affairs and Health, and the Ministry of Education and Culture. Other key participants included representatives of the Radiation and Nuclear Safety Authority (STUK), VTT Technical Research Centre of Finland as the representative of research institutes, and the following universities: Aalto University, the universities of Jyväskylä, Oulu and Helsinki, and Lappeenranta University of Technology. The power companies involved in the work were Fennovoima, Fortum, TVO, Posiva and the industrial association FinNuclear. Industrial Counsellor Riku Huttunen from the MEE (Director General of the Energy Market Authority from 1 August 2011) acted as chair of the committee.

The committee convened nine times. The majority of committee work, however, was conducted in the divisions established at the beginning of the project. The duties of the divisions were distributed as explained below. The allocation of the chapters of the report among the divisions is also mentioned. The chair of the committee was responsible for chapter 9. The head of each division appears in brackets:

- 1) Conducting the survey and organising the data obtained; chapters 1 and 2 (Jorma Aurela)
- 2) Conducting an extensive review of the need for basic higher education, postgraduate education and further education and supplementary training; chapter 3 (Jarmo Ala-Heikkilä)
- 3) Investigating the opportunities for Finnish participation in the forthcoming major nuclear power plant projects; chapter 7 (Juhani Hyvärinen )
- 4) Surveying the research infrastructure available to nuclear actors and research; chapter 5 (Heikki Purhonen)
- 5) Examining Finnish research activities and participation in international research activities; chapters 4 and 6 (Eija Karita Puska)
- 6) Reviewing the situation regarding the VTT research reactor; chapter 8 (Jaana Avolahti)

The composition of the committee and each division is presented in appendix 1. The appendix also lists the number of meetings held by each division. A total of 20 meetings were held. In all, some 150 people were involved in the work of the divisions and in the writing of this report. The report was mostly written within the divisions,

although the committee as a whole participated in the harmonisation of the text. Each chapter presents recommendations made within the separate divisions, but chapter 9 outlines observations and recommendations made at the committee level.

The mandate of the committee was extended from the original deadline (31 May 2011) and the work continued throughout autumn 2011. The final committee report was translated into English. A list of abbreviations is presented in appendix 8, although some abbreviations are explained as they occur in the text.

The International Atomic Energy Agency (IAEA) in 2011 adopted an Action Plan on Nuclear Safety on the basis of the Fukushima accident. One of the key aspects of this plan is competence, in this case headed “Capacity Building”. This report will serve as Finland’s self-evaluation report in the said programme.

## 1.3 Presentation of the Survey and its Objectives

The committee was in need of up-to-date information to complete its work. For this reason, one of the essential parts of committee work was to conduct a survey, the practical arrangements of which were made by Innolink Research Oy.

The following organisations were selected as target groups for the survey:

- 1) key nuclear actors, i.e. the parties involved in the Committee for Nuclear Energy Competence in Finland, complemented by the organisations defined below (20 in total)
- 2) universities and other higher education institutions (just over 20)
- 3) industries closely associated with power companies (several dozen)
- 4) other related industries (the rest, approx. 200)

In other words, the first target group included all the parties represented on the Committee for Nuclear Energy Competence in Finland: the four ministries, five universities, four power companies, VTT and STUK. Outside the actual committee the target group included Tekes – the Finnish Funding Agency for Technology and Innovation, the Academy of Finland, and the companies Platom, Pöyry and ÅF-Consulting; a total of 20 organisations.

Group 2 included the seven universities and 19 polytechnics (universities of applied sciences) selected by division 2. Group 3 mostly included organisations named by power companies with which the power companies are engaged in cooperation or business relations of different types. Group 4 consisted of companies with addresses on FinNuclear’s mailing list.

In accordance with the division into groups, the consultant gave different instructions for different organisations. Contact persons were specified for each organisation. In all, the survey was sent to 299 different addresses. The number of replies was 64, which places the response rate at 21.4%. The low response rate is



probably explained by the fact that the survey was very extensive, and that many organisations did not recognise themselves from the description or considered it too difficult to answer the survey. All organisations belonging to target group 1 answered the survey, and an inquiry was made of those belonging to target group 2 whether their non-response derived from the education institute in question not having any related activities. A follow-up inquiry was also conducted for target group 3. This report will be disseminated to all recipients of the survey.

## 1.4 Presentation of the Parts of the Survey

The survey form is included in this report as appendix 2. The first part of the survey examined the existing personnel resources such that the number of experts was defined, on the one hand, on the basis of educational background and, on the other, on the basis of experience within the nuclear sector. The various areas of competence are described in chapter 2. The educational background was defined for the purposes of the survey as higher university or polytechnic degree (Master) suitable for the industry, equivalent lower university or polytechnic degree (Bachelor) or secondary-level vocational qualification.

The second part of the survey outlined each organisation's need for labour with the equivalent level of competence in 2015, 2020 and 2025. In this part, the organisations were also to take into account the loss of personnel due, for example, to retirement. Since the survey also aimed at receiving freely formulated replies, it was asked under item 3 what experts other than those specified on the form the organisations might need in the future.

The fourth part of the survey examined the Finnish research infrastructure and investment in research. These questions were targeted at group 1 only. In addition to research equipment, this part of the study also inquired about the use of different databases and software. The research funding of various organisations was also included here. The purpose of the fifth part was to explore participation in international research and EU projects.

The sixth part of the survey investigated the offering of education and training. This was divided into sections concerning basic higher education, postgraduate education, further education and supplementary training and concerned primarily target groups 1 and 2, although personnel development methods employed by the organisations were also inquired of target groups 3 and 4. This part of the survey concerned ongoing activities as well as future plans. In addition, and separately from the results obtained, the universities and polytechnics that had replied to the survey were asked to provide presentations of the universities and education institutes operating within the sector in accordance with appendix 3.

Olkiluoto island in winter 2011-2012. From left Olkiluoto 3 under construction and operating nuclear power units Olkiluoto 1 and 2.



## 2 Nuclear Energy Sector Personnel Resources in 2010

This chapter summarises the results of the survey concerning nuclear energy sector personnel commissioned by the Committee for Nuclear Energy Competence in Finland. Appendices 4–6 present the comparable results for three groups: 1) Power companies and Posiva; 2) the authorities; and 3) universities and research institutions.

### 2.1 Employment Structure and Figures in the Energy Sector from 2005 to 2025

The Memorandum and Report of the Ministry of Education and Culture Working Group 2011:16 “Towards balanced employment development by 2025 - proposal for targets concerning the offering of education and training in 2016” has studied and estimated the employment structure and number of those employed in various sectors between 2005 and 2025.

The nuclear energy sector is included in the part of the report covering the operation area of “energy, heat and water supply”. Table 2.1 shows the report estimate on the employment structure within various sectors in Finland in 2005.

The report also estimates the development of employment figures by sector from 2005 to 2025. The number of those employed within the energy, heat and water supply sectors in 2005 is estimated at 15,710 and the estimated need for such personnel in 2025 at 12,051. According to the report, the energy sector is not considered a labour-intensive branch, compared to public administration or industry, for example.

**Table 2.1.** The number of employees per operating sector in 2005 and in different scenarios for 2025.

Operating sector	2005	2025 (BASIC)	2025 (TARGET)
Operating sector	127,183	108,767	97,154
Manufacturing	432,985	305,998	371,783
Construction	164,607	187,319	189,353
Financing and business services	289,288	290,564	353,140
Public administration and national defence	175,014	177,909	145,822
Education	161,306	170,400	181,009
Health care	171,312	241,274	205,152
Social services	181,619	257,332	232,782
Other social and personal services	126,583	130,522	136,681
Trade, hotel and restaurant sector	382,750	422,279	437,048
Transport and communications	170,511	167,960	182,431
Energy, heat and water supply	15,710	11,652	12,051
<b>Total</b>	<b>2,398,869</b>	<b>2,471,976</b>	<b>2,544,406</b>

Source: Memorandum and Report of the Ministry of Education and Culture Working Group 2011:16

## 2.2 Current Personnel within the Nuclear Energy Sector

The Committee for Nuclear Energy Competence in Finland inquired of the major actors within the nuclear energy sector in Finland how many of their personnel have special competence in the nuclear energy sector, by area of competence. According to the results of the survey, there are some 3,300 people working within the nuclear energy sector with special competence in the field. This covers about one fifth of those employed in the energy, heat and water supply sectors as reported in the abovementioned Ministry of Education and Culture memorandum. Since the committee's survey did not fully cover the subcontractors, the actual number of people employed within the nuclear energy sector is higher than this.

Continuous improvement of nuclear safety is characteristic of the nuclear energy sector; as a consequence most of the tasks within the sector are specialist duties. For this reason, a high proportion of personnel possess a higher university or polytechnic degree (Master). Table 2.2 shows the educational background distribution in 2010 of the entire nuclear energy sector personnel in Finland on the basis of the committee's survey. About half of those currently employed within the sector have passed a higher university or polytechnic degree.

**Table 2.2.** Educational background of nuclear energy sector personnel in 2010. The numbers of licentiate's and doctoral degrees itemised separately among those with a higher university or polytechnic degree.

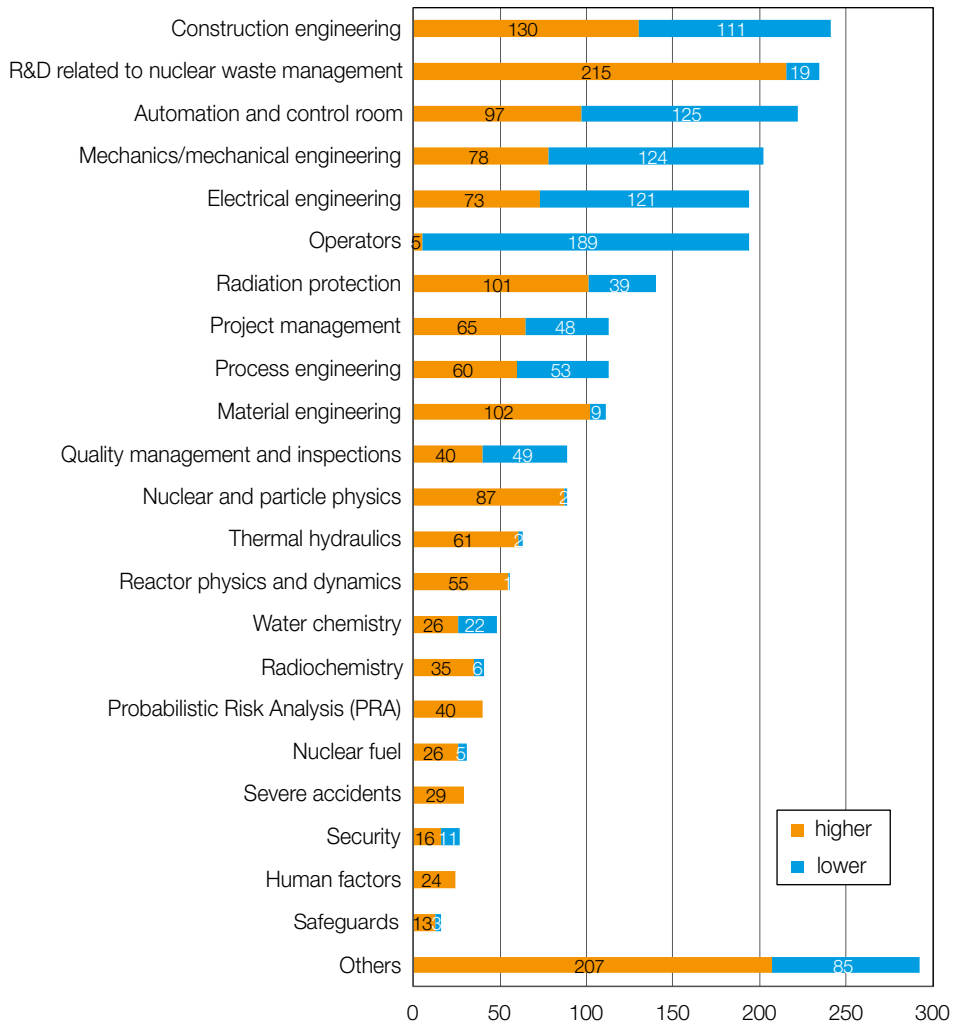
Degree	number	
Higher university/polytechnic degree (Master)	1,585	
Licentiate		55
Doctorate		232
Lower university/polytechnic degree (Bachelor)	1,024	
Secondary-level vocational qualification	676	
<b>Total</b>	<b>3,285</b>	

Within the nuclear energy sector, 18% of those with a higher university or polytechnic degree completed a postgraduate degree in science, in other words a licentiate or doctoral degree. On average, 14% of those with a higher university or polytechnic degree obtain a licentiate or doctoral degree (source: Ministry of Education and Culture, KOTA system). In technology the average figure is 15%, and in natural sciences 28%. On the basis of the committee's survey, about one fifth of the nuclear energy sector licentiates and doctors work as authorities, one fifth in power companies and the rest in universities and research institutions.

Figure 2.1 shows placement of those with a higher university or polytechnic degree in various fields of competence within the nuclear energy sector. As the figure shows,

the majority of the duties require basic technical or scientific university education. The column 'Others' includes support functions, such as procurement, personnel administration, training duties and document management.

**Figure 2.1.** Placement of nuclear energy sector personnel in various specialist duties. The figure shows persons with a higher education degree.



This study and survey examined the resources within the 22 sectors described below. The potential contents of various specialist positions are clarified below in accordance with the number of personnel within the sectors specified for the purposes of this study. The descriptions given serve as examples, since the task descriptions vary with each actor.

**Construction engineering** includes construction technical and fire technical design, building development and supervisory duties, together with the relevant specialist positions. Such duties can be found in new building, renovation, and maintenance and repair of nuclear facilities and in real property management. The most important competence areas can be considered to be those in engineering and maintenance of reinforced concrete and tendon structures, in structural fire protection, and infrastructure construction, including rock engineering.

The purpose of duties related to **nuclear waste management** is to ensure safe and efficient management of the power plants' low-, medium- and high-level nuclear waste, as well as their safe final disposal in accordance with existing requirements. The work requires, for example, understanding of the factors affecting the generation of nuclear waste; waste processing and storage methods; and assessment of the suitability of the final disposal site from the perspectives of construction, operation and long-term safety. Competence in the handling of nuclear waste and during the operation related to final disposal include similar competence in nuclear safety and radiation protection as required in the operation of nuclear power plants. Nuclear waste management tasks are multidisciplinary, and gaining familiarity with the sector through work assignments is an important part of the development of competence within the field.

**Automation and control room:** The purpose of automation is to keep the power plant process under control by means of automatic functions or measures taken by operators. The automation system designer is assigned by process designers to develop the functions by which the power plant is to be controlled, and designs the implementation of these in the automation systems. The automation system designer must have comprehensive knowledge of the power plant operations to ensure that the systems function in a correct manner.

Control room designers plan the interface between humans and machines such that the power plant operators remain sufficiently informed of how the power plant process functions under any circumstances, and of whether the various systems of the plant are in a proper state to perform the functions required by the operator. In the opposite direction, control room designers ensure that the control commands are transmitted to the machines as quickly as the situation requires. Control room designers must be familiar both with the automation systems and with human behaviour under different circumstances.

**Mechanics/Mechanical engineering** refers to engineering duties relating to mechanical devices and structures. Most of the design duties related to mechanical engineering of power plants are associated with the design of pipelines, pressure vessels, support structures for equipment, cable racks, and maintenance platforms. The key areas of competence include mechanical engineering, mechanical drawing, mechatronics, and manufacturing, strength, material and inspection technology.

Power companies in particular have duties related to **electrical engineering** ranging from one extreme to another. In maintenance, condition monitoring and

electrical planning there are fitters, installers and supervisory staff for all voltage levels up to 400 kV high voltage. Electrical work safety is an integral part of the work, and each of the personnel in this line bears responsibility. Pursuant to the Electrical Safety Act, each power plant must also have supervisors of electrical work and the use of electricity. The supervisors are responsible for any electrical work carried out and for supervision of the use of electrical equipment. Power plants also have an internal inspection body for electrical and automation work, performing commissioning inspections on behalf of the licensee on any alterations covered by safety classification. In addition, within this field there are specialists working in planning duties involving the drawing up of, for instance, plans in principle, pre-service inspection materials for system alterations, feasibility studies, and installation plans on the basis of Regulatory Guides on Nuclear Safety (YVL guidelines).

**Operators** refers to the shift team in the nuclear power plant main control room that normally consists of at least three operators qualified in accordance with the YVL Guide, one of whom is an approved shift supervisor and two who are approved other operators. Before initial fuel loading into the reactor can begin, a new nuclear power plant must have a sufficient number of operators with approval from the authorities.

In accordance with the YVL 1.6 Guide operators must be given in-depth training in the structure, functions and operation of the plant and its systems. The obligation to operate the plant in accordance with the Operational Limits and Conditions and the plant procedures must be emphasised in the training. In preparation for the various plant operational conditions, as well as for disturbance and accident situations, the operators must assimilate sufficiently extensive knowledge and skills pertaining to plant behaviour, observation of plant conditions and performance of control operations. Operator training must give good teamwork readiness as required by the duties, and similar readiness for the administrative control and supervision of work performed at the plant. Shift supervisors must be given training in managerial and communicative skills, and their training must be more wide-ranging than that of other operators.

The training of operators at nuclear power plants takes several years, and their competence and skills are monitored by regular assessments (a written examination, an oral examination, and demonstration of professional skill).

**Radiation safety and protection** includes duties relating to radioactive substances and their spreading, as well as protection against radiation. In terms of radiation safety and protection, the key objectives include prevention of the spreading of radioactive materials, keeping employees' exposure to radiation at a minimum, and protection of various devices and rooms from radiation. The focus of radiation safety is on the design and investigation of the potential repercussions of operational disturbances and accident situations. In radiation protection, on the other hand, the emphasis is on everyday operations of nuclear power plants, and on minimising and monitoring employees' exposure to radiation.

**Project management** includes project planning, implementation and monitoring, as well as management of project-related risks and quality management relating to the project. The overall size of projects to be managed defines which management methods need to be employed. Large projects often have participants from various organisations. Within the nuclear energy sector, project management duties also comprise management of nuclear and radiation safety risks and quality assurance. As a field of competence, project management refers to the ability to implement complex work packages in a coordinated manner within a specific schedule and budget.

**Process engineering** includes process technical engineering duties. In power companies, the main focus of such duties is on the design of system modifications in nuclear power plants. The duties include, for instance, planning of system entities and modifications of outdated systems, dimensioning of process equipment, and planning and implementation of trials and testing of new or modified systems. The key areas of competence are heat transfer and fluid dynamics competence, and knowledge of process equipment and systems.

**Material engineering** comprises manufacturing of materials and knowledge of processing methods; knowledge of material properties; understanding of ageing and corrosion mechanisms; and familiarity with trial and testing methods for different materials. The field of manufacturing technology, on the other, hand covers workshop manufacturing techniques and knowledge of the related metallurgical impacts. The duties include selection of manufacturing and processing methods; development and assessment duties; strength calculation; and assessment of damage mechanisms, including corrosion, ageing and embrittlement; among others. Other manufacturing technology duties, closely linked with material engineering, cover approval of welding qualifications and quality assurance of welding activities.

The area of **quality management and inspections** covers quality planning, quality control, quality assurance and quality improvement. As specific duties, quality management refers to steering the organisation in quality-related issues; setting quality goals and monitoring achievement of these; assignment of processes and resources; and development of operations in accordance with the principles of continual improvement. Quality management duties can also include assessment and auditing of products and functions for compliance with requirements. Other competences related to quality management in addition to knowledge of quality-related techniques include knowledge of standards and assessment methods and competence in auditing.

**Nuclear and particle physics** refers to basic research of theoretical and experimental nuclear and particle physics. In Finland, experts in the field work mainly in universities. In the area of nuclear energy this expertise is applied to practice in the creation of initial data for chains of calculations in reactor physics. However, such data must always be integrated into international nuclear data libraries before it can be applied via the reactor physical computing system.



**Thermal hydraulics** covers competence in heat transfer and fluid dynamics required for cooling nuclear reactors during normal operation and in emergency situations. Specialists within the field work in nuclear power plants, for example in the areas of operation or safety technology, or in official and research organisations, with issues related to incident and accident analysis and testing operations. Educational background is typically in, for instance, energy technology.

**Reactor physics** deals with modelling of neutron interaction in the reactor core and thus the control of nuclear chain reaction. This also requires calculation of radioactive materials during fuel burn-up. Typical duties at power plants include annual planning of fuel consumption and reload cores, as well as attending to nuclear criticality safety. The field also comprises reactor dynamics, employed for computing the dynamic behaviour of the chain reaction, in other words the output development in power control situations and in incidents and accidents. Experts in reactor dynamics must also have competence in thermal hydraulics. The education is typically obtained in an educational programme of applied physics or energy technology.

The **water chemistry** laboratory monitors the chemistry of water vapour circulation by taking samples from the various systems included in the process. Water chemistry conducts, for instance, metal and anion analyses, and titrimetric and potentiometric analyses. High-standard water chemistry will maximise the useful lives of plant components and ensure fuel integrity. Efforts are made to minimise corrosion phenomena in plant units. Those working in water chemistry laboratories are educated in universities as chemists, laboratory assistants, laboratory engineers or technicians.

**Radiochemistry** studies the chemical behaviour and use of radioactive materials. In nuclear power plants the radiochemistry laboratory personnel will take water and gas samples from the various systems of the process and conduct radioactivity analyses of these, and monitor radioactive emissions into water and air. The goal is to ensure that radiation levels remain low. In the field of final disposal of spent nuclear fuel, key competence is related to chemical processes of long-lived radioactive materials in the ground and bedrock.

**PRA (probabilistic risk assessment/analysis)** involves development and application of probabilistic models and computing methods, risk assessment of operational incidents related to normal operation of plants, and modelling and assessment of risks associated with external events. The duties can include the development of PRA models and related computing, assessment of safety impact of malfunctions and incidents, or inspection of plans made.

The objective of duties related to **nuclear fuel**, the most important of which include licensing of the design and manufacturing of nuclear fuel and fuel technical and reactor physical research, is to ensure safe use of nuclear fuel. The duties comprise, for instance, review of nuclear power plant design principles and analyses; performing parallel analyses; processing of design and structure documentation;

monitoring of manufacturing; and auditing of fuel suppliers. In power companies, duties related to nuclear fuel research include monitoring of fuel performance properties; assessment of research needs; fuel research; and acquisition of reference data. In research institutions the specialist positions are related to heat and material technical modelling of fuel rods and the radioactive isotopes generated in them during normal operation at various burn-up levels, as well as under dynamic conditions in incidents or accidents.

Duties related to assessment of the probability and consequences of **severe accidents** include assessment of large early release frequency (using PRA modelling); deterministic analyses of severe accident event chains and experimental activities; impact assessment of radioactive materials; and emergency response arrangements. A PRA-based safety assessment includes the assessment of the phenomena associated with a severe reactor accident and systems available for controlling them with a view to plant safety. Deterministic analysis models for severe accidents are primarily developed for the purposes of PRA modelling. Migration modelling of radioactive substances results in the obtaining of an estimate for radiation levels in the nuclear facility premises and of the radiation doses caused by the release. Testing conducted by research institutions is employed, for example, in the development of computing models. With a view to controlling a severe accident, it is of vital importance that power company personnel and authorities operate in a correct manner during an accident situation. This is practised, for instance, in annual emergency exercises.

**Security** refers to administrative and technical arrangements by which nuclear facilities and materials are protected against intentional damage and stealing. Security in nuclear facilities is largely based on normal industrial security systems and arrangements, but due to the special features and vulnerability of nuclear facilities, securing them requires special expertise, particularly at the level of design and management.

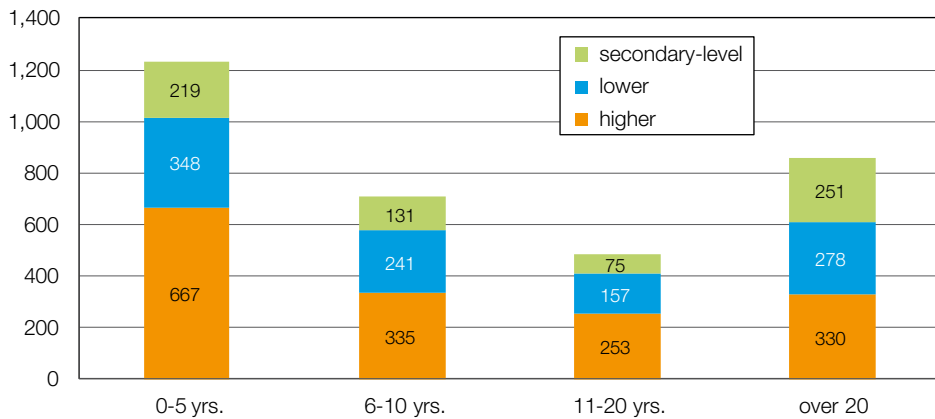
**Human factors** comprises observance of factors affecting human activities and behaviour at various phases and levels of operation, such as planning, processes and modes of operation. An area associated closely with this is the safety culture that consists of safety-oriented modes of operation, as well as working atmosphere and attitudes recognising safety as an overriding priority. The duties can include, for instance, participation in equipment and system design; development of modes of operation; investigation of organisational factors in connection with incidents; assessment or promotion of safety culture; and identification of targets for development relating to safety culture.

**Safeguards** involve monitoring of nuclear materials in accordance with the commitments of international conventions. The Safeguards are imposed to ensure that nuclear materials are not used or transferred for the purpose of manufacturing nuclear weapons.

## 2.3 The Current Nuclear Energy Sector Personnel by Years of Experience and Age

Figure 2.2 shows the distribution of personnel working in the nuclear energy sector, by years of experience within the sector, based on the results of the commissioned survey. In this figure the personnel have also been classified in accordance with their educational background. Qualification for many work duties can also be acquired elsewhere, outside the nuclear energy sector. However, due to the critical importance of safety and the consequent special characteristics of the sector, a decision was made to focus in this study particularly on the nuclear energy sector experience.

**Figure 2.2.** Work experience of current nuclear energy sector personnel in nuclear energy sector duties.



The figure also reveals that in 2010 38% of the nuclear energy sector personnel had worked in the field for no longer than five years, while 26% had more than 20 years of experience in the nuclear energy sector. In other words, in the distribution of personnel by duration of experience the emphasis on the one hand is on those who have been in the sector for a short time and on the other on the very experienced. This is a factor worth noting, since familiarising new personnel with the safety culture and special characteristics of the nuclear energy sector takes time, even if the person has already acquired qualifications for his or her special field in other industrial sectors. Long-term employment is therefore characteristic of the nuclear energy sector.

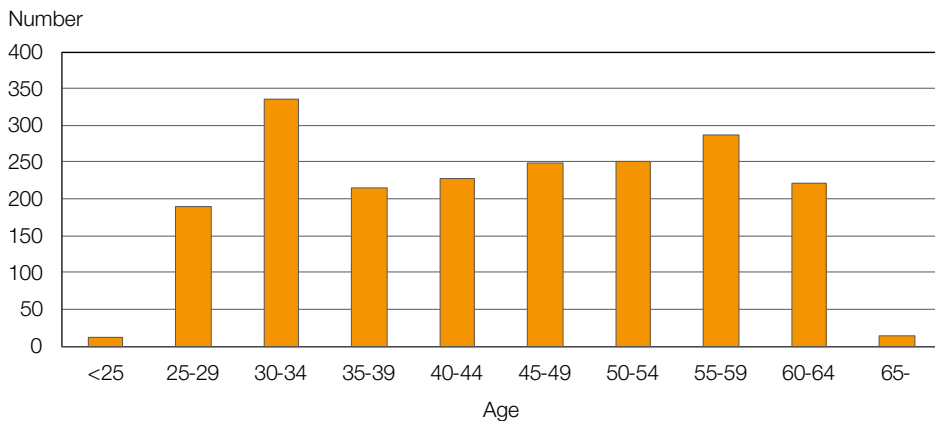
The number of those with 11-20 years of experience within the nuclear energy sector is pronouncedly small. The reason behind this is the Chernobyl accident, after which no new projects were launched for many years, and only small numbers of personnel were hired for the sector. The research and educational activity within the field also narrowed down. Since no jobs were available, students took no interest in

the sector. The small number of personnel in this generation of personnel is already causing challenges in the transfer of know-how to new specialists.

The survey of the Committee for Nuclear Energy Competence in Finland did not ask about the age distribution of personnel. However, the committee decided to supplement the material collected by obtaining experts' age distribution data from the major actors (power companies, Posiva, VTT and STUK). Figure 2.3 shows the age distribution in these companies in 2010. It can be deduced from the figure that about 39% of the personnel of the major companies within the nuclear energy sector will retire by 2025.

Figure 2.3 shows that the age distribution in the nuclear energy sector is more balanced and therefore healthier than the distribution by work experience (figure 2.2). By comparing the two figures it can be concluded that persons with similar long experience within the nuclear energy sector are not necessarily of the same age. This means that persons who have acquired their expertise within other sectors are transferring into the nuclear energy sector. The nuclear energy sector has a well-established tradition in personnel training and development, which means that it has been possible to develop those entering the field without former experience into nuclear energy experts. However, this has required and will continue to require that the organisations within the field invest in further education and supplementary training.

**Figure 2.3.** Age distribution of the major nuclear energy sector organizations in 2010



## 2.4 Current Personnel of the Nuclear Energy Sector by Competence Area

This chapter studies the placement of nuclear energy sector personnel in various competence areas on the basis of the results of the Committee for Nuclear Energy Competence in Finland survey. The investigation covered three groups: those with a

higher university or polytechnic degree, those with a lower university or polytechnic degree, and those with secondary-level vocational qualification.

**Figure 2.4.** Those with a higher university or polytechnic degree by area of competence and years of experience

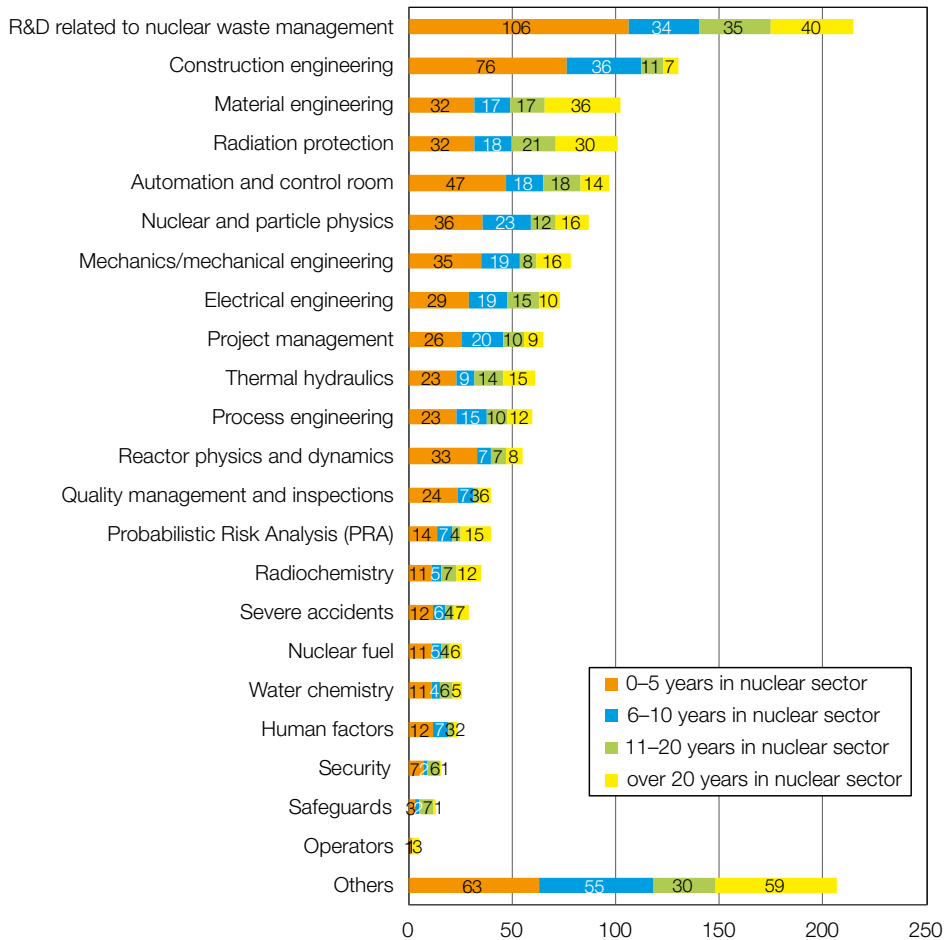


Figure 2.4 displays the placement of personnel with a higher university or polytechnic degree in various specialist positions within the nuclear energy sector. In 2010, the biggest personnel groups within the sector were those of nuclear waste management and construction engineering.

The large number of experts within nuclear waste management obtained in the survey derives from the multidisciplinary nature of the field, and from the ongoing research, development and design phase in which Finland, among the first countries in the world, is preparing for final disposal of spent nuclear fuel. In the survey,

duties involving special characteristics of nuclear waste management were not incorporated into other identified fields of specialisation. This kind of competence was instead addressed as a single, separate entity. The large proportion of construction engineering is due to the ongoing nuclear power plant modernisation and construction projects. New personnel have been recruited for the needs of these projects, visible in the large number of those with short experience within the sector.

On the basis of figure 2.4 new personnel have been recruited continuously in certain fields of competence within the nuclear energy sector. Figure 2.3 in the chapter above revealed the small number of those with 11–20 years of experience within the field. On the basis of figure 2.5 this seems to concern particular areas of competence, such as mechanics and mechanical engineering.

In some competence areas the share of those with more than 20 years of experience within the sector seems to be emphasised. In the future, the need to recruit replacements will be especially high in these areas. In the fields of material engineering, radiation protection and probabilistic risk analysis, for example, the proportion of those with 20-year experience within the sector is approximately 30%.

Figure 2.5 shows the placement of personnel with a lower university or polytechnic degree in various specialist positions within the nuclear energy sector. The operators of nuclear power plants are the biggest single group in this category. Among the personnel groups included in the scope of this survey the most evenly recruited over the years have been operators, which is explained by their work duties and the long training period required. Because the training of operators takes a long time and their duties are of critical importance with a view to safe and reliable operation of nuclear power plants, enhancing the engagement of this personnel group in the branch and maintenance of their professional skills is particularly important.

In the fields of mechanics, process engineering, quality management, and radiation protection the share of those with 20 years of experience is some 30%. Replacement recruitment will become particularly necessary in these sectors. In radiation protection, the situation is the same for those with a higher and those with a lower university or polytechnic degree.

**Figure 2.5.** Those with a lower university or polytechnic degree by area of competence and years of experience

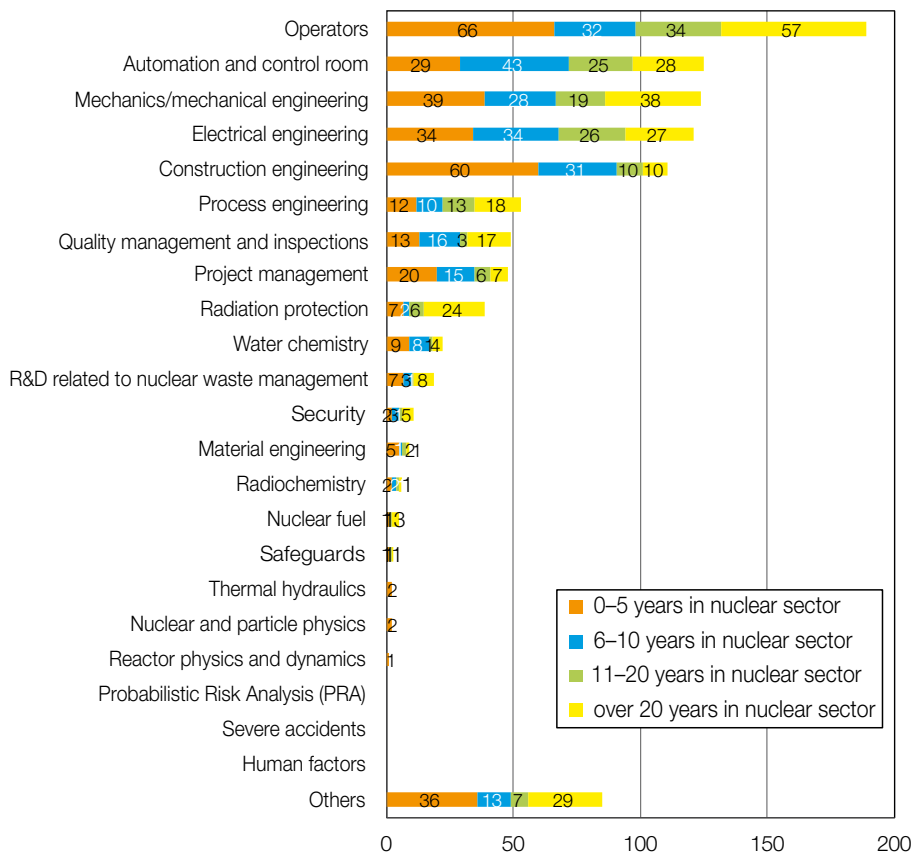
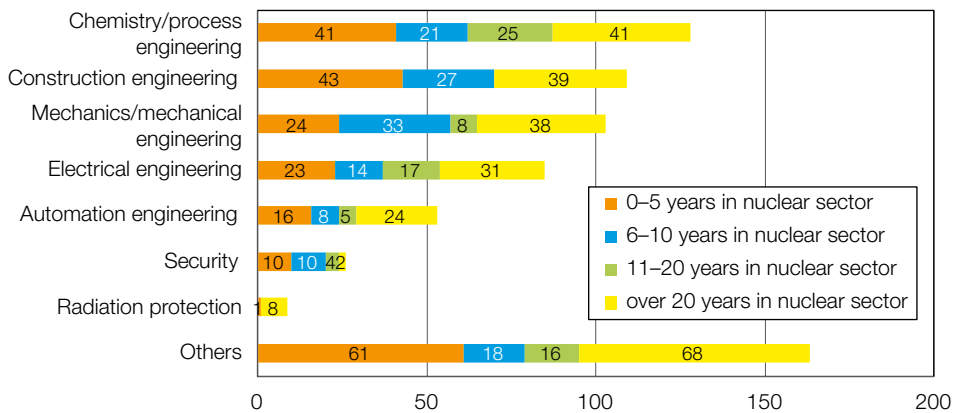


Figure 2.6 displays the placement of personnel with secondary-level vocational qualification in various positions within the nuclear energy sector. The majority of those with secondary-level vocational qualification work in nuclear power plants or supplier companies. In the light of the results of the Committee for Nuclear Energy Competence in Finland survey, the distribution by work experience of those with secondary-level vocational qualification is more balanced than for those with a higher education degree. However, in this group too, the impact of the interval in construction of new nuclear power plants is evidenced by the lower number of those with 11-20 years of experience within the field.

The proportion of chemistry and process engineering personnel among those with secondary-level vocational qualification is significant. These personnel are employed particularly in production and operational duties in nuclear power plants.

**Figure 2.6.** Those with secondary-level vocational qualification by years of work experience.



## 2.5 Future Personnel Needs within the Nuclear Energy Sector

### 2.5.1 Overall Need for Personnel within the Nuclear Energy Sector

In the future the nuclear energy sector will need more personnel, principally for two reasons. On one hand, the retirement of the baby-boomer generation brings about the need to recruit replacement personnel; on the other, the sector is growing along with new projects, so that more personnel will be needed than at present. The present educational and training resources have been planned with the current state of the field in mind. Accordingly, the Committee for Nuclear Energy Competence in Finland in its survey concentrated on the increase in the need for personnel due to the growth of the sector. The survey did not enquire separately about the number of those entering retirement age, but this can be deduced from the age distribution presented in the chapter above.

Table 2.3 shows a summary of the results of the survey of the Committee for Nuclear Energy Competence in Finland concerning personnel for 2010-2025. On the basis of the results, the need for personnel with competence in the special characteristics of the nuclear energy sector will grow by 38% (some 1,200 persons) by 2025. In other words, the total need will be approximately 4,500 persons. In the Memorandum of the Ministry of Education and Culture Working Group referred to at the beginning of this chapter, the combined need for personnel within the energy, heat and water supply sectors is calculated to be 12,000 in 2025, which means that the nuclear energy sector would constitute a significant proportion of this.



In addition to the growth shown in table 2.3, the current personnel retiring by 2025 will also need to be replaced. These represent some 39% of the personnel level of 2010, which means that a total of approximately 2,400 new persons will need to be hired for the nuclear energy sector.

**Table 2.3.** The overall need for nuclear energy sector personnel

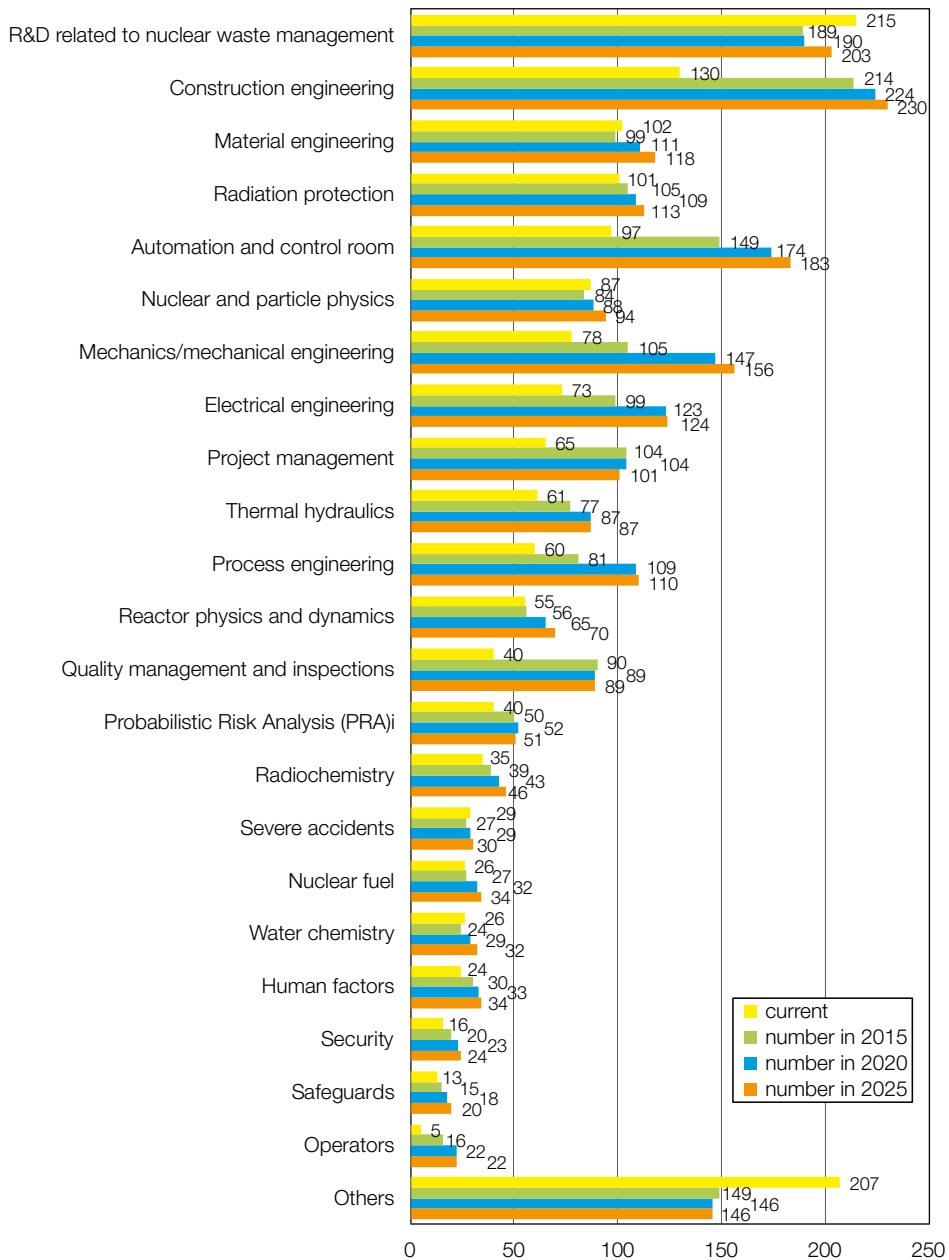
Degree	number in 2015	number in 2020	number in 2025
Higher university or poly-technic degree (Master)	1,849	2,047	2,117
Licentiate	46		
Doctorate	253		
Lower university or poly-technic degree (Bachelor)	1,126	1,465	1,573
Secondary-level vocational qualification	742	841	832
<b>Total</b>	<b>3,717</b>	<b>4,353</b>	<b>4,522</b>

## 2.5.2 Need for Personnel by Field and Level of Basic Higher Education

In 2025, the nuclear energy sector will need 34% (532 persons) more personnel with a higher university or polytechnic degree than they had in 2010. Figure 2.7 shows the need for personnel in the coming years by area of competence. The growth is the highest in the following fields (growth from 2010 to 2025 in parentheses)

- construction engineering (100 persons, 77%)
- automation and control room (85 persons, 89%)
- mechanics/mechanical engineering (80 persons, 100%)
- electrical engineering (50 persons, 70%)
- quality management and inspections (50 persons, 123%)

**Figure 2.7.** Future need for personnel within the nuclear energy sector by area of competence, those with a higher university or polytechnic degree.



Such areas of competence that require specialisation in nuclear studies are generally regarded as the key areas of the nuclear energy sector. Examples of such fields include radiation protection, reactor physics, tasks related to nuclear fuel, and thermal

hydraulics. However, based on the survey of the Committee for Nuclear Energy Competence in Finland, the growth is the highest in other areas of competence. This is mainly due to the new power plant projects and the modernisation projects of the existing power plants.

Experts in areas other than the traditional fields of the nuclear sector must be primarily specialists within their own field. In addition, they need to acquire sufficient familiarity with the special characteristics of the nuclear energy sector by studying the field as a minor subject or through further education or supplementary training. On the basis of the committee survey, the need for this kind of education and training will increase. Full-time professors in the field of nuclear energy and other university instructors familiar with the sector will also be needed for providing minor-subject level and further education.

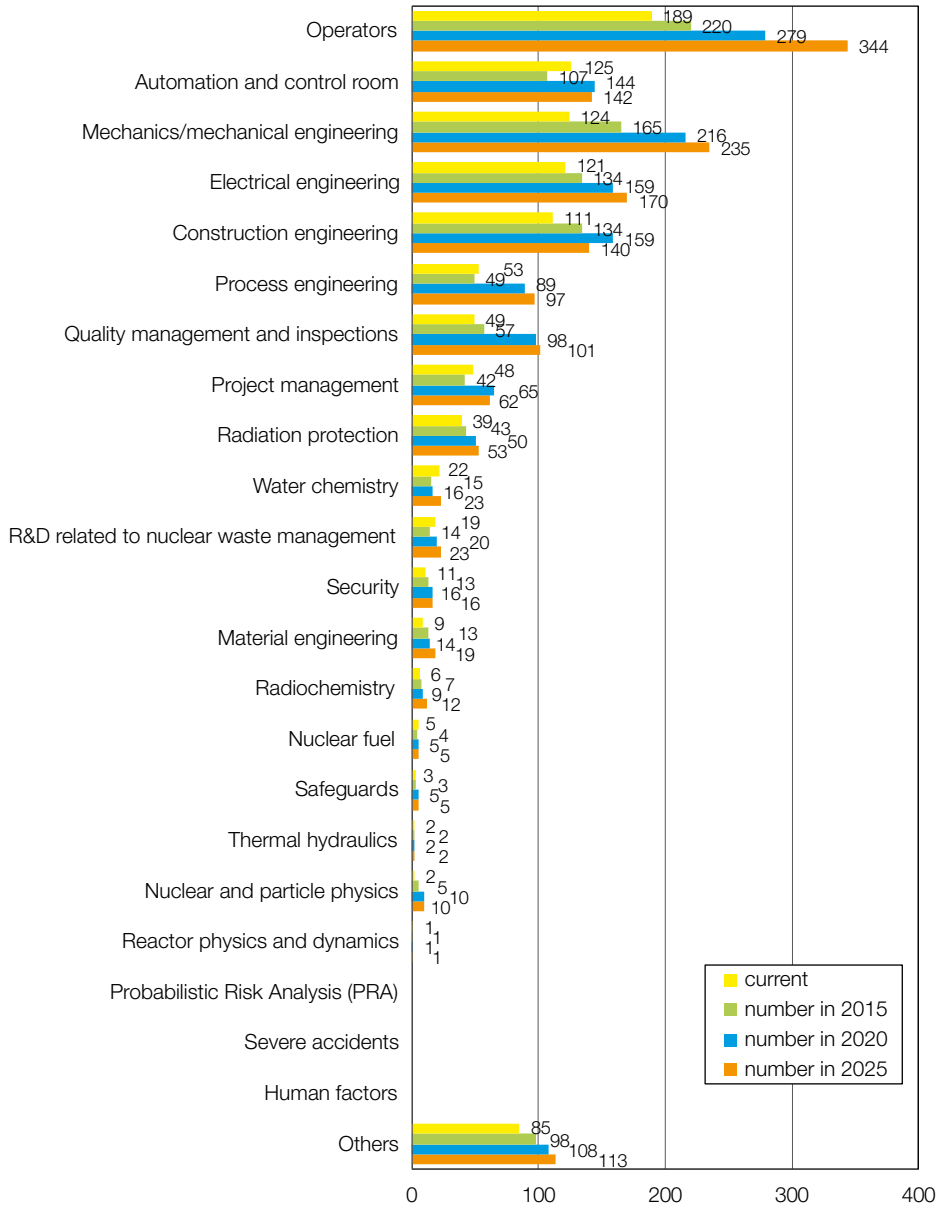
Within the key areas of competence of the nuclear sector, such as reactor physics, radiation protection or tasks related to nuclear fuel, the growth of the need for personnel is not that significant. However, the critical nature of nuclear safety alone requires competence within these fields to be kept at a high level, and new personnel needs to be educated to replace those retiring from such duties. As described in the chapter above, a large proportion of radiation protection personnel in particular have been employed in the sector for more than 20 years, and the need to recruit replacements will be high. The key nuclear sector duties require specialisation in nuclear studies, and maintenance of education at this level must therefore be secured in Finland.

In 2025, the need for persons with a lower university or polytechnic degree will be 53% higher (approx. 540 persons) than it is presently. Figure 2.8 shows the need for personnel in the coming years by area of competence. Operators of the new nuclear power plants (growth 155 persons) form the major part of the need for growth. Other growing fields include (growth from 2010 to 2025 in parentheses):

- mechanics/mechanical engineering (110 persons, 90%)
- process engineering (50 persons, 83%)
- quality management and inspections (50 persons, 100%)

If examining duties other than power plant operators, the growth in the need for personnel with a lower university or polytechnic degree will be at the same level as for those with a higher university or polytechnic degree. Variation exists within the areas of competence mainly due to the rise in the general level of education.

**Figure 2.8.** Future need for personnel, those with a lower university or polytechnic degree.

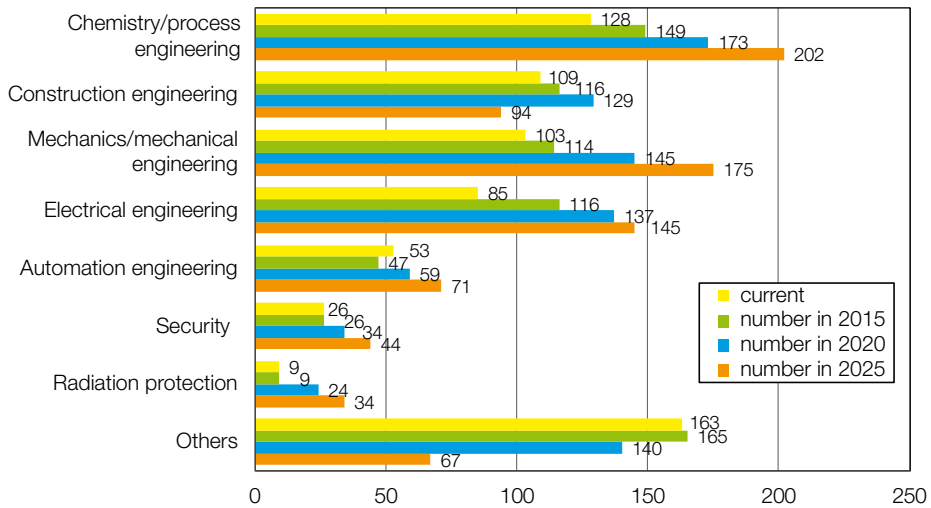


In 2025, the need for those with secondary-level vocational qualification will be 23% higher than it is today. Figure 2.9 shows the need for the coming years by function.

The need for specialists will grow the most within the following sectors:

- mechanics/mechanical engineering
- electrical engineering

**Figure 2.9.** Future need for personnel, those with secondary-level vocational qualification.



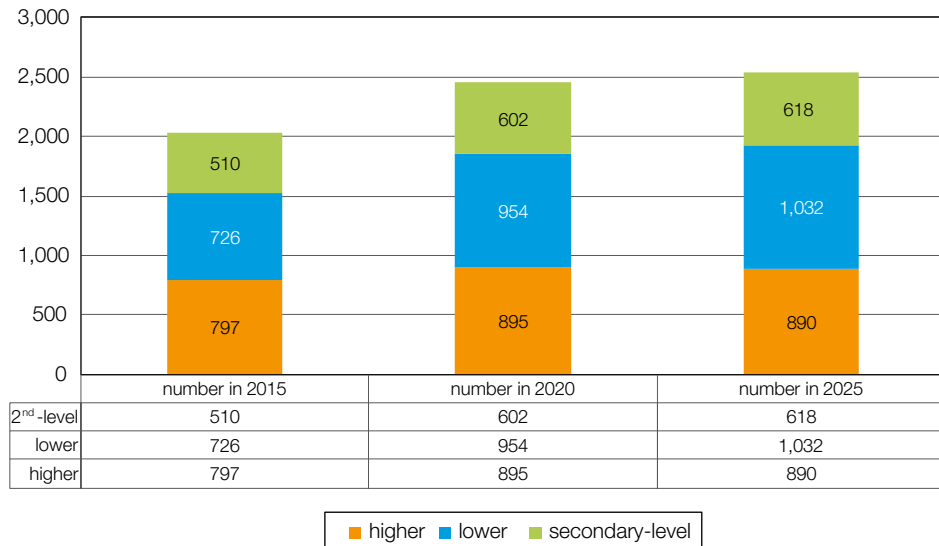
### 2.5.3 Personnel Needs of Power Companies, Authorities, Research Institutions and Universities

In the following, the future personnel needs will be reviewed from the perspective of three groups providing employment within the field: the power companies and Posiva, the authorities, and research institutions and universities. The needs of suppliers have been excluded from this study since the survey did not provide sufficiently comprehensive results. Studies concerning the personnel needs of suppliers have been previously conducted by FinNuclear, for example.

#### 2.5.3.1 FUTURE PERSONNEL NEEDS OF POWER COMPANIES AND POSIVA

This chapter will focus on the future personnel needs of power companies and Posiva. Most of these jobs will be found in the locality of the nuclear facilities. Figure 2.10 shows a summary of the growth of personnel from 2010 to 2025. The need for growth will be the highest among personnel with a higher education degree, the need being approximately 70% higher in 2025 than at present.

**Figure 2.10.** Change in personnel needs of power companies from 2010 to 2025.



The new nuclear power plant projects and the modernisation projects of the existing plants are clearly visible in the personnel needs of this group. Regarding those with a higher university or polytechnic degree, the need for personnel will grow the most within the following areas of competence:

- mechanics and mechanical engineering (70 persons, 323%)
- automation and control room (79 persons, 179%)
- process engineering (40 persons, 213%)
- project management (40 persons, 115%)
- quality management and inspections (40 persons, 146%)
- electrical engineering (30 persons, 153%)
- construction engineering (30 persons, 147%)

With regard to those with a lower university or polytechnic degree, the major part of the growth of personnel is due to the increased number of power plant operators.

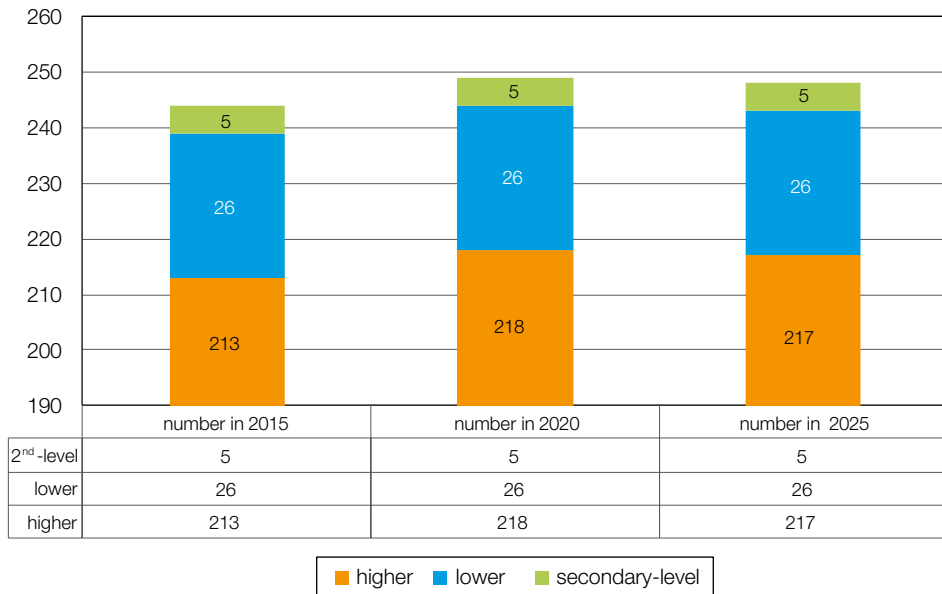
The changes in personnel will be the most significant within the following fields:

- operators (155 persons, 82%)
- mechanics/mechanical engineering (70 persons, 90%)
- process engineering (40 persons, 114%)
- quality management and inspections (30 persons, 100%)
- construction engineering (20 persons, 100%)

### 2.5.3.2 FUTURE PERSONNEL NEEDS OF NUCLEAR SECTOR AUTHORITIES

The second individual group for which personnel needs were reviewed was nuclear sector authorities, including STUK, MEE and other ministries that participated in the Committee for Nuclear Energy Competence in Finland survey. Figure 2.11 shows a summary of the growth of personnel from 2010 to 2025.

**Figure 2.11.** Personnel needs of authorities from 2010 to 2025



According to the Committee for Nuclear Energy Competence in Finland survey, there does not seem to be any major changes in the personnel numbers regarding authorities. This derives, for instance, from the fact that inspections of pressure equipment, mechanical equipment, and steel and concrete structures traditionally conducted by STUK are being transferred to approved certification or inspection agencies.<sup>1</sup>

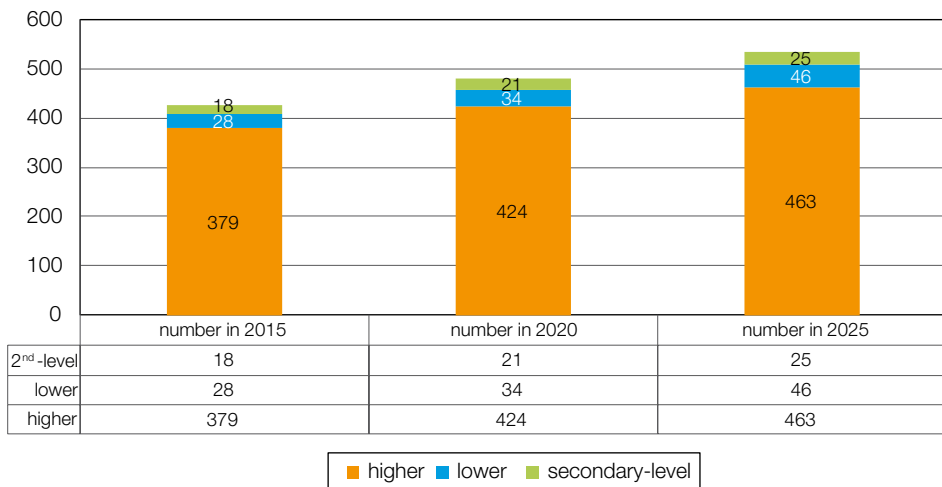
A partial explanation for the reduction in the need for those with a lower university or polytechnic degree is the general rise in the level of education mentioned above. In connection with the recruitment of replacements for those retiring, those with a former college-level technician's or engineer's qualifications that are no longer included in the Finnish educational system are often replaced by a person with a higher university or polytechnic degree.

<sup>1</sup> The resources needed for these tasks have not come up for any organisation involved in the survey, since at the time of the survey preparations for the change were in their very early stages.

### 2.5.3.3 FUTURE PERSONNEL NEEDS OF RESEARCH INSTITUTIONS AND UNIVERSITIES

This section examines the change in the personnel needs of VTT and universities that participated in the Committee for Nuclear Energy Competence survey. Figure 2.12 shows a summary of the growth of personnel from 2010 to 2025. The maintenance and continuous improvement of nuclear safety requires buttressing by high-quality research; this in turn requires personnel. The survey results concerning university personnel cover both research personnel and instructors, but most of the instructors are also involved in research. Research activities are described in closer detail in chapter 4.

**Figure 2.12.** Personnel needs of research institutions and universities from 2010 to 2025



The personnel needs of universities and VTT are growing, but growth is not as high as in the power companies. However, there is reason to suspect that in their growth scenarios universities did not observe the growing need for minor subject education. The growth in the number of those with a lower university or polytechnic degree is largely due to the needs of material engineering.

## 2.6 Summary and Conclusions

The nuclear energy sector needs highly educated personnel. In 2010, the sector provided employment for approximately 3,300 persons with competence in special features of the sector. Of these, 80% had a higher or lower university or polytechnic degree. Most of the duties within the field require technical or scientific basic education.



In quantitative terms most of the specialist positions in 2010 were found in nuclear waste management and construction engineering. In the field of nuclear energy, the number of those with more than 20 years of work experience is high, especially in the fields of material engineering, mechanics, process engineering, radiation protection, and probabilistic risk analysis. In addition, the number of those with 10–20 years of experience in mechanics or mechanical engineering is pronouncedly low, which will make the transfer of competence within these sectors from the retiring personnel to new generations more difficult.

At the moment, the distribution of the duration of work experience among the nuclear sector personnel resembles a two-humped camel. The personnel consist of a large number of new employees and of experienced employees, but the number of those with 10–20 years of experience within the field is small. This part of the personnel has entered the field in the aftermath of the Chernobyl accident, when the sector did not provide employment or attract students. We must make do with this small number of experienced employees now that the baby boomer generations are retiring and being replaced by a significantly smaller group of experts. This will make the transfer of know-how from one generation to the next more difficult.

One factor affecting nuclear safety is the maintenance of know-how and ensuring the continuity of such competence. This also includes the continuous need to attract new competent personnel into the field. Factors affecting the availability of new experts include the attractiveness of the field, investments in research activity, the willingness of companies to conduct research and development (R&D) and make investments, and the offering of high-standard education and training. It is thus important to ensure that the Fukushima accident does not result in a similar drop in the number of nuclear sector experts as occurred after the Chernobyl accident.

The age distribution among nuclear sector personnel is balanced, which shows that persons who have acquired their professional competence in other fields are transferring to the nuclear sector. Such transfer is also needed in the future, because the number of personnel with 10–20 years of experience of the nuclear sector is small. Induction of personnel transferring from other fields into the special features of the nuclear sector requires continuous investments in education and training, both within the relevant organisations and in the supplementary training sector.

The nuclear energy sector in Finland is growing, and by 2025 its need for personnel will grow by 38% (approximately 1,200 persons). In 2025, some 4,500 persons will be needed within the field, representing one third of those employed within the energy, heat and water supply sectors, according to the Ministry of Education and Culture's estimate for 2025.

In 2025, the need for persons with a higher university or polytechnic degree will be 34% higher than in 2010, for those with a lower university or polytechnic degree 54% higher, and for those with secondary-level vocational qualification 23% higher. The need for growth in nuclear sector personnel will be the highest in the power companies. These jobs will be placed in the locality of the nuclear facilities and other

of the companies' locations. In addition, the authorities, VTT and universities will continue to be major providers of employment within the field.

More personnel will be especially needed within the following areas of competence: construction engineering, automation and control room, mechanics and mechanical engineering, electrical engineering, process engineering, and quality management and inspections. In the survey, nuclear power plant operators emerged as the biggest personnel group with lower university or polytechnic degree.

In addition to the recruitment needs caused by the growth of the nuclear energy sector, new experts must also be found to replace the retiring personnel. As an estimate, approximately 39% of the present nuclear sector personnel will retire by 2025. Considering both the growth of the nuclear sector and the retirement of the existing personnel, by 2025 the field will need some 2,400 new persons with competence in the special features of the sector.

Among the areas of nuclear sector competence, the biggest growth concerns so-called 'central fields of technology', whose experts are primarily specialists in sectors other than nuclear energy. These experts are not required to have specialised in nuclear energy studies, but to have acquired the necessary competence in the special features of the nuclear sector – such as the significance of safety – as part of their minor-subject level education or further education and supplementary training for their own field of competence.

Part of the growth need in nuclear sector personnel is within fields that are not traditionally regarded as fields of engineering, such as quality management and project activities. This should have some impact on the education and content of education within these sectors.

The key areas of nuclear competence requiring education to be provided as the subject of speciality are – and will continue to be – areas of operation requiring professional personnel. Although personnel needs within these fields are growing less rapidly than those of construction engineering, for example, a significant proportion of the current specialists are about to retire, and new experts are needed. In other words, education allowing specialisation in nuclear studies must continue to be kept at a high level.

# 3 Education

This chapter describes nuclear energy sector education and training in Finland, beginning with the general educational system and the requirements set by authorities, and proceeding to basic higher education degrees, further education in science, supplementary and in-house training provided by the organisations involved, and the need for educators and trainers. Due to the composition of the Committee for Nuclear Energy Competence in Finland, emphasis will be placed on the viewpoints of technology and science and the universities, but as shown in chapter 2, the nuclear energy sector needs experts from many different fields.

## 3.1 Structure of the Finnish Education System<sup>2</sup>

The Finnish education system is divided into various levels of education. Usually a student completing one level is always eligible for the next-level studies. The qualifications of each level are governed by separate legislation. In addition to legislation, the quality assurance system also comprises the national curricula for the various educational levels and demonstrations of competence, permits for arranging education and related licensing, and external evaluation. Provisions concerning the qualification requirements for teachers are also an important part of the quality assurance system.

The education system in Finland is composed of:

- nine-year basic general education (comprehensive school), preceded by one year of voluntary pre-primary education;
- post-compulsory upper secondary education, comprising vocational and general academic education; and
- higher education, provided by universities and polytechnics (universities of applied sciences).

Adult education is available at all levels.

The post-compulsory upper secondary level comprises general academic and vocational education (initial vocational qualifications, and further and specialist qualifications). Upper secondary school provides general education and prepares students for a matriculation examination. After upper secondary school diploma or an initial vocational diploma students may apply to higher level education.

Completion of upper secondary school or initial vocational qualification takes three years.

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<sup>2</sup> (Source: <http://www.minedu.fi/OPM/Koulutus/koulutusjaerjestelmae/?lang=en>)

Those with an initial vocational qualification have the basic vocational skills and the professional competence required in working life within their field of study. The extent of the qualification is 120 credits, which takes three years of full-time study. Prior studies or work experience may shorten the time required for studies.

Further and specialist qualifications are part of continuing professional education. Further and specialist qualifications can be obtained through a demonstration of competence and preparatory training is arranged for such qualifications.

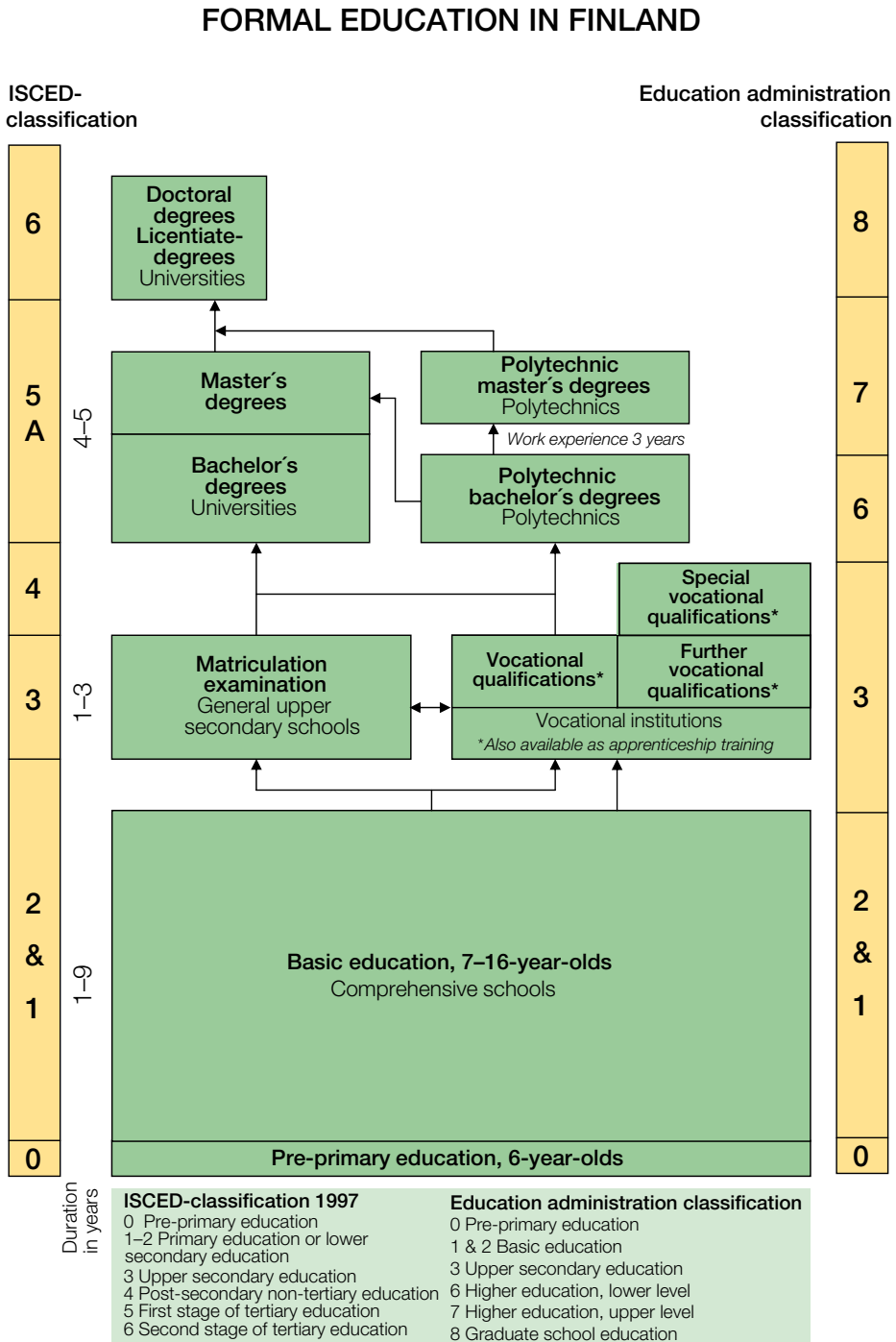
In university education, the emphasis is on scientific research and instruction based on it. Polytechnics provide practical education in response to labour market needs.

At universities students can study for lower (Bachelor's) and higher (Master's) scientific or artistic degrees and scientific postgraduate degrees, which are the licentiate and the doctorate. Acquiring a polytechnic degree takes 3.5-4.5 years. The requirement for a polytechnic Master's degree is a polytechnic Bachelors' degree or other equivalent degree. In addition, at least three years of work experience within the field is required after the first degree.

In adult education, the prior knowledge, skills and life situation of the students are taken into account in the contents and arrangements of education or training. Adult education can cover training for an initial vocational qualification; studies required as part of qualifications; training preparing for demonstration of competence; apprenticeship training; further and continuing training designed to upgrade and update competencies; social studies relating to citizenship and labour skills; and studies in different crafts and subjects on a recreational basis.

Participants in adult education can fund their studies themselves, or studies can take the form of apprenticeship training, labour market training or staff-development and other training provided or purchased by employers. Adult education is organised in education institutions belonging to the youth education system, in educational establishments organising adult education only, in enterprises, and as staff training in workplaces.

Figure 3.1. The Finnish education system



Source: Ministry of Education and Culture

### 3.1.1 Education Policy Guidelines until 2016

The Government adopts a development plan every four years for education and research conducted in higher education institutions. The development plan for 2011-2016 was adopted at the end of 2011.<sup>3</sup>

The priorities of the development plan will include guaranteeing equal opportunities for education and training, extending working careers, and enhancing the level of competence in Finland. The objective is to improve the availability of a competent labour force by enhancing the operation of the education system and improving the targeting of the offering of training and education, which in practice means reducing the time used for completion of a degree, shortening the transitional phases, reducing overlapping education and training, enhancing course completion rates, and improving the balance between offering of education and demand for labour force.

The education offering of higher education institutions in 2016 will be dimensioned on the basis of national foresight information, according to which the total volume of the education offering of universities should be maintained at the current level of some 20,000 entry places, and the number of entries in polytechnics reduced from the present 28,000 entry places by approximately 2,200 in 2013. In polytechnics, the plan is to target the reductions particularly at the cultural, tourism, catering and financial sectors and the fields of technology and traffic.

In recent years, the structural development of higher education institutions has advanced on the basis of development plans drawn up by the higher education institutions themselves. The number of universities has fallen from 20 to 16 and that of polytechnics from 30 to 25. At the same time, the higher education institution network has become more sparse as the number of operational units of higher education institutions has fallen. The network still remains too fragmented, however. The problems relating to course completion, attractiveness and employment are more common in the small ancillary units of universities and polytechnics.

The reform of the financing model of higher education institutions will place emphasis on quality and efficiency. The purpose of funding granted to universities and polytechnics is to provide better support than is currently available for improvement of the completion of education, faster transfer to working life, enhancement of the quality of education and research, internationalisation, and profiling of higher education institutions in their own areas of competence.

The number of students in the field of technology will probably be reduced in polytechnics within the next few years. Polytechnics should seek closer cooperation and clarify the division of duties in the arrangement of education in the technology

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3 Source: Ministry of Education and Culture: "Tasapainoiseen työllisyyskehitykseen 2025. Ehdotus koulutustarjonnan tavoitteiksi vuodelle 2016", OKM työryhmämuistioita ja selvityksiä 2011:16 [In Finnish; "Towards balanced employment development by 2025 – proposal for targets concerning the offering of education and training in 2016; Memoranda and Reports of the Ministry of Education and Culture Working Groups 2011:16], available at [http://www.minedu.fi/OPM/Julkaisut/2011/Ehdotus\\_koulutustarjonnan\\_tavoitteiksi\\_vuodelle\\_2016.html?lang=fi](http://www.minedu.fi/OPM/Julkaisut/2011/Ehdotus_koulutustarjonnan_tavoitteiksi_vuodelle_2016.html?lang=fi)

sector. The emphasis in the duties of polytechnics is on the connections with working life and regional impact, in accordance with which any nuclear-related education organised in polytechnics should be focused on higher education institutions, which are operating in the immediate sphere of influence of nuclear power plants and have sufficient competencies and education volume within the relevant fields of technology.

## 3.2 Qualification Requirements Concerning Personnel

In accordance with section 55 of the Nuclear Energy Act, the Radiation and Nuclear Safety Authority (STUK) may set qualification requirements for persons involved in the use of nuclear energy, and supervise the fulfilment of these requirements. Section 125 of the Nuclear Energy Decree defines the qualification requirements for a responsible manager, and section 119 clarifies STUK's role in supervision of the arrangement of proper training and competence of personnel.

STUK has set more detailed requirements on the competence of personnel and on training in several YVL guides, e.g.:

- Requirements are set for organisations and their competencies in the guides concerning testing and inspection organisations, management systems of nuclear facilities, and quality management of nuclear facilities (YVL Guide 1.3, YVL Guide 1.4, and YVL Guide 1.9).
- Requirements concerning the qualifications of the operators and other nuclear facility personnel are presented in YVL Guide 1.6 and YVL Guide 1.7.

Guidelines regarding technical systems and equipment set qualification requirements for personnel, for instance, in the systems engineering guide, the pressure equipment guides, the guidelines concerning construction, the electrical and automation engineering guides, the fuel design guide, and the radiation protection guide.

STUK is in the process of updating the YVL guides, and the requirements presented in this context stipulated by various guides will be collected into YVL A4 Guide "Personnel and Organisation of Nuclear Facilities". The new guidelines will enter into force by the end of 2012.

**Figure 3.2.** Simulator training of nuclear power plant operators (photo: TVO)



Section 14 of the Radiation Act sets requirements for the operating organisations concerning obligation to provide training, and sections 36–38 specify the requirements concerning training provided to employees. In addition, as authorised by section 44 of the Radiation Act, the Ministry of Social Affairs and Health Decree (10 May 2000) lays down provisions on, for instance, requirements concerning radiation protection training as required by clinical responsibility.

ST1.8 Guide “Qualifications of Persons Working in Radiation User’s Organisation and Radiation Protection Training Required for Competence” describes the training and qualification requirements of a responsible manager, a specialist in medical physics, a radiation specialist, and other persons acting in the radiation user’s organisation. The guide also describes the requirements set for organisations providing training that qualifies persons for these duties.

In accordance with the Nuclear Energy Act, an operating organisation must arrange sufficient training for the maintenance and development of the competence and skills of its personnel performing duties relating to nuclear security. However, no training suited for this purpose has been available for responsible managers and other persons in charge mentioned above, especially with regard to security arrangements. With the lack of suitable training the activity has been largely based on self-study by persons in charge.

Persons in charge of security in nuclear facilities who act within the framework of the Nuclear Energy Act and decrees issued under it, and who use powers granted under these regulations, are also required to have basic training as security guards or equivalent. The Private Security Services Act, and statutes issued under the Act, lay down stipulations on guard training, as well as training relating to use of forcible means and forcible means equipment, and annual refresher training. In this respect, the provision of training is sufficient.



## 3.3 Basic Higher Education Degrees in Universities and Polytechnics

The nuclear energy sector needs experts within several special fields and their education is provided by Finnish universities and polytechnics. Personnel for nuclear organisations are particularly provided through the educational programmes in engineering and sciences. The necessary competence areas will be described in more detail in chapter 3.3.1.

Education in the fields of specialisation related to nuclear energy will be described in chapter 3.3.2, and minor-subject level education of these special fields in chapter 3.3.3. The nuclear energy sector requires in-depth know-how that can be obtained through postgraduate education in science (3.4), further education and supplementary training (3.5) and staff training within organisations (3.6).

### 3.3.1 General Remarks

A nuclear power plant is a thermal power plant, the construction, modernisation and use of which require contributions from professionals representing a wide range of fields of technology, as shown by figure 3.1., drawn up on the basis of the survey conducted. However, certain areas of competence needed primarily or even exclusively within the nuclear energy sector can be distinguished.

According to IAEA, the main safety functions related to nuclear safety are (source: Basic Safety Principles for Nuclear Power Plants, 75-INSAG-3 Rev 1/INSAG-12, 1999 IAEA Austria):

**A** Management of reactivity

**B** Cooling

**C** Containment building function, i.e. ensuring the integrity of release barriers

From these it is possible to deduce nuclear-specific fields of specialisation that serve as a feasible division for the purposes of this study, when the first and last of the safety functions above are divided into two. To ensure efficient and safe production of nuclear energy and treatment of nuclear waste one must have competencies in:

1. generation and management of a dynamic chain reaction in interaction with a coolant;
2. criticality safety i.e. treatment of fissionable materials in such a manner that the chain reaction does not occur anywhere else or at any time other than when producing power in the reactor core;
3. cooling of nuclear fuel and decay heat removal under any potential normal operating conditions or in incidents and accidents, which in the case of light water reactors requires competence primarily in the thermal hydraulics of water and gas;
4. avoidance of power-producing chemical reactions in incidents and accidents; and

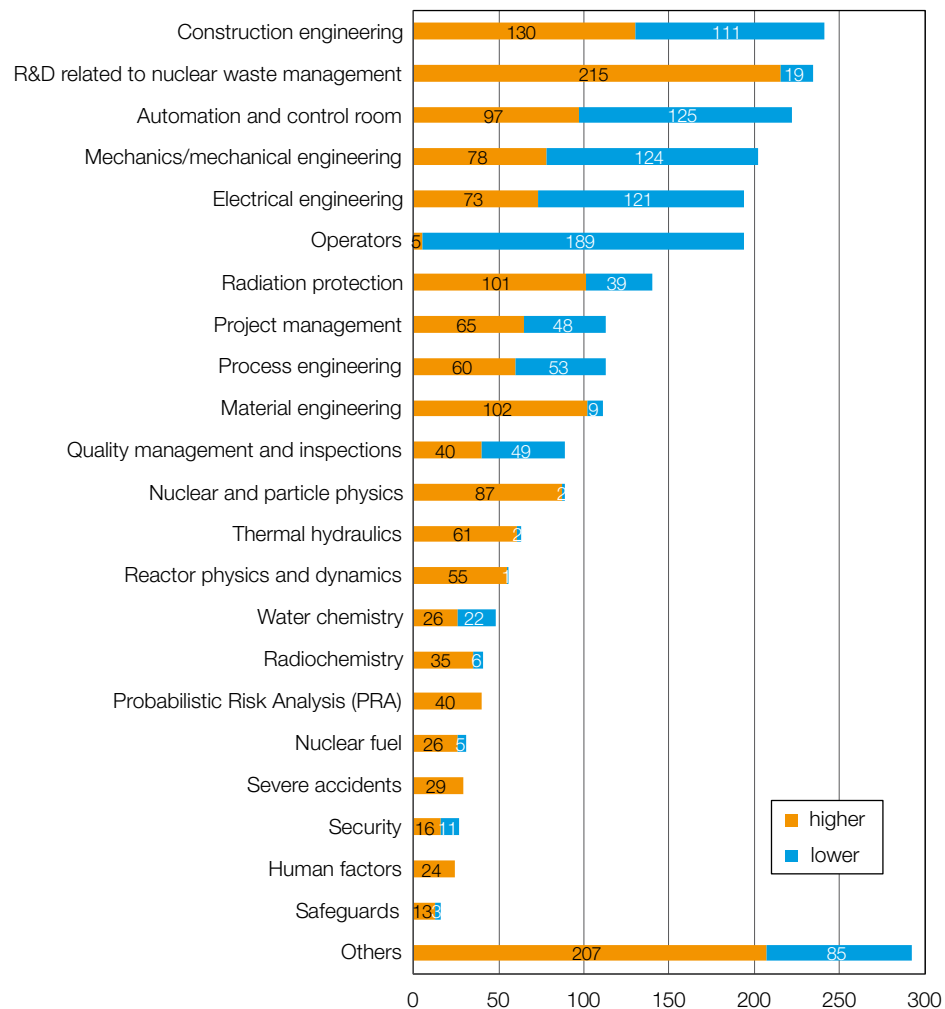
5. interactive impact of radiation and chemical reactions on structural durability and ageing, and the spread of radioactive materials.

Safety issues are in order when efforts are being made for the maintenance of nuclear safety, radiation safety and safety culture, including the motivational factors for understanding the primary significance of safety issues in nuclear energy production and the high quality requirements. In other words, the list above needs to be supplemented with two additional points:

6. Radiation safety; and
7. Safety culture.

The relationship between the main functions of nuclear safety and fields of competence within the nuclear energy sector is examined in table 3.1.

**Figure 3.3.** The current nuclear energy sector personnel by fields of competence



Everyone working within the nuclear energy sector must be familiar with the safety culture, but for a large proportion of the professionals within the field, knowledge of nuclear and radiation safety is necessary in order to provide sufficient motivation for understanding the importance of safety culture. For these professionals it is sufficient that such matters are taught to them during their supplementary training phase. Competence in radiation safety is important particularly for anyone working in an actual nuclear facility. Respect of competence is part of the safety culture, and if safety fails, cost-efficiency is also invariably lost.

Competence in reactivity and heat transfer is also the foundation of power production and these, along with the required power plant technology, require know-how in, for instance, electrical engineering and material and automation technology. These have been listed in the tables charting the numbers of specialists, but these fields are not as nuclear-specific as those mentioned above. Processing and final disposal of nuclear waste require knowledge from various fields of science.

Actual competence in any of the nuclear-energy-specific fields listed above requires several years of theoretical study, which means that this should be obtained in the basic degree phase as part of either specialisation or minor subject studies. It would also be advisable to teach these matters at least as minor subjects in several areas of competence related to nuclear power plants. Some of the competencies can be obtained through supplementary education or training.

Loviisa power plant on the island of Hästholmen in Loviisa. Source: Fortum



**Table 3.1.** To give a rough illustration of the situation: which of the seven competence areas in nuclear safety are most essential for the representatives of the different areas of competence working within the nuclear energy sector. A specialist must primarily be an expert within his or her own field. In addition, he or she needs basic competencies in all seven areas of competence. Some of the experts need more in-depth education in one or more of these seven areas of competence, marked with x in the table below.

Nuclear sector fields of competence	1 chain reaction	2 criticality	3 cooling	4 transient sit.	5 chemistry	6 radiation	7 culture
Security						x	x
Safeguards		x					x
Radiation protection						x	x
Radiochemistry		x		x		x	x
Water chemistry				x			x
Nuclear and particle physics						x	x
Operators	x	x	x	x	x	x	x
Electrical engineering							x
Automation and control room	x						x
Mechanics/Mechanical engineering				x			x
Construction engineering				x			x
Human factors							x
Reactor physics and dynamics	x	x	x				x
Nuclear fuel	x	x	x				x
Thermal hydraulics	x		x		x		x
Process engineering	x				x		x
Severe accidents		x	x		x		x
Material engineering				x			x
Probabilistic risk analysis	x		x		x		x
Quality management and inspections				x			x
Project management							x

Those working with nuclear waste management must also have competencies in the main functions of nuclear safety as applicable, along with know-how related to the special characteristics of underground working environments and traditional occupational health and safety.

The survey made for the purposes of this project studied the educational offering of universities and polytechnics providing nuclear energy sector education. This information is presented in summary in appendix 3, by higher education institution. In the following, the key offering of basic degree programmes and courses:

- **Aalto University (Aalto):** several education programmes suitable for the sector, such as energy sciences (fission and fusion), foundation and rock engineering, material technology of mechanical engineering, applied materials science, work psychology and leadership, and information and computer systems in automation.

- **University of Helsinki:** Master's programme in radiochemistry, Master's programme in physics, study programme in medical physics.
- **University of Eastern Finland:** study programmes in environmental health and environmental biology, study programme in medical physics.
- **University of Jyväskylä:** the Department of Physics offers several suitable study programmes, for instance in nuclear and accelerator-based physics, applied radiation and biophysics, material physics and industrial physics.
- **Lappeenranta University of Technology (LUT):** study programme in nuclear engineering; in addition suitable programmes in mechanical engineering, chemical engineering, industrial management, technical physics and mathematics.
- **University of Oulu:** subjects serving the educational needs of the nuclear energy sector at the Faculty of Technology, and in the Departments of Physics and Chemistry at the Faculty of Science.
- **Tampere University of Technology:** nuclear-energy-related education in the study programmes of automation engineering, mechanical engineering, construction engineering, signal processing and communications engineering, electrical engineering, information technology, industrial management, and environmental and energy engineering.
- **Åbo Akademi University:** study programme of nuclear physics in the Department of Physics.
- **Kajaani University of Applied Sciences (polytechnic):** a nuclear energy sector course entity (15 credit points) in the study programmes of information technology, mechanical and manufacturing engineering and construction engineering.
- **Central Ostrobothnia University of Applied Sciences (polytechnic):** plans for a nuclear energy sector course entity in the study programme of electrical engineering.
- **Oulu University of Applied Sciences (polytechnic):** plans for nuclear energy sector courses in the study programme of energy engineering.
- **Satakunta University of Applied Sciences (polytechnic):** plans for a nuclear-sector study module in engineering studies and supplementary education.

### 3.3.2 Nuclear-energy-related Fields of Specialisation in Universities

Typically, universities that provide nuclear technology education in European countries have a few professorships in nuclear-specific fields, which cover the areas of competence listed in table 3.1 (such as reactor physics, reactor engineering, severe accidents, radiation monitoring and instrumentation). Each professorship is responsible for one or more of these special fields, and the field of nuclear power technology is covered in its entirety with the help of several professorships.

However, in Finland, Lappeenranta University of Technology (LUT) and Aalto University each has only one professorship within the field. These provide the nuclear energy competence required for relevant degrees. In LUT, the professorship is in the study programme of energy engineering. The LUT graduates have competencies in the nuclear power plant process in its entirety, heat transfer and fluid dynamics, and reactor physics. In Aalto, the professorship is in the study programme of applied physics, and the students have basic competencies in physics and mathematics and therefore readiness for theoretical modelling of a range of issues.

The Laboratory of Radiochemistry of the University of Helsinki is the only university unit in Finland providing wide-ranging instruction in radiochemistry. The Master's programme education given by the Laboratory of Radiochemistry of the University of Helsinki is unique in its comprehensiveness, even in international terms. The University of Turku also has a professorship in radiochemistry, but compared to Helsinki instruction is given on a much smaller scale, and research focuses only on radiopharmaceuticals chemistry. Instruction in detection and monitoring of radiation is also provided in other University of Helsinki units and other higher education institutions, but the amount of tuition in radiochemistry is limited.

The University of Eastern Finland gives systematic radiation protection education as part of a Master's degree programme. The study programme in environmental science comprises a compulsory basic course on radiation issues and, in addition, students specialising in environmental health (which is one of the two study programmes available) can select several courses relating to radiation protection. There is one professor working within this field covering both ionising and non-ionising radiation. The Department of Applied Physics provides instruction in medical physics, which includes know-how in radiation protection needed by physicians acting within this field. Even though the perspective here is in radiation protection of patients and nursing staff, the competence provided is also suitable for addressing radiation protection issues associated with the use of nuclear energy. Other universities too, including Aalto University and LUT, offer radiation protection education, which can provide the qualification of a responsible manager.

### **3.3.3 Nuclear Energy Sector Education as Minor Subject**

It is unrealistic to imagine that all universities could establish professorships in all fields of speciality. Universities must therefore be encouraged to collaborate with each other. However, because of other simultaneous studies, basic degree students are unable to commute to other localities to take courses. This means that modern opportunities for distance learning must be put to use. The variety of course offering has also been increased by using guest lecturers, although financing is always harder to come by. One option to consider is the coordinated involvement of different types of nuclear-energy-sector organisations in a versatile arrangement of basic degree education.

In addition to persons with an educational background in actual nuclear studies, the sector provides employment for – and requires a large number of – specialists competent in, for instance, structural safety/material engineering, and behaviour of organisations and people. It would be good if, with an eye for such matters, universities could offer nuclear technology introduction courses or minor subject entities for students taking university degrees in these areas of study. These could be common subject entities for several departments or even universities, and widely available as optional study modules. Supplementary training is an extremely important issue, but steps could already be taken during the basic degree studies to ease entry into the field.

### 3.4 Postgraduate Studies in Science

Out of a total of 1,585 experts with at least a higher university or polytechnic degree involved in the nuclear energy sector, 232 (15%) have a doctoral and 55 (3%) a licentiate degree. It is not known what share of these experts have obtained their doctoral education in university units other than those specialising in actual nuclear-energy-sector education and earned their qualifications for the sector through work experience and supplementary education or training. The proportion is probably quite high.

The largest share of experts with a doctor's degree work in universities (Aalto University, the universities of Helsinki, Jyväskylä and Eastern Finland, and LUT), where an average of 43% of them are employed (25–73%). The share of doctors is also relatively high, 30% (24–34%), in research institutions (VTT, the Geological Survey of Finland), as well as in official organisations (STUK, MEE, Tekes), where it is 17% (17–18%). Among specialists, the proportion of doctors is least in the nuclear power production and design industry (TVO, Fortum, Fennovoima, ABB, and FinNuclear), where it is only 5% (0–9%). In companies specialising in nuclear waste management, on the other hand, the share of doctors is significantly higher than this, at 15% (14–15%). On the basis of the study it is impossible to deduce in which special fields of nuclear energy the doctors are employed.

Actual doctoral education focusing on the nuclear energy sector is provided by Aalto University, Lappeenranta University of Technology (LUT) and the Laboratory of Radiochemistry of the University of Helsinki. In addition to these, a significant share of the doctors entering the field have been educated in the Department of Physics of the University of Jyväskylä, which is the leading unit of nuclear physics in Finland. The Kuopio unit of the University of Eastern Finland provides doctoral education focusing on radiation protection. In research institutions, VTT in particular, there are a large number of persons engaged in doctoral studies and preparing their doctoral dissertations for one of the universities mentioned above.

In this context, attention must be drawn to the fact that postgraduate students enrolled in universities are not the same thing as doctors about to graduate. A

large share of postgraduates study part-time, doing their theses alongside their work, in which case the graduation times are long, and some never complete their dissertations. Not all postgraduate students reported by universities are nuclear-energy-sector students, representing instead tangential fields whose students never end up in the nuclear energy sector. In other words, the volume of postgraduate education must be studied in the light of doctorates, not the number of postgraduate students.

In Aalto University, the Department of Applied Physics has traditionally been responsible for education in reactor and radiation physics. The fission and fusion research groups operating therein educate doctors of technology for the purposes of the nuclear energy sector in particular. The number of students in the doctoral programme is usually 15, four of whom act in the research area of fission and radiation physics (burn-up computing, fuel behaviour and gammaspectrometry) and the rest in the fusion area of research (plasma turbulence modelling, simulation of particle trajectories, modelling of plasma edge area and first wall). In addition to these, a large number of non-university researchers, especially from VTT, Fortum and STUK, are preparing doctoral theses for the Department of Applied Physics. On an average, 2-3 doctors of technology specialising in the nuclear energy sector graduate from the Department of Applied Physics each year, most of them within the field of fusion research.

In Aalto University, departments other than that of applied physics also educate doctors for the nuclear energy sector. Seven postgraduate students are currently preparing their doctoral theses, some of them part time, in the research groups of the Department of Civil and Environmental Engineering, studying rock engineering, engineering geology and geotechnical engineering for the purpose of geological final disposal of nuclear waste. An average of around one dissertation is completed every two years. In the Department of Engineering Design and Production there are eight students preparing their doctoral theses related to structural safety, material and production engineering and to research of the materials and manufacturing and inspection technology of final disposal canisters, with one student graduating each year. Aalto University's new plan for establishment of a centre of excellence in nuclear energy know-how in Otaniemi will certainly increase the production of doctors in this field. The goal is to effect a 4- to 5-fold increase in the production of doctors in this field within five years.

In the study programme of energy technology at Lappeenranta University of Technology (LUT) there are research units of nuclear engineering and nuclear safety, as well as more general fluid dynamics, their most important area of research being experimental and computational thermal hydraulics. Supplementary and related fields of research include computational research in nuclear fuel cycle and reactor physics. A total of about ten nuclear sector doctoral students are preparing their doctoral theses in these units, and the number of doctoral graduates within the field is about one a year. LUT also has a significant number of postgraduate students, who



are conducting doctoral studies part-time while working in other nuclear sector organisations. The goal is to triple the production of doctors within five years.

The Laboratory of Radiochemistry of the University of Helsinki is the only radiochemistry unit in Finland producing doctors of radiochemistry for the field of nuclear energy. At the moment, there are 14 students working on their doctoral theses at the laboratory, ten of whom have a subject within the field of nuclear energy. The largest area of research is the migration and retention of radionuclides dissolving from spent nuclear fuel in the bentonite buffer, bedrock and soil. Additional areas of research include environmental radioactivity and selective separation of radionuclides from nuclear waste effluents using inorganic ion exchangers.

Over the past ten years, an average of 1.7 doctoral theses has been completed annually. Almost half of these were research papers completed outside the Laboratory of Radiochemistry. Approximately one third of the doctoral theses are directly related to the nuclear energy sector, one third to environmental radioactivity, and the rest to other fields of study. Starting from 2012, the number of doctoral theses completed at the Laboratory of Radiochemistry will about double, and most of the dissertations will be on subjects within the field of nuclear energy. In addition, there are four persons working on their doctoral theses in the Department of Physics of the University of Helsinki. Their fields of research are radiation damage of reactor materials, plasma-wall interactions in fusion reactors, and radiation tolerance of radiation detectors.

The Department of Physics of the University of Jyväskylä has some 70 persons doing their doctoral theses, and the number of doctors graduating each year is 10–15, slightly over half of whom specialise in nuclear, elementary particle and accelerator based physics. Most of the research is basic research in subatomic physics and material physics conducted at the Department of Physics Accelerator Laboratory and CERN, but it also includes applied projects within the fields of nuclear medicine, nanotechnology, space research, and nuclear and radiation safety. The graduating doctors do not usually have immediate practical readiness for nuclear sector positions. Through on-the-job learning and supplementary training, several doctors who have graduated from the Department of Physics of the University of Jyväskylä have become experts within the field of nuclear energy. The Department also conducts research related directly to the nuclear sector, particularly in development of analysis methods for porosity and internal structure of rock; in experimental and theoretical research of migration phenomena (matrix diffusion and similar); in thermomechanics and erosion of bentonite buffers; in the fields of study related to fission cross sections regarding both nuclear safety and nuclear energy; and in reactor decay heat. Six doctoral theses are being prepared in these fields.

The radiation research team operating in the Department of Environmental Science of the Kuopio Unit of the University of Eastern Finland primarily studies non-ionising radiation. Currently, three persons working on their theses are engaged in ionising radiation research (biological impact of radiation, and migration of

radionuclides in the biosphere). The Doctoral Programme in Environmental Health (SYTYKE) operates under the coordination of the University of Eastern Finland. Radiation is one of the theme areas of education and research in the programme (others include air, water and chemicals). Other parties involved in the project in addition to the University of Eastern Finland are the National Institute for Health and Welfare, the Radiation and Nuclear Safety Authority (STUK), the Finnish Institute of Occupational Health, and the University of Helsinki.

Being a research institution, VTT cannot produce doctors on its own, but research conducted by VTT has generated and continues to generate a considerable number of doctoral theses. Most of these are completed for Aalto University. Each year several doctors within the field of nuclear energy graduate from VTT, and almost 30 researchers are currently engaged on their dissertations, although most of them are part-time.

The opportunities for postgraduate education within the field of nuclear energy improved significantly in Finland in 2011 when the Academy of Finland granted funding for the Doctoral Programme for Nuclear Engineering and Radiochemistry (YTERA) from 2012 to 2015. The programme is coordinated by Aalto University, the other academic partners being the University of Helsinki and Lappeenranta University of Technology. Other partners include VTT, the authorities (STUK, MEE), and the nuclear energy industry (Fennovoima, Fortum, TVO, and Posiva). Seven new students working on their dissertations started their work within this doctoral programme from the beginning of 2012. In addition to these, all other researchers producing dissertations within this field with funding from other sources – a total of more than 50 persons – are included in this doctoral programme. The programme will constitute an excellent cooperation and planning forum for Finnish postgraduate education in the field of nuclear energy. Common seminars and courses will also be arranged within this programme.

The biggest shortcoming in Finnish researcher education is the shortfall in senior supervisors, particularly professors. There are only three nuclear-specific professorships in Finland, those in nuclear engineering at Aalto University and LUT, and that in radiochemistry at the University of Helsinki. In addition, VTT has a research professor in the research area of final disposal of spent nuclear fuel, while several doctoral degrees are earned under the supervision of various VTT specialists. Due to the thinness of nuclear-energy-sector research in Finland, many postgraduate students are quite alone with their areas of speciality. In the future, reliance on international research and education cooperation through, for instance ENEN, CINCH and Petrus networks<sup>4</sup> must be increased. However, one must bear in

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4 The European Nuclear Education Network (ENEN) is an association of universities teaching nuclear engineering, offering international courses. Its members include Aalto and LUT. The Cooperation in Education in Nuclear Chemistry (CINCH) is a similar but younger cooperation network within the field of radiochemistry. The Laboratory of Radiochemistry of the University of Helsinki is a member. The Petrus network (the Programme for Education, Training and Research on Underground Storage), operating within the field of final disposal of nuclear fuel, consists of European universities (incl. Aalto), nuclear waste management organisations, education and training organisations, and research institutions.

mind that the nuclear energy sector also contains national special requirements, so that domestic know-how must also be enhanced.

### 3.5 Further Education Offered by Higher Education Institutions

On the basis of research material collected for this study, the same can be concluded about further education and training as about education within the nuclear energy sector in general: that which is included in the scope of further education within the sector can be understood in a narrow or wide sense. Some of the respondents have addressed the matter in such a manner that it comprises everything from material sciences to business management. Others have focused mostly on nuclear engineering and safety.

The majority of supplementary training is presently implemented through internal training and on-the-job learning in companies. There was great variation among organisations on how many external courses were taken, ranging from 0.25 to 5 person days per year.

Training organisations offer different supplementary training courses related to the sector, with the help of which organisations supplement their internal training. The best known, oldest and most comprehensive of these is the YK course, or national training course in nuclear safety, organised by a consortium consisting of Lappeenranta University of Technology, Aalto University, VTT, MEE, STUK, Fennovoima, Fortum, TVO and Posiva and (see chapter 3.6.1).

Other providers of further education and supplementary training:

- The University of Eastern Finland offers supplementary training related to environmental risks. In addition, the university provides the qualification of a responsible manager in general medical use of radiation and radiology.
- Edutech, Centre for Continuing Education at Tampere University of Technology, is presently conducting a commissioned training programme related to nuclear power plants. The professors of the Tampere University of Technology are actively involved in the instruction.
- The open electronic polytechnic AVERKO of Central Ostrobothnia University of Applied Sciences also offers supplementary training courses. In the future, cooperation with Fennovoima will increase the proportion of nuclear technology in the curriculum.
- The Prizztech Ltd - FinNuclear Training concept has been launched in collaboration with power companies with an aim of providing basic information about the operating environment.

There are also many other training and education organisations that have plans to increase further education and supplementary training to be offered to the nuclear energy sector. The University of Oulu and Lappeenranta University of Technology are preparing to initiate nuclear engineering education at the former. The universities

signed a letter of intent at the beginning of August 2011 concerning the provision of training in nuclear engineering and nuclear power construction and the development of related research. The purpose of cooperation is to offer education in the field of nuclear energy in the Oulu region, where it is not yet available.

At the first stage the training offering will include supplementary courses at the end of 2011 targeted at company personnel and, at the next stage, professional-development (PD)-level supplementary training in the area of nuclear energy. PD training will be implemented during 2012 as two consecutive intakes of students (30–40 students in all). In the future, nuclear energy education can also be included as part of a university degree suitable for positions within the sector.

The goal is to train experts particularly for the construction and operation of Fennovoima's nuclear power plant to be located in Pyhäjoki. The large long-term project needs a large number of experts within the field, and recruitment could be difficult in the absence of further education and supplementary training provided in Northern Finland.

Satakunta University of Applied Sciences is planning nuclear energy related training in collaboration with Teollisuuden Voima Oyj (TVO). The target group for the training cycle would be those who have already completed their studies through open or further education, but who would like to complement their qualification with competence in nuclear energy.

Other universities and polytechnics also have plans for increasing their training offering. The existing and planned supplementary training covers the needs, but instructor resources are overworked because the training takes place alongside their other duties.

Even in the future, nuclear sector supplementary training should offer companies courses tailored to meet the needs of their respective staffs. In addition, supplementary training could be offered in the form of conversion courses with an aim of deepening existing professional competence in the field of nuclear technology. In this way new specialists could be trained for the sector, for instance from engineers within other sectors, thus contributing to enhanced employment of engineers.

Supplementary training is a quick and flexible way of meeting the needs of companies. Compared to basic education, it is also a faster way of acquiring new specialists in the field when the need for them is urgent. In supplementary training, training in theory alternates with practical on-the-job learning periods. This results in the student putting what he or she has learnt into immediate practice and gives the company immediate access to the new competencies.

### **3.5.1 Radiation Protection Training**

Well-functioning radiation monitoring on a continuous basis is the precondition for assessing the need for radiation protection measures. The radiation monitoring of nuclear energy and its use in Finland and abroad is conducted by the Radiation and

Nuclear Safety Authority (STUK), the Finnish Meteorological Institute, the Finnish Defence Forces, power plants, rescue authorities and the Customs. In radiation-related emergency situations, these actors can offer assistance to health authorities in targeting radiation protection measures for the general public and employees, both in urgent situations and in situations requiring longer-term risk management.

Under normal conditions, environmental health authorities have only a limited number of official duties related to ionising radiation, and their only routine monitoring measure is supervision of the level of radioactivity in drinking water. Here, the environmental health authorities resort to the laboratory know-how possessed by the Radiation and Nuclear Safety Authority. Environmental health authorities have also assisted households, in separate campaigns or on the basis of individual complaints, in the measuring of radon levels in indoor air. These are also conducted at the Radiation and Nuclear Safety Authority.

In practice, the only radiation monitoring duties of occupational health authorities are those related to measuring radon levels of indoor air in workplaces (such as mines).

A wide-ranging radiation situation may emerge as a result of an unlikely though potential nuclear power plant accident in Finland or in the neighbouring areas. A committee acting under the Ministry of the Interior, and working simultaneously with the Committee for Nuclear Energy Competence in Finland, has been pondering instructions issued by authorities in the event of a wide-ranging radiation situation. The starting point for this work is that the Radiation and Nuclear Safety Authority does not have regional or local officials for the execution of radiation protection related duties or use in a wide-ranging radiation exposure situation. In such a case, the Radiation and Nuclear Safety Authority's role is to give recommendations on the basis of which other authorities operate. In practice, in the event of an extensive radiation situation environmental health authorities would have to act as the competent regional authority and implement risk management measures as recommended by the Radiation and Nuclear Safety Authority under the steering of Regional State Administrative Agencies, which operate under the supervision of the National Supervisory Authority for Welfare and Health. The Ministry of Social Affairs and Health is the highest actor responsible for the steering of measures under the Radiation Act.

Occupational safety and health authorities lack training in occupational health and safety aspects associated with radiation accidents. In the event of a wide-ranging radiation situation they can provide support for local risk management conducted by environmental health organisations by monitoring radiation hygienic purity of water and food. The Radiation and Nuclear Safety Authority (STUK) has supplied meters to environmental health laboratories for such purposes, but training related to these is still insufficient.

Radiation protection issues associated with medical examinations and treatment concerning both patients and health care staff date back much further than nuclear

safety work. The need for know-how related to radiation protection is significant and concerns a considerable part of the everyday activities within the entire health care system. In spite of this, the survey conducted jointly by STUK and the Ministry of Education and Culture [[http://www.stuk.fi/stuk/tiedotteet/fi\\_FI/news\\_694](http://www.stuk.fi/stuk/tiedotteet/fi_FI/news_694)] reveals the shortcomings in radiation protection training over the entire health care service system. The survey conducted in 2010 investigated the radiation protection training included in the basic and further education of health care personnel participating in medical examinations and treatment (Report STUK-B133). The employer estimates of the radiation protection knowledge and skills of the newly graduated personnel groups confirmed the results of the survey conducted among the training organisations.

The survey provides foundations for discussion on the development of radiation protection training of health care staff. It would be recommended that training institutions appoint persons responsible for radiation protection training to ensure that the requirements for such training are met and course descriptions for relevant training are drawn up and objectives described. Cooperation among training organisations and employers should also be increased.

Radiation protection training as described in STUK's ST 1.7 Guide should be part of basic and further education of each professional personnel group within health care. However, this Guide does not concern authorities engaged in environmental health care or occupational safety and health. It is recommended that radiation protection training is provided for them as a separate course.

The fact that radiation protection training for the entire health care system – environmental health care included – falls short of the recommendations in many respects would probably make risk management in the event of a wide-ranging radiation situation more difficult, especially with regard to management of the load on health care services and on securing appropriate risk communication. In radiation protection training related to treatment and examination of patients, the content of instruction should be developed such that principles of radiation hygiene and radiation protection of the general public would also be addressed in an integrated manner, because those working in health care services would need this knowledge in the aftermath of a wide-ranging radiation situation.

Partnering with the University of Lapland, the University of Oulu in 2012 will initiate specialist education in the use of radiation in nursing (30 credit points, EFQ-level 6-7). The education programme is targeted at health care professionals conducting transient radiation work, but on a permanent basis. Twenty students involved in working life with a higher education degree or corresponding knowledge will be selected for the programme.

On the basis of what has been stated above, it is clear that environmental health care and occupational safety and health must possess sufficient competence in radiation protection. In other words, the key position is held by education institutions providing environmental health and occupational safety and health education at university (University of Eastern Finland) or polytechnic (Mikkeli University of Applied Sciences)

level. In both of them some radiation protection knowledge is already included in the degree programmes, but development and cooperation among these educational institutions and other actors within the field (such as the Radiation and Nuclear Safety Authority) is needed to bring the extent and contents of this training to the required level. In addition to the development of the contents of degree programmes, there is also a need to develop supplementary training in radiation protection targeted at environmental health care personnel and other related fields.

### 3.5.2 Security Management Training

One prerequisite for safe use of nuclear energy is ensuring that nuclear facilities and materials are not harmed intentionally, whereby they may cause danger to humans and the environment. Security arrangements refer to administrative and technical arrangements by which nuclear facilities and materials are protected against intentional damage and theft. Security arrangements of nuclear facilities are largely based on normal industrial security systems and arrangements, but due to the special characteristics and vulnerability of nuclear facilities securing their operation requires special competence, especially at the level of planning and management.

**Figure 3.4.** In recent years, security management of the nuclear energy sector has been developed vigorously in cooperation with the International Atomic Energy Agency (IAEA). In the picture Director Lasse Reiman from STUK (on the left) and Senior Nuclear Security Officer Arvydas Stadalnikas from IAEA, organisers of the MEE, STUK and IAEA seminar “Workshop on Nuclear Security Culture” held in October 2011. (Photo: Mauri Riihonen)



Education leading to a qualification in security management is provided in both polytechnics and universities. Laurea is the only polytechnic in Finland with a study programme in the field of security aiming at a higher polytechnic degree in security management. Security management training is also available at Tampere University of Applied Sciences, Turku University of Applied Sciences and the Police College of Finland. Security Studies can also be taken as a field of specialisation or minor subject or as individual courses as part of the Master of Science in Technology degree at Tampere University of Technology. Aalto PRO provides training in security management as university-level supplementary education. None of the above-mentioned study programmes comprises any nuclear-specific security management education.

### 3.6 In-house Supplementary Training

Organisations operating within the field of nuclear energy have traditionally taken responsible care of the training and development of their personnel as required by their work assignments. This supplementary training and personnel development work has focused primarily on the post-basic degree development and/or maintenance of professional skills. This trend still seems to be prevalent in the light of the survey conducted by the Committee for Nuclear Energy Competence in spring 2011. As methods of development and training, organisations use both training they implement themselves and commission from outside, as well as various methods of on-the-job learning.



**Figure 3.5.** An example of the supplementary training path of a shift supervisor. Anna Räsänen, Engineer of Process Engineering, successfully applied for a job at TVO immediately after having graduated from Satakunta University of Applied Sciences at the end of 2000. At TVO she has trained as a nuclear facility shift supervisor. Räsänen's work career of 10 years has included an average of 17 training days a year, and she has taken a total of 147 courses at TVO. The training has taken place alongside her work (Photo: TVO)



The organisations that responded to the survey organise internal training 3–20 days/person/year, depending to some extent on the actor. The contributions to internal training vary, partly according to economic trends within the sector, to personnel turnover and retirement, and to other factors affecting development within the field. It is worth noting that the major actors within the sector invest significantly in internal training organisations, with highly systematic instruction of their own personnel – and, to a certain extent, their subcontractors – in the special characteristics of the nuclear energy sector. These actors have at their disposal hundreds of persons acting alongside their own work as instructors within their particular area of competence, as well as the necessary facilities and equipment for training activities. The themes of internal training are most often related to special features of the nuclear energy sector, such as safety and security culture, various technical themes, guidelines and legislation, and quality control and quality assurance.

In addition to in-house training activities, the organisations also take advantage of training acquired from outside. The following emerged from the survey as the most common examples: national training courses in nuclear safety (YK courses),

FinNuclear training, Posiva's nuclear waste management course "Introduction to safety assessment of geological disposal of spent nuclear fuel", further education commissioned from higher education institutions on specific topical themes, and education on issues of topical interest organised by other training organisations.

The survey showed that participation in training outside the organisation varies greatly, the figures ranging from 0.25 to 6 days/person/year.

In Finland, personnel training in nuclear waste management has largely been built upon the offering organised by power companies, Posiva and STUK. As an example, Posiva organises annual training in the basics of safety assessment of geological disposal of spent fuel, intended for the entire personnel and also open to subcontractors. International training networks have also been developed for the purposes of personnel training.

### **3.6.1 National Training Course in Nuclear Safety (YK Course)**

Measures for additional construction of nuclear power were relaunched in Finland slightly over ten years ago. This emphasised the importance of the preservation and development of nuclear sector know-how, especially when a considerable proportion of long-term experts in the field were due to retire within ten years. These factors acted as the impetus for establishing a course aimed at enhancing professional competence, involving cooperation among the key actors of the sector. Nine such courses have been organised between 2003 and 2012, and the tenth YK course, or national training course in nuclear safety, will be initiated in autumn 2012. In all, more than 500 nuclear sector employees have attended these courses.

The demand for YK courses has remained stable, with no sign of the demand falling, since the actors organising the courses have continued and are still continuing the recruitment of personnel. The course consists of six training periods, lasting slightly under one week each, organised in different localities at the premises of the organisations participating in course arrangements. The contents of the course, while avoiding excessive detail, give comprehensive coverage of the fields and principles required for ensuring nuclear safety.

The purpose of the course is to provide an overview of the nuclear energy sector, and thus increase understanding of the factors affecting nuclear safety. Currently the number of lecturers and persons supervising exercises and demonstrations is approximately 90. The course is held for representatives of all parties involved – authorities, power plants and research units – simultaneously. The lecturers also come from all organisations involved in the arrangement of the course, and the perspectives of all parties involved are presented. All course materials, some 900 pages of lecture notes and 2,000 pages of PowerPoint slides, have been placed on the LUT's website, where they are available not only to the course participants and lecturers but also to all postgraduate students. In addition to serving the purpose of

training, the YK course has an important role as an information-storing project and transfer of knowledge from one generation to the next, as well as an opportunity for networking.

### 3.6.2 National Nuclear Waste Management Course (YJH Course)

Under MEE steering, plans have been made on national nuclear waste management training since 2008, and the first pilot course was executed in 2010. The aim is to expand the training with provision on a permanent basis from 2011, operating conditions permitting, so that all parties interested could participate in both training and training provision. The training will partly replace Posiva's training on the basics of safety assessment of geological disposal of spent fuel, which has already been organised eight times since 2003.

**Figure 3.6.** Group photo of the participants of the pilot course in national nuclear waste management in 2010. (Photo: Tanja Lindholm)



In addition, Posiva has sought through its international training networks to reach a sufficient number of trainees from the personnel of various nuclear waste management organisations, on both a European and worldwide scale. This is due to the smaller number of those involved in nuclear waste management and operations that require multi-disciplinary scientific competence, which means those needing this kind of training are few in number. The most important of such networks is Petrus (Programme for Education, Training and Research on Underground Storage), composed of European universities (including Aalto), nuclear waste management organisations, education and training associations (ENEN and ITC-School), and research institutions.

### 3.7 Teacher Resources and Need for Professors and Trainers within the Field

It has long been acknowledged that there are only two professorships in nuclear technology in Finland: one in the Department of Applied Physics at Aalto University, and one at Lappeenranta University of Technology. In addition to these, the University of Helsinki's professorship in radiochemistry can be regarded as falling within the scope of nuclear energy. As the conducted survey shows, the situation is considerably better when the teaching staff of all fields tangential to nuclear technology are appropriately taken into account. Since an important part of nuclear energy sector instructors also provide education in other fields, no commensurate number of professors or lecturers can be given.

However, it may be concluded that within the more extensive framework defined for the purposes of this study, 30–40 professors in eight Finnish universities (Aalto, University of Helsinki, University of Eastern Finland, University of Jyväskylä, LUT, University of Oulu, Tampere University of Technology and Åbo Akademi University) participate in education within the field of nuclear energy, along with dozens of other lecturers and university instructors. At the same time the need for additional professors has been observed, and Aalto University and Lappeenranta University of Technology are making efforts to react to this need. The first-mentioned is in the process of establishing an Aalto Nuclear Safety programme, the key part of which is establishment of four new Tenure Track professorships within the field of nuclear engineering, and networking of the existing nuclear energy sector professorships into a centre of excellence. LUT, on the other hand, is making preparations for the establishment of a second professorship in nuclear engineering.

The University of Helsinki, Laboratory of Radiochemistry would seriously need a professor tasked with teaching the chemistry of processing and final disposal of nuclear waste, and coordinating research within this field of study. There are currently some 30 researchers and persons working on their dissertations at the University of Helsinki, Laboratory of Radiochemistry, and that is too much for one professor to manage.

In the Department of Environmental Science of the University of Eastern Finland, one professor teaches radiation protection included in the field of environmental health, with the participation of two other teachers. However, the research and instruction focus largely on non-ionising radiation. In the Department of Applied Physics, teaching of radiation protection forms a minor part of the education of medical physics, and two other professors participate in this along with their other instruction duties. This education could be developed by increasing cooperation between these two departments, but upgrading the education to meet present requirements (see 3.5.1) would require enhancing competence within the field of ionising radiation.

The Department of Energy and Process Engineering at Tampere University of Technology presently provides wide-ranging teaching in power plant technology, with steam technology as an integral part. Tampere University of Technology has a traditionally extensive teaching offering in this topic, as Tampere and its environs are the location of boiler industry, manufacturers of other power plant components such as valves, and companies designing information and automation systems for power plants. The same training also provides strong support for the needs of nuclear power plants, particularly with regard to emergency cooling systems. Steam technology education is well supplemented by the institute's comprehensive teaching and research in fluid dynamics and in computational fluid dynamics (CFD) in particular. Management of safety issues associated with the emergency cooling systems of light water reactors requires solid competence in power plant processes and steam technology. To reinforce teaching in this field, Tampere University of Technology has a need to establish a new professorship. The new professor could also focus on, for instance, new fluid dynamics modelling tools, pressure shocks, heat transfer crisis analyses, etc.

None of the 25 polytechnics in Finland has actual training programmes in nuclear engineering, but all but three educate polytechnic engineers within various fields. Mechanical, electronic, construction, automation, process and chemical engineers graduating from these polytechnics are employed by the nuclear energy sector. Satakunta University of Applied Sciences is currently planning a training module in nuclear energy in collaboration with Teollisuuden Voima Oyj (TVO), while Kajaani University of Applied Sciences, Central Ostrobothnia University of Applied Sciences and Oulu University of Applied Sciences have similar plans with Fennovoima. These polytechnic modules may need new instructor resources, even though they are partly relying on the experts of power companies. At Mikkeli University of Applied Sciences, preparedness for radiation situations is included as part of health engineer training, and the institute has plans to reinforce this training programme as well as organise related supplementary training.

In terms of supplementary training, it is evident that the national training course in nuclear safety (YK course), organised annually since the autumn of 2003, will continue for a long time to come. The YK course has emerged from the need identified by the sector, and not by official requirement, and the key organisations involved in the sector cooperate as arrangers of the courses on a voluntary basis. Efforts are being made to establish a national course in nuclear waste management run in a similar manner. This national YJH course, piloted in 2010, has largely been built upon the offering provided by Posiva and STUK. In addition to these, there is also clear demand for nuclear sector training provided by FinNuclear in Finnish companies engaged in or planning to participate in the construction projects of nuclear power plants. However, these training programmes rely on the experts of the organisations acting within the sector, so they do not significantly increase the need for instructors.

There is an additional demand, due to the new nuclear power plant projects, for supplementary education organised by universities. The University of Oulu has plans to organise supplementary training in collaboration with Fennovoima, which is justifiable for geographical reasons. LUT is involved in this project. Aalto-PRO, the further education unit of Aalto University, for its part is involved in the Aalto Nuclear Safety plan that nevertheless takes advantage of Aalto University professors providing basic and further education. The University of Eastern Finland offers further education related to different environmental risks, which would need supplementary personnel resources.

### 3.8 Conclusions and Recommendations

Guaranteeing top-level university education requires top research and postgraduate students. This can be ensured only by increasing nuclear-specific teaching staff – professors and senior researchers in particular – in the Finnish universities. At the moment, nuclear sector research is thin, leaving many postgraduate students alone in their fields of speciality.

In addition to experts competent in nuclear-specific issues, the nuclear energy sector needs specialists in other fields who would have competence in nuclear technology at minor-subject level. Mutual cooperation among the universities in arranging minor subject education is important, since it is not reasonable to establish nuclear-specific professorships in every university. On the other hand, experts needed for minor subject education in universities and as polytechnic teachers need similar competencies to those teaching subjects of specialisation.

Teaching staff of universities and polytechnics not teaching nuclear-related subjects full time should be offered an opportunity to obtain qualifications in these subjects. On the other hand, personnel of research institutions, power companies and other organisations within the sector can still be used for part-time teaching. Cooperation among the organisations, such as the commissioning of theses from companies involved, contributes to this.

In-depth competence, created through on-the-job learning, is required to ensure safe use of nuclear energy. Building up such competence takes a long time, necessitating long-term activity. It should be noted that more professionals must be trained for the sector than mere numbers would indicate, since it can be expected that some experts will transfer to other sectors or abroad. Even though the quantitative need for experts in reactor physics, for example, may be small, it will still be necessary to maintain in-depth education readiness for such competence.

The recent initiatives in the education sector, such as the Doctoral Programme for Nuclear Engineering and Radiochemistry (YTERA), and the continuing education courses of various higher education institutions, are steps in the right direction. The higher education institutions and other organisations involved in the field must

monitor how those graduating within the sector are employed, and map potential further needs.

Universities are involved in international cooperation within the field of nuclear technology through, for instance, the ENEN network and PETRUS II project, and in the field of radiochemistry through the EU project CINCH. International courses are suitable, especially at the postgraduate education phase. On the other hand, foreign lecturers have been used, for example, in summer schools and seminars, which are also open to basic degree students. The ultimate reason limiting participation in international courses is cost, and mechanisms should therefore be developed for covering such expenses.

International courses complement Finnish education and training, but they cannot replace domestic offering, since the nuclear energy sector contains special national requirements. Provision of supplementary international training is needed in special fields concerning small personnel groups that lack any such offering in Finland.

With a view to the operation of the nuclear energy sector, a major role is played by the training provided by parties other than education institutes, especially internal training within organisations. This must be maintained and developed further, with reinforcement of networking in training production. For those involved in the sector, significant sources of 'external' training include the YK courses, FinNuclear training activities, and training provided by higher education institutions or arranged in collaboration with other actors within the field.

National supplementary training in nuclear waste management should be consolidated and its operational conditions ensured.

In the arena of education, the European Union aims to enhance the quality, reciprocal approval, and mobility of the labour force. To promote lifelong learning, the intention is to expand the practices of the approval of learning outside the qualification system to cover personnel training in accordance with, for instance, ECTS/ECVET models<sup>5</sup>. This will help especially nuclear waste management personnel to conduct further scientific studies by reducing duplication of studies and enhancing mobility among various organisations and research infrastructures in Europe.

Radiation protection training in Finland was investigated in a survey by STUK and the Ministry of Education and Culture in 2010-2011, and the results can be found in the report STUK-B133. In accordance with the conclusions drawn, the partly insufficient radiation protection training of the entire health care system - environmental health care included - would probably make risk management in the event of a wide-ranging radiation situation more difficult, especially with regard to management of the load on health care services and securing appropriate risk communication.

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5 ECTS = European Credit Transfer and Accumulation System; ECVET = The European Credit system for Vocational Education and Training

General security sector study programmes are available in several higher education institutions, and form the basis for basic education in the field of nuclear security. There is no special training available for the medium- and higher-level management of nuclear security, such as responsible managers and their deputies referred to in nuclear energy legislation. Companies themselves must organise the necessary training for their personnel, or the persons in question must obtain the required competence by self-study.

The general education in the field of security is also sufficient for providing the nuclear security sector with basic readiness. There is a clear need, however, for the arrangement of regular special training for specialists belonging to the medium- and higher-level management of the nuclear sector, as well as for those performing operative functions in the security organisation. The number of persons trained is nonetheless relatively small, for which reason it is not feasible to create several new special training programmes in the field of nuclear energy. The best way of implementing such education might be under a single new training programme with a few related separate courses.



# 4 Research in Finland

## 4.1 National Research Programmes

In Finland, public research in the field of nuclear energy was organised into three- to five-year research programmes at the turn of the 1980s and 1990s. There are specific research programmes for nuclear power plant safety, nuclear waste management and fusion. The Academy of Finland's research programme on sustainable energy, including a research project on fourth generation (GenIV) nuclear reactors, was also under way from 2008 to 2011.

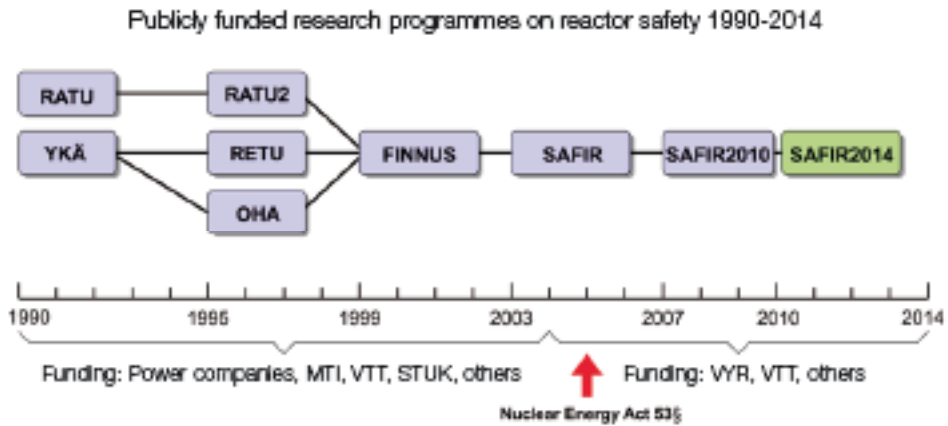
The national research programmes are described briefly below. Additional information is available on the websites of the ongoing programmes.

### 4.1.1 National Nuclear Power Plant Safety Research (SAFIR Programmes)

The history of nuclear power plant safety research programmes is described in figure 4.1. Research was carried out at first in parallel programmes, and from 1999 within a single programme. These research programmes played, and continue to play, a central role in ensuring sufficient domestic know-how in the area of nuclear safety. The national safety research programme is heavily based on Chapter 7A ("Ensuring expertise") of the Finnish Nuclear Energy Act that came into effect in 2004. In accordance with this chapter, the objective of the programme is to ensure that should new factors concerning safe operation of nuclear facilities emerge that could not be foreseen, the authorities have such sufficient and comprehensive nuclear engineering expertise and other facilities at their disposal that can be used, when necessary, to analyse without delay the significance of such factors.

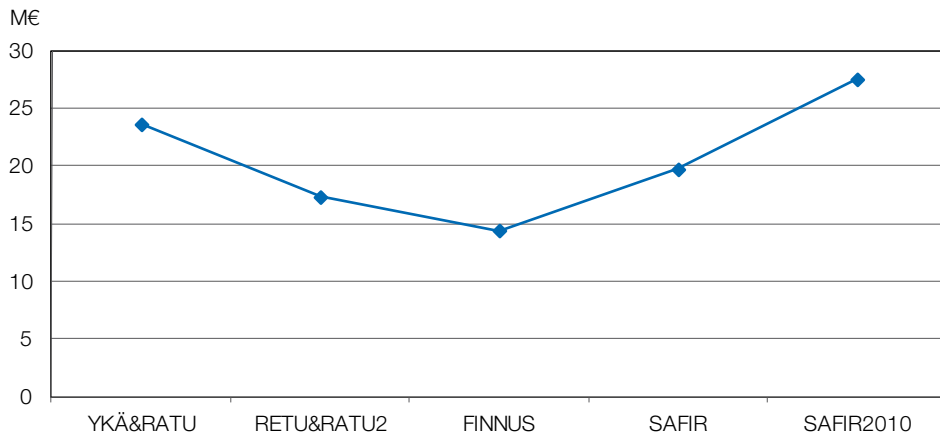
High scientific quality is required of the research projects in the programme. Their results must be available for publication, and their usability must not be restricted to the nuclear facilities of a single licence holder. In practice, the programme benefits the entire Finnish nuclear community by producing new research results, methods and experts. The present administrative model - in which ministries, authorities, power companies, research institutions and universities participate jointly in the steering group of the programme, steering of research activities and supervision thereof in the reference groups - is exceptional. Alongside high-quality results, this element has emerged as a positive factor in international evaluation of the research programmes.

**Figure 4.1.** The history of reactor safety research programmes.

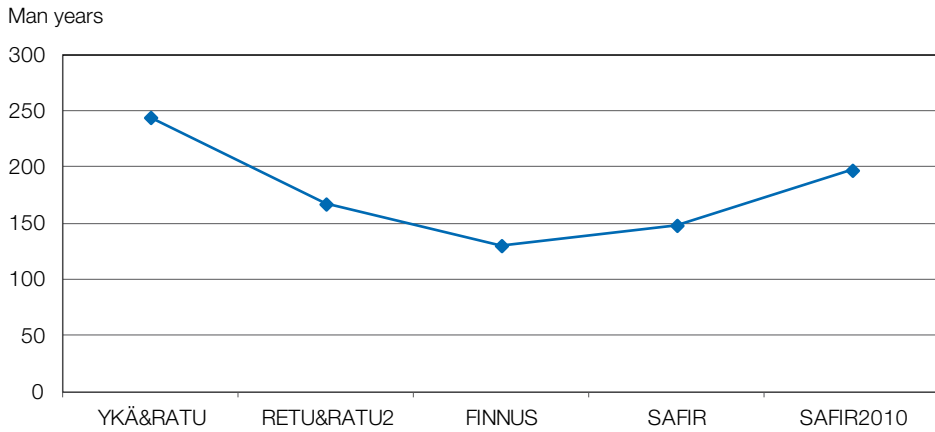


According to a survey conducted in connection with the final seminar of the SAFIR2010 programme, the programmes have generated a total of 3,300 publications, 33 doctorates, 18 licentiates and 92 Master's or Master of Science Degrees in Technology. Figures 4.2 to 4.4 show the funding and key outcomes of the various programmes. The total volume of these research programmes in euro and person years is presented in figures 4.2 and 4.3. Overall funding turned towards growth after bottoming with the Finnus programme. However, the sums presented are undiscounted and it can be discerned on the basis of figure 4.3 that the actual extent of research has not yet returned to the level of the early 1990s. As concerns the outcomes of the programmes, it can be concluded that the number of publications has started to grow, as well as the number of Master's degrees. The drop in the number of licentiate's degrees reflects the basic trend within the technical field of entering on the doctoral dissertation immediately after the basic degree.

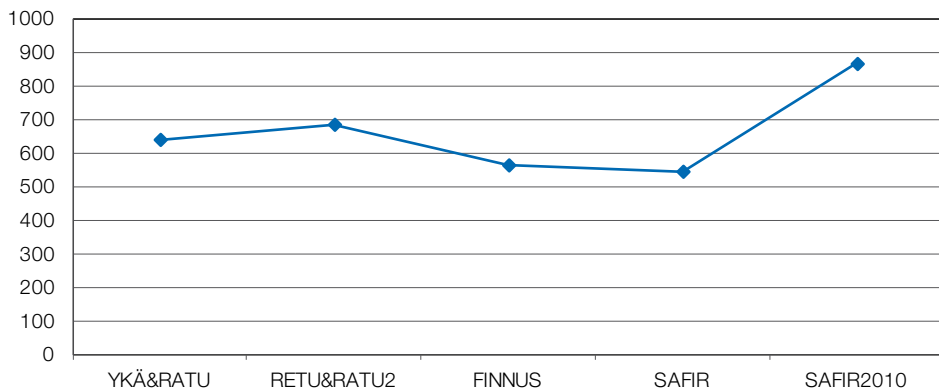
**Figure 4.2.** Funding of reactor safety research programmes.



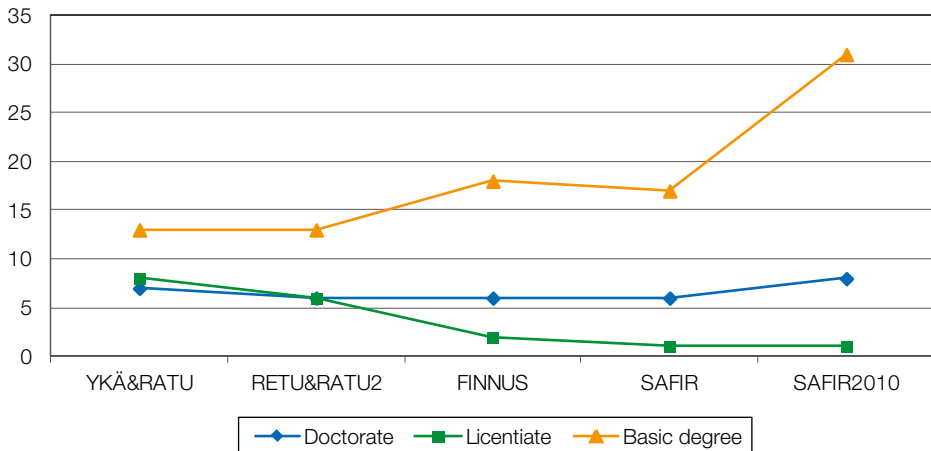
**Figure 4.3.** Volume of work in reactor safety research programmes in person years.



**Figure 4.4.** Number of publications in reactor safety research programmes.

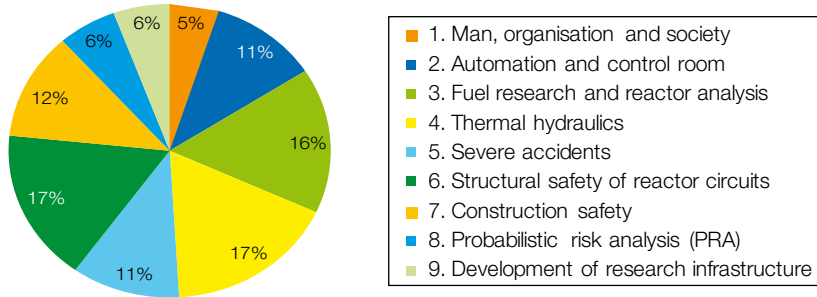


**Figure 4.5.** Number of higher education degrees in reactor safety research programmes.

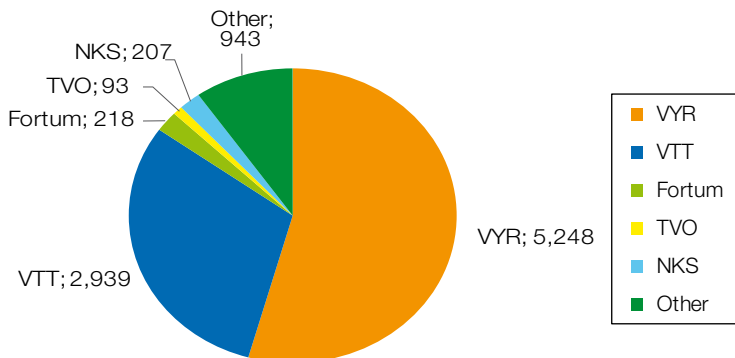


The ongoing SAFIR2014 programme provides ‘a thin coverage’ of all key areas of nuclear power plant safety. A new area compared to former programmes is the development and maintenance of research infrastructure. The research programme areas and division of funding for each area is shown in figure 4.6 and the sources of funding in figure 4.7. Funding from the State Nuclear Waste Management Fund (VYR) for the SAFIR2014 programme increased to 5.2 million euros at the beginning of 2011 with the decisions-in-principle concerning Fennovoima’s and TVO’s new nuclear power plants made in July 2010, and the total volume of the programme also increased to a total of approximately 9.6 million euros in 2011. The key characteristic of the research programmes with regard to reactor safety is their long-term approach. The project application for the research programme in 2012, however, also took into account the research needs resulting from the Fukushima nuclear accident, in addition to the research needs identified in the framework plan of the programme.

**Figure 4.6.** Distribution of funding for various areas of research in the SAFIR2014 programme in 2011.



**Figure 4.7.** Sources of funding for the SAFIR2014 programme in 2011.



Alongside research carried out under the programme itself, features characteristic of all research areas are enhancement of competence, education and training, and interaction between the parties involved. Links to international research projects, especially those of OECD/NEA, and participation in different international taskforces are features shared by all research areas.

There were 38 ongoing projects in the programme in 2011: 24 of these were projects carried out by VTT, seven were joint projects conducted under VTT coordination with one or more partners, four were LUT projects, one was an Aalto University project, one a joint project between Aalto University and the Finnish Institute of Occupational Health, and one a project of the Finnish Meteorological Institute.

The emphasis in the SAFIR2014 research area of Man, Organisation and Society is on safety management in a networked operating environment, and on the practices for developing nuclear safety competence and safety culture. The aim is to support safety at various stages of the life of the plant. During the SAFIR2014 period Finland will have plants at the design, construction and commissioning phases in addition to the power plants in operation. Sociological research related to nuclear safety also falls within the scope of this research area.

In the research area of Automation and Control Room, the introduction of digital automation to new and existing power plants also poses research challenges. One of the key areas is the development of formal methods for verification of nuclear power plant automation, which will be continued on the basis of the good experiences obtained during the prior programme. Clear and concrete further research needs include, for example, developing methods to support the modularisation of models needed in managing complex systems, and the management of problems related to the timing of asynchronous systems.

In fuel research the key topics include the new fuel types and the challenges posed by fuel burn-up increases and potential load-follow operation. The use of statistical methods will increase in the analysis. With research of reactor physics and dynamics it is essential to maintain the entire chain of know-how and methods, from creation of basic nuclear constants to transient analysis. The key fields of research include deterministic and stochastic methods; production of cross-section data for safety analysis programmes; expertise in nodal methods and codes; development of flow calculations for hot channels; burn-up credit; and statistical methods.

With regard to thermal hydraulics, a key role is played by the application of Computational Fluid Dynamics (CFD) methods and closer linking of CFD tools with 'system codes', and by statistical methods. Characteristic of the research field is that the utilisation of computational methods is closely linked to the thermal-hydraulic experiments at Lappeenranta University of Technology. Experiments are made to study, for example, condensation pool behaviour, behaviour of non-condensable gases in primary circuit and in containment, and passive safety systems used in the new plant concepts.

With respect to severe accident research, the greatest research needs concern passive safety systems of potential new plant concepts and various severe accident management strategies, as well as specific issues related to existing power plants. Both traditional and CFD calculation methods are applied in this area. Small-scale domestic experimental activity supports the development and validation of calculation methods.

In research related to structural safety of reactor circuit the focus is on the safety of new power plants, though not ignoring the research needs created by extension of the service lives of existing power plants, and their relicensing. Key areas of research include new power plant materials and structural solutions; new manufacturing technologies; component inspectability and new inspection methods; management of water chemistry; plant life management; and integration of calculation methods with plant lifetime data.

Central research challenges in the research area of structural safety include expanding the lifetime management system developed in the SAFIR2010 programme to cover reinforced and pre-stressed concrete structures; use of monitoring and simulation in the assessment of the in-service life of structures and repair needs; the storage of inspection and repair data; and cathodic protection management. Another area of focus is the analysis of structural integrity in exceptional conditions. In this research, the structural impact test facility developed at VTT in connection with the prior research programmes plays a central role.

In the area of Probabilistic Risk Analysis (PRA) the key research needs include improvement of risk analysis methods; programmable automation; Probabilistic Risk Analysis methods for plants containing passive systems; human factors; fire safety; weather phenomena and other external risks; and the environmental impact of severe accidents.

The facilities identified as key research infrastructures in Finland include VTT's hot-cell facilities and other large experimental nuclear engineering facilities, the maintenance and modernisation of which in up-to-date premises is one the biggest challenges of the entire research programme. The thermal-hydraulic facilities at Lappeenranta University of Technology constitute another major research infrastructure entity.

#### **4.1.2 The Finnish Research Programme on Nuclear Waste Management (KYT)**

Finnish authorities have been coordinating nuclear waste management research programmes since 1989 (table 4.1). Since 2002, these research programmes have been based on Chapter 7A (“Ensuring expertise”) of the Finnish Nuclear Energy Act (990/1987), according to which the aim of research activity is to “ensure that the authorities have such sufficient and comprehensive nuclear engineering expertise and other facilities at their disposal that are needed for comparisons of the various

ways and methods of carrying out nuclear waste management”. High scientific quality is required of the research projects in the programme. Their results must be available for publication, and their usability must not be restricted to the nuclear facilities of a single licence holder.

**Table 4.1.** Public administration's coordinated research programmes.

Period	Name of research programme
1989–1993	Publicly Funded Nuclear Waste Research Programme (JYT)
1994–1996	Public Administration's Nuclear Waste Research Programme (JYT2)
1997–2001	Public Administration's Nuclear Waste Research Programme (JYT2001)
2002–2005	Finnish Research Programme on Nuclear Waste Management (KYT)
2006–2010	Finnish Research Programme on Nuclear Waste Management (KYT2010)

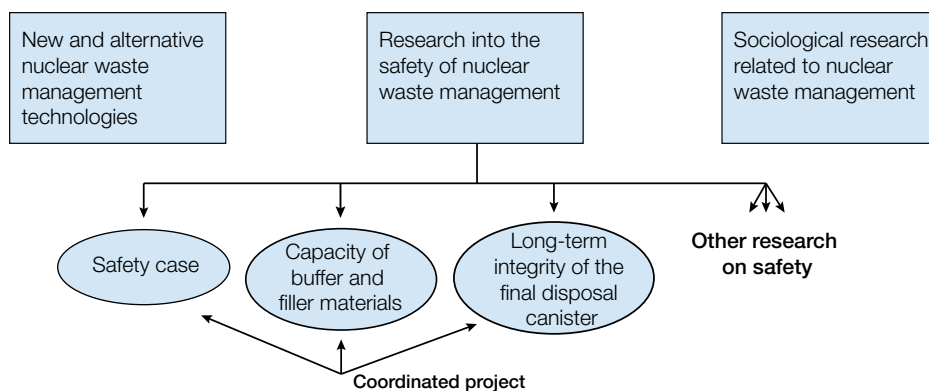
The operation of the Finnish Research Programme on Nuclear Waste Management (KYT) is based on mutual cooperation and division of duties between the steering group formed by the organisations carrying out nuclear waste management and a reference group, and the relevant research projects. The research programme has an appointed coordinator.

In 2007, the evaluation group of the Finnish Research Programme on Nuclear Waste Management paid attention to such issues as existence and availability of relevant competence, and maintenance and development of this know-how in the field of nuclear waste management. In 2008, the research programme surveyed educational and training opportunities and needs in nuclear waste management. On the basis of this study, a National Short Course on Nuclear Waste Management was executed as a pilot project in 2010.

The ongoing programme is called the Finnish Research Programme on Nuclear Waste Management KYT2014 and the research period is from 2011 to 2014. The overall financing of this research programme in 2011 was 2.8 million euros, of which funding from the State Nuclear Waste Management Fund (VYR) covered 1.7 million euros. In 2011, the total extent of the research programme in person years was 23.5.

The research areas of the KYT2014 programme include the new and alternative technologies of nuclear waste management, research of nuclear waste management safety, and sociological research related to nuclear waste management as shown in figure 4.8.

**Figure 4.8.** The topics of the KYT2014 research programme, MEE (2010)<sup>6</sup>.



Research into new and alternative technologies would enhance the security of implementing nuclear waste management in Finland, if the current primary option, geological final disposal, is not realised as planned or if new methods are developed e.g. to reduce the amount of waste generated. The authorities must have access to up-to-date information and expertise on alternative forms of geological final disposal undergoing research and development. They must also have access to the competencies required for comparisons between various ways and methods of carrying out nuclear waste management in Finland. The technology area of research comprises, for example, solutions based on reprocessing of spent fuel, implementation alternatives for geological final disposal, storage options, and new solutions for implementing decommissioning.

The objective in research into the safety of nuclear waste management is to ensure that high-level expertise on technical implementation of geological final disposal and the related alternative methods and solutions are available to the authorities, independent of the licence applicant. The research areas within safety research include the safety case, the capacity of buffer and filling materials, and the long-term integrity of the final disposal solution. Management of both operating waste and spent nuclear fuel fall within the scope of safety research.

Sociological research related to nuclear waste management has been included in a number of research programmes since the 1990s. For instance, KYT2010, the previous research programme, analysed local views on nuclear waste management and their transformation. The Fukushima nuclear power plant accident further emphasises the importance of nuclear facility safety research and related sociological research.

<sup>6</sup> MEE, 2010, Finnish Research Programme on Nuclear Waste Management KYT2014. Framework Programme for the Research Period 2011–2014. Publications of the Ministry of Employment and the Economy, Energy and Climate 68/2010



### 4.1.3 Fusion Research in Finland as Part of International Entity

Finland has been involved in the EU fusion programme since 1995, when the Association Euratom-Tekes was established, making it one of the 27 Euratom partners in Europe.

The Finnish fusion research unit consists of research groups from VTT, Aalto University, the University of Helsinki, and Tampere and Lappeenranta Universities of Technology. In 2007, the University of Tartu from Estonia joined the Association Euratom-Tekes by a separate agreement. VTT is in charge of research coordination.

The volume of research at the annual level is some 5 million euros, corresponding to 40 to 45 person years. The focus of research is on fusion technology which accounts for approximately 70% of the activity. The remaining portion consists of research in fusion and plasma physics. The majority of physics research is conducted within the EFDA (European Fusion Development Agreement) work programme, where the shared experimental activities of JET (Joint European Torus) play the central role.

JET is still the fusion device with the highest capacity in the world and its purpose is to pave the way for the use of ITER. Finland plays a visible role in JET cooperation and Finnish experts hold key positions as experimental team leaders and in modelling of experiments. Research in Finland focuses on the key issues with a view to ITER:

- energy and particle transport and transport barriers of tokamak plasma
- plasma-wall phenomena, erosion, material transport and deposition
- plasma diagnostics

The main areas of Finnish fusion technology research are:

- development of remote maintenance systems for ITER and the DTP<sub>2</sub> test platform
- characterisation and modelling of construction materials, joints and coatings by MD simulation
- advanced welding techniques and welding robots
- magnetic diagnostics for ITER

These technologies have been selected from among fields of research where Finland has existing expertise and interest in applying this in practice on a larger industrial scale. The focus in fusion technology research is on the development and testing of remote maintenance systems for ITER. The main purpose of VTT's DTP<sub>2</sub> (Divertor Test Platform) facility located at VTT in Tampere is to search for the best solution for removal/replacement of divertor cassettes from ITER. The divertor region of ITER consists of more than fifty cassettes, weighing almost ten tons each, exposed to extremely heavy heat and particle loads, for which reason they have to be replaced at least a few times over the service life of ITER.

EFDA initiated concept design for a demonstration power plant (DEMO) in 2011, and part of the Association Euratom-Tekes technology research will be targeted at DEMO activity. In accordance with EFDA's wishes, Finland will participate in the

development of remote maintenance systems, materials research, and research into issues related to edge plasma and plasma- wall interaction.

#### **4.1.4 Research Programme of Next Generation Reactors (Gen IV)**

The extent of Finnish research into next generation reactors (fourth generation, Generation IV) has previously been limited. Such questions have mostly been considered in the assessment of opportunities for alternative fuel cycles when pondering final disposal solutions. However, towards the end of the first decade of the 21st century, universities within the field, VTT, and other key actors organised a GEN4FIN network. The network produced a roadmap which estimated opportunities for a Finnish contribution to Generation IV nuclear energy research. A NETNUC research project was established in connection with this project as part of the Sustainable Energy (SusEn) research programme, initiated simultaneously by the Academy of Finland.

In the NETNUC (New Type Nuclear Reactors) project (from 2008 to 2011) Lappeenranta University of Technology, Aalto University and VTT engage in basic research to generate additional scientific knowledge concerning fourth generation technologies, to reinforce international connections within the field, and to educate a new generation of researchers.

The underlying themes of the project include the safety features of Gen IV technologies; significantly improved opportunities for efficient use of nuclear fuel, serving sustainable development goals; a reduced amount of waste requiring final disposal; economic utilisation of nuclear energy (higher efficiency); and more extensive application opportunities, such as production of process heat and hydrogen.

In Lappeenranta, the areas of focus are the supercritical water-cooled reactor concept (SCWR) and gas-cooled reactors (VHTR and GFR). The research of supercritical water reactors is linked to experimental thermal-hydraulic research on light water reactors that has continued for some time. As far as gas-cooled reactors are concerned the emphasis is on research into reactor physics, fluid dynamics and safety aspects by means of modelling. Research on thermal hydraulics of the SCWR concept has also been conducted at Aalto, but investments have also been made in Monte Carlo simulation of reactors, possibly using thorium fuel.

VTT concentrates on the development of reactor physics technologies, materials testing for SCWR reactors and utilisation opportunities in the process industry for heat generated by nuclear energy. Outside the research project, VTT has participated in the EU's supercritical reactor (HPLWR) research projects and materials research in the GETMAT project. VTT also participates in the development of the Jules Horowitz Material Testing Reactor (JHR) to be built in France. When completed the JHR reactor will significantly enhance the materials testing opportunities of both existing and future reactors.

## 4.2 Research in Universities and Research Institutions

### 4.2.1 Lappeenranta University of Technology (LUT)

LUT Energy of Lappeenranta University of Technology (LUT) is the largest academic research and education organisation in Finland's energy sector. It works in close and continuous cooperation with VTT and all universities associated with the field, and it is also involved in close research collaboration with relevant companies and research institutions both nationally and internationally. The main application areas of energy technology research include energy production and conversion processes, and energy-efficient equipment and processes in accordance with sustainable development principles. The research operations within these areas are built primarily upon robust basic competencies in thermal dynamics, fluid dynamics and heat transfer.

For decades, the primary research area of the Nuclear Engineering Laboratory has been the experimental and computational research of nuclear safety. Several extensive test facilities have been constructed at the university research laboratory for simulation of light water reactor safety systems: PACTEL, PWR PACTEL, PPOOLEX. Unique test data has been produced using these test facilities primarily for the purposes of software validation. This data is utilised every year by various organisations in several SAFIR<sub>2014</sub> research programme projects. The SAFIR<sub>2014</sub> projects accordingly constitute the foundations of the research activity at LUT.

LUT also has competence, if necessary, for rapid development and production of separate effect test facilities and this opportunity has been exploited by the authorities, power plants and plant suppliers in their R&D projects and safety assessments.

Using its own test results, LUT has participated in development and application of calculation codes for thermal-hydraulic and fluid dynamic safety analyses of transient and accident phenomena as part of several international projects, such as the ongoing EU projects and within OECD/NEA. These thermal-hydraulic and CFD codes (APROS, CATHARE, RELAP<sub>5</sub>, SMABRE, Fluent, TransAT, NEPTUNE CFD) have also been applied to the analysis of own experiments. Over the years the organisation has also participated in plant safety analyses. The latest measuring systems are utilised with the aim of producing accurate validation data required for 3D CFD computing.

The NETNUC project studies phenomena related to new types of nuclear reactors in a consortium coordinated by LUT, with Aalto University and VTT as partners, under the Sustainable Energy research programme of the Academy of Finland. LUT focuses particularly on modelling of gas-cooled Pebble Bed Modular Reactors (PBMR), taking advantage of the institute's competence in combustion plant modelling. Reactor physics modelling has been carried out using VTT's Serpent software. LUT is also a member of the Sustainable Nuclear Energy Technology Platform SNETP of the EU.

LUT's Laboratory of Fluid Dynamics has long-term experience in process calculation, and fluid dynamic engineering and modelling (CFD) of turbines. The turbine sizes range from small bio energy units via wind turbines to nuclear power plant applications. The process efficiency and reliability of these has been successfully increased due to improved materials and developments in flow computing.

Some nuclear sector research is also carried out in LUT Metal Technology and CEID (The Centre of Computational Engineering and Integrated Design), which specialises in numerical modelling of industrial processes, one of the focus areas of LUT research. A particular field of application is welding technology. In its own project, the Mechatronics Unit is developing a welding robot for the primary wall of the ITER fusion test reactor, taking advantage of its expertise in remote operating and virtual engineering.

## 4.2.2 Aalto University

Aalto University has versatile nuclear-related special expertise dispersed into several research units. The research conducted by the various units is an integral part of the education programme and further education in particular.

The fission and fusion research groups of the Department of Applied Physics are in charge of traditional reactor and radiation physics research and education, with a total of almost thirty researchers and postgraduate students. The operation of these groups is mutually synergistic and heavily computational, and in addition to using the department's own computational resources also exploits the relevant resources of the IT Center for Science Ltd (CSC). The fission group has at its disposal conventional nuclear technical measuring devices, which are also used for practical student work. VTT's Triga research reactor, located in the Otaniemi campus area, is also at the disposal of the department. The fission group participates in SAFIR<sub>2014</sub> fuel projects, thorium fuel cycle analyses, KYT<sub>2014</sub> transmutation research, and development of expert systems for spectrum analysis. The fusion group research is integrated into Euratom's fusion research and is carried out in close collaboration with VTT's fusion research groups (see chapter 4.1.3).

The NETNUC project in SusEn programme (2008-11) of the Academy of Finland has played an important role in the nuclear engineering research of the Aalto fission group (chapter 4.1.4). With regard to experimental activity, the group's strategic goal is to become a national partner in some of the major European fission technology research projects (for example the Jules Horowitz test reactor). The experimental activities of the fusion group focus on Euratom's two international tokamak test devices, AsdexUG and JET, the ITER test reactor constituting the latest challenge.

Aalto University's Department of Civil and Environmental Engineering conducts research in construction engineering and geo- and rock engineering from the perspective of final disposal of nuclear waste. The group develops Aalto University's research know-how related to geological final disposal sites of nuclear waste with

regard to identification of geological, hydrogeological, hydrochemical and rock mechanical characteristics of bedrock. The focus of research is on modelling of the long-term safety of geological final disposal and on development of related methods, assessment of the properties of natural materials as engineered release barriers (such as bentonite buffer or backfilling), and design and optimal construction of underground facilities for final disposal. The research also takes account of the requirements for geological disposal posed by nuclear waste produced by transmutation.

The research group for material engineering in the Department of Engineering Design and Production possesses profound experimental and theoretical competence concerning materials, welding and NDT research on nuclear power plants and nuclear waste disposal canisters. The group has comprehensive experimental facilities of its own, and its activities rely on efficient national and international cooperation. Other Aalto University activities in the field of nuclear engineering that need to be mentioned include fluid dynamics, risk analysis, energy efficiency, organisations, plant engineering, safety-critical software, etc., which all have significant research groups.

Aalto University has coordinated cooperation with LUT and networks closely with VTT, power companies and STUK, a proof of which are, for example, the many dissertations made in these organisations under the guidance of experts within the field. The importance of Aalto University's nuclear engineering research can be further increased by enhancing internal networking within the university. Aalto University coordinates the Doctoral Programme for Nuclear Engineering and Radiochemistry (YTERA). The partners include LUT and University of Helsinki, Laboratory of Radiochemistry, while VTT researcher education is also an important contributor. The YTERA programme was initiated at the beginning of 2012.

### **4.2.3 The University of Helsinki**

Nuclear research at the University of Helsinki is conducted at the Laboratory of Radiochemistry at the Department of Chemistry and the Department of Physics. The Laboratory of Radiochemistry is the only general university unit in Finland within its field, and is a very large university unit even on an international scale. The largest area of research is final disposal of nuclear fuel. The laboratory plays a central national role especially in the study of the behaviour, retention and migration of radionuclides dissolving from nuclear fuel in bedrock and soil. The laboratory has developed an internationally unique method for determining rock porosity, and this is applied, for instance, to in-situ diffusion testing of radionuclides in Olkiluoto. The Laboratory of Radiochemistry also studies the effects of radiation on dissolving of uranium fuel.

Another important area of research related to the nuclear sector is development of inorganic ion exchangers for selective separation of radionuclides from nuclear

waste effluents. Fortum produces three types of exchangers developed at the laboratory in industrial scale and these have been used in many nuclear facilities in several countries. In this area, the Laboratory of Radiochemistry is the leading research unit in the world. The third nuclear-related research field is environmental radioactivity. The most important current research focuses on dissolving and migration of radionuclides from mine tailings (Sokli phosphate deposit, former Paukkajanvaara uranium mine, and Talvivaara mine) in the ground and waterways. The laboratory also develops methods for determination of radionuclide contents in nuclear waste.

In the Department of Physics, the most important research areas related to nuclear energy include research of radiation damage to materials and utilisation of nuclear physical techniques in materials analysis. The areas of focus include research of basic mechanisms of neutron radiation damage in reactor materials, in which the researchers of the Department of Physics use radioactive ion beams produced by the Cern/ISOLDE facility for the analysis of diffusion properties of topical materials, research of plasma-wall interactions in fusion reactors, and research on radiation tolerance of semiconductor detectors and glass materials.

#### 4.2.4 The University of Jyväskylä

There is a strong need in nuclear research for the determination of cross-sections and decay characteristics of fission products (fission yield, decay heat, neutrons delayed by beta decay) for the purposes of fuel research. The Accelerator Laboratory of the Department of Physics at the University of Jyväskylä (JYFL) has used several techniques of modern nuclear physics for determining these characteristics. The laboratory's two cyclotrons and one direct-current accelerator, as well as versatile research facilities for radioactive radiation and materials research, provide an excellent framework for research and review projects related to radiation and nuclear safety, and to nuclear energy.

In the early 1980s the department developed separation techniques for radionuclides based on an ion guide method, in which a mass extracted ion beam of high ion-optical quality is produced from primary ions produced by nuclear reaction. The method is equally suited for study of fusion and fission reactions. With regard to fission reactions, the ion guide method has some interesting applications related to nuclear energy research.

Using the ion guide of the JYFL Accelerator Laboratory, fission production yields have been measured for fission of  $^{238}\text{U}$  and  $^{232}\text{Th}$  induced by 20–40 MeV proton, deuteron, alpha particle and neutron. In the early 21st century a Penning ion trap (JYFLTRAP) was built in connection with the JYFL isotope separator, intended primarily for very accurate atom mass measuring of isotopes. The trap can also be utilised as an isotope separator with very high mass resolution, as well as for direct measuring of fission yields. The most important areas of application include

measuring the decay heat caused by the radioactivity of fission products, and beta-delayed neutron decay.

The key partners in this work are CIEMAT, Madrid (Spain), UPC-Barcelona (Spain), the University of Valencia (Spain), the Institute of Nuclear Research in Debrecen (Hungary) and STUK (Finland). The cooperation continues both as mutual collaboration and within the ANDES (Accurate Nuclear Data for Nuclear Energy Sustainability) project as part of the Euratom Fission Programme.

During 2011, the mass separation apparatus based on ion guide technology and the attached Penning trap were moved to the JYFL Accelerator Laboratory's new MCC30/5 accelerator. There are plans for using the very intense proton beam, produced by the new accelerator for the purposes of fission research, in a new manner by building a neutron conversion target. This research is associated with fourth generation reactors in particular.

#### **4.2.5 Research Activities of the Radiation and Nuclear Safety Authority (STUK)**

The purpose of the research activities of the Radiation and Nuclear Safety Authority (STUK) is to support the mission of the entire institution: to protect people, society, the environment and future generations from the harmful effects of radiation. The aim of STUK's research activities is, on the one hand, to provide new knowledge, and, on the other, to develop professional competence needed for the purposes of radiation protection. The following of STUK's own research areas particularly support the competence base required for ensuring safe use of nuclear energy:

- health effects of radiation
- preparedness for radiation hazards and accidents
- environmental research
- research related to dosimetry and measurement standards, and
- natural radiation research (on a smaller scale)
- CTBT and nuclear materials regulation.

In addition to these, the Radiation and Nuclear Safety Authority conducts research on medical use of radiation, and metrology and health effects of non-ionising radiation. In total, 50.8 person years of labour were used for research activities at STUK in 2010. About 80% of this was targeted at the six research fields mentioned above.

STUK research related to regulation of nuclear safety is conducted in national programmes presented and discussed in chapter 4.1. STUK takes active part in the operation of the steering and reference groups of these programmes.

In the research on the health effects of radiation, the objective is that STUK will be capable of meeting the information needs of decision-makers and citizens concerning the emergence of health effects of ionising and non-ionising radiation in the population, and presents well-founded opinions of the birth mechanisms of health effects. Research on the health effects also produces experts with in-depth

knowledge of the field who have readiness to participate in national and international debate concerning the grounds for radiation protection, and to make statements based on research data concerning special issues associated with the Finnish society.

In environmental research, the goal is that STUK responds to the information needs of decision-makers, stakeholders and citizens concerning the occurrence of radioactive substances in the environment in Finland and the neighbouring areas, living organisms and food, and presents well-founded estimates of exposure to radiation among various citizen groups and living organisms, along with methods for its reduction. Environmental research produces data on the occurrence of radioactive substances in the environment, living organisms and food. STUK also contributes to preparation of regulations concerning concentration limits.

In research related to preparedness for radiation hazards and accidents the goal is that STUK responds to the information needs of decision-makers, stakeholders and citizens concerning the impact on safety of various radiation hazards and risk situations, prevents radiation hazards in advance, acts efficiently and expediently in radiation hazard situations and gives recommendations, based on research data and advance planning, for reduction of exposure to radiation. For this purpose, STUK continuously maintains and develops its measuring readiness and expertise in order to ensure rapid response and effective operation in radiation hazard situations.

The goal in research related to dosimetry and measurement standards is to ensure high international quality of measurements, analyses and dosimetry conducted by STUK, and to provide reliable foundations for STUK's activities as regulatory authority and research institution. Internal research and development activity provides STUK with versatile and up-to-date analysis readiness, and the quality and availability of such services meets the needs of stakeholders.

The nuclear safety-related research conducted by STUK supports STUK's supervisory duties regarding nuclear facilities, and contributes to meeting the societal impact targets that are maintaining the high standard of nuclear safety in Finland and ensuring that the safety cases are in keeping with good international practices. In order to carry out its supervisory duty, STUK must remain independent of the organisations under its supervision. Nuclear safety research is therefore organised in Finland in such a manner that this independence is not jeopardised.

STUK can participate in projects that concern events outside nuclear facilities (spreading of releases and their effects on the environment), being allowed to participate in such basic research that is clearly related to the development of radiation safety. In addition, STUK participates in basic research that aids the development of radiation measuring techniques and detectors for the purposes of radiation safety, CTBT regulation and nuclear materials regulation.

Any research and related research projects connected with the development of nuclear energy and funded from national nuclear safety funds are clearly excluded from the scope of nuclear safety research conducted at STUK. Furthermore, research funding is not accepted from organisations that STUK supervises as a regulatory



authority (power companies, Posiva). The volume of research related to nuclear safety has been relatively small in recent years (less than 1 person year).

An international evaluation group assessed STUK's research activities in 2000 and 2005. The group concluded that research at STUK is of a high standard and in certain fields even of the highest international level. The most recent evaluation was conducted in October 2011. The two reports drawn up for evaluation purposes provide a comprehensive description of STUK's research activities from 2005 to 2010, as well as research projects in progress at STUK:

Salomaa and Sulonen (Eds): Research activities of STUK 2005-2010, STUK-A248 (August 2011) Salomaa and Sulonen (Eds): Research projects of STUK 2008-2011, STUK-A249 (August 2011)

## 4.2.6 VTT Research Activity outside National Programmes

VTT is by far the largest research institution conducting nuclear energy research in Finland. VTT activity covers most of the topics related to nuclear power plant safety research, final disposal of nuclear waste, and fusion research. About 60% of VTT's nuclear research is self- or co-financed research activity, some 60% of which falls within the scope of national research programmes. VTT contributions to these projects make up slightly over 80% of the total research volume of the SAFIR2014 programme, and slightly less than 50% of the volume of KYT2014. Contributions to the NETNUC project and the international fusion research programme are also significant. Research carried out under these is described in chapter 4.1.

The need to train new experts in VTT is so great that only part of the training can be carried out within the framework of national programmes. The rest of the education activity is either totally self-funded or conducted in collaboration with important strategic partners, such as Posiva Oy. With regard to generic research topics, research conducted in other sectors develops competencies that can be utilised for nuclear power applications (for example material engineering and organisational and human factors).

In addition to national programmes, VTT is also engaged in significant self-and co-financed development of strategic competencies, which is clearly targeted at commercial assignments and products. The development since 1986 of APROS simulation software in collaboration with Fortum is one example of such a project. The other main targets of self- and co-funded research activity are the EU projects presented in chapter 6, participation in the Jules Horowitz project, development of internal strategic competencies, and joint projects falling outside the scope of national programmes.

One of the major research investments made by VTT is the contribution to the Jules Horowitz test reactor (JHR) being built in Cadarache, France. VTT is engaged in the project with a major work contribution and a total funding amounting to

10 million euros, against which the institute may have access to two per cent of the operation time of the future reactor. Finland participates in the development of technologies for this reactor through VTT and, in the future, as a partial owner, probably to include experimental research in the JHR reactor.

VTT is extensively involved in the OECD/NEA and Euratom research projects described in chapter 6. Most of the OECD/NEA projects are linked with the SAFIR2014 programme. Euratom projects include the nuclear waste management projects CROCK and REDUPP, the ASAMPSA2 and HARMONICS projects related to advanced safety assessment methods, the material research projects GETMAT, MATTER, LONGLIFE, PERFORM60, NULIFE, SCWR and STYLE, the simulation software development project NURISP, and the network project SARNET-2 for severe accidents. Development is under way on the NULIFE project, coordinated by VTT; the project's development into "a legal entity" is intended to play a major role in the steering of European nuclear research.

The know-how developed within national programmes and other self- and co-financed projects is applied extensively to commercial assignments for the Radiation and Nuclear Safety Authority, Posiva, domestic power companies and foreign customers, including both safety authorities and power plants.

VTT's main research facilities are presented in chapter 5. We should mention here the analysis software for nuclear power plant safety research, which incorporates codes developed by the institution itself and obtained through international cooperation; testing devices and know-how for reactor materials research (hot cells, fracture mechanics testing equipment); aircraft impact simulation equipment; research equipment for radiochemistry; bentonite characterisation devices related to final disposal of nuclear waste; fusion research software and first wall measuring devices.

The research readiness for nuclear power plant materials is used for investigation of both new material solutions and assessment of degradation phenomena in ageing power plants. The available methods include the versatile microscopic and analysis techniques (SEM, FEG-STEM, EDS) and the NDE equipment (ultrasonic, eddy current and x-ray devices) for non-destructive testing of materials. Equipment available for characterisation of materials includes static materials testing machines (tensile strength, bending and impact durability tests) and fatigue testing devices. Loads can be applied on material samples and can also be examined in autoclaves simulating water chemistry of nuclear power plants. Irradiated samples from nuclear power plants can be studied and tested in hot cell facilities and autoclaves designed for radioactive materials.

Materials testing and monitoring devices are also utilised for investigation of material damage in nuclear power plants. Studies are made for both domestic and foreign nuclear power plants and authorities.

The impact simulation device for aircraft crashes is used primarily in research projects with several funding partners. The equipment is internationally unique, and

in addition to the involvement of Finnish stakeholders the project also has European and North American partners. The apparatus can also be used for simulation of other impact situations.

VTT safety analysis software, described in closer detail in chapter 5, is used for conducting verifying safety analyses related to nuclear power plant construction and operating licences for authorities, when the authorities inspect the safety analyses conducted by the reactor vendors. This means that the course of a certain type of accident situation is simulated, using independent software, in order to ensure that the safety systems of the plant are efficient enough to secure coolability of the reactor core and safe shut-down.

Safety analyses are also carried out for the power companies according to need. Reactor physics software is used for calculating power peaking and efficiency of power control in support of fuel loading patterns, isotope composition as the burn-up advances, radioactivity inventories, and criticality safety in the core, in fuel transport canisters and storage pools, and in final disposal canisters. This software is also used for the creation of nuclear cross-section data needed by reactor safety codes for the purpose of steady state and transient calculations. Fuel behaviour as the burn-up advances is calculated using fuel codes created for this purpose. The aim is to ensure, for instance, that the internal fuel rod pressure does not exceed the allowed limit, and that the fuel cladding is not damaged. Such analyses are made for the needs of both nuclear power plants and authorities employing different code packages.

Simulation of severe accidents is a research topic of its own, by which the effectiveness of the steps taken to mitigate the course of nuclear power plant accidents is evaluated by tests using verified calculation methods. Critical phenomena include power plant pressure control, coolability of the molten core, hydrogen control and potential steam explosions. With the help of such calculations, potential releases and the time of their occurrence can be predicted. VTT has internal calculation software at its disposal for estimating the spread of releases.

VTT plays a very significant role in the research of the management and final disposal of spent nuclear fuel conducted for Posiva. In 2011, Posiva was VTT's biggest corporate sector customer. The topics of assignments include, for instance, assessment of long-term safety; modelling of groundwater flow and chemistry; analysis of the functioning capacity of bentonite (modelling and experimental research) and design of the use of backfilling material and experimental research, and demonstrations in support of this; solubility and other properties of spent nuclear fuel; technical design basis for the repository and encapsulation techniques; development of inspection methods for the disposal canisters and canister components; probabilistic risk analysis of the encapsulation plant and repository for the disposal of spent nuclear fuel; and assessment of environmental impacts of the transport of spent nuclear fuel in case of alternative transport methods (road, rail and sea transport) to the disposal site.

VTT has been strongly involved as Finland's representative in international cooperation and projects in the fields of probabilistic risk analysis, automation and control rooms, and development of process control. VTT also applies new methods and competencies developed through research in its role as the Technical Safety Organisation (TSO) of the Radiation and Nuclear Safety Authority, and as services offered to power companies.

With regard to human and organisational factors, the main part of nuclear energy research is conducted in national programmes. Assignments carried out for domestic and foreign power companies and authorities increase the understanding of practical challenges and phenomena. This sector-specific know-how and the combination of competencies in behavioural sciences and fields of technology made possible by VTT's multidisciplinary expertise are crucial with a view to supporting the safe use of nuclear power. Research carried out in other areas increases the amount of experts. Safety culture and management research conducted in safety-critical areas deserve particular mention. Relevant competencies also emerge in the research of organisational and network management research relating, for example, to subcontracting chains.

## 4.3 Research in Power Companies and Posiva

This chapter briefly presents the internal research activities of Fennovoima, Fortum, Teollisuuden Voima (TVO) and Posiva. These corporate research activities aim at enhancing the safety in construction and operation of nuclear facilities and ensuring their sustainable and economic operation.

### 4.3.1 Research Activity at Fennovoima

Fennovoima conducts its research activity along two main lines of operation: research providing direct support for project execution, and participation in national research projects.

For the purposes of project execution, Fennovoima has commissioned in-depth analyses of the environmental circumstances of its alternative nuclear power plant sites, including geology and seismology and extreme weather phenomena (temperatures, wind, rainfall, sea-level variation range), also taking account of the effects of climate change on these during the planned operation and decommissioning of the plant. Design principles related to environmental factors have been specified for the plant on the basis of these studies.

From the very beginning of its own project Fennovoima has also participated in the funding of national nuclear safety research, at first through independent financing targeted at selected research projects (e.g. SAFIR2010/EXWE) and, in the year following ratification of the decision-in-principle, in the extent of the statutory State Nuclear Waste Management Fund (VYR) charge. In addition to VYR funding,

Fennovoima also participates in the financing of JHR and GEN4FIN projects and NKS, and certain Tekes projects of interest with a view to the project.

In all, Fennovoima's investment in research is approximately 10% of the company's current budget.

### 4.3.2 Nuclear Energy Research at Fortum

Fortum, formerly Imatran Voima Oy (IVO), has long traditions in conducting research related to nuclear energy. This is largely due to the decision made in the early 1970s to build a Russian-type nuclear power plant in Loviisa. One of the challenges of the project was how to implement Finnish safety culture in a power plant designed in the Soviet Union. Because of this, the company decided to launch a research programme that still continues in Fortum today. The objective then, as today, was to investigate the nuclear safety of existing nuclear power plants as comprehensively as possible, without forgetting research related to waste management.

In order to ensure the maintenance of Fortum's existing power plants, six research programmes are in operation:

TERMO - Thermal-hydraulic methods

PORE - Nuclear fuel and reactor physics

O&M - Operation and maintenance

YJ - Nuclear waste management

YVMAT - Nuclear power plant materials

APROS - Nuclear power plant simulation

In addition, Fortum has cooperation projects aiming at the development of future power plants, and participates in several national nuclear energy research projects.

Fortum has a strong organisation and know-how targeted at the maintenance of nuclear energy, part of which is directed for research and development. The focus is on projects related to obtaining an operating licence for the new nuclear power plant, with solid scientific know-how as an integral part of the process. Experiments are carried out in collaboration with national and international partners, many of which are described in this report.

The producer of nuclear waste is responsible for all technical nuclear waste management measures concerning the waste produced by it, and the associated costs, in a manner ensuring safe implementation of the final disposal. For this purpose, Teollisuuden Voima and Fortum established the co-owned company Posiva Oy, tasked with the design and implementation of safe final disposal so that the official requirements are met. According to the government decision-in-principle, preparedness for final disposal of spent nuclear fuel must be achieved by the end of 2020. Research activities related to this, at which most of Fortum and TVO investments in research are targeted, are described in chapter 4.3.4.

### 4.3.3 Research Activities at Teollisuuden Voima Oyj (TVO)

The needs of research and development concerning nuclear safety and technology have changed significantly over the past few years, due to development within the field, construction of the new OL3 nuclear power plant unit, and the subsequent decision-in-principle concerning the OL4 power plant. The related R&D challenges are both national and global. TVO's primary targets include:

- In terms of safety, construction of new reactors and modernisation meeting all safety requirements and increasing the passive features of safety systems.
- In terms of efficiency, extending the service life of nuclear power plant units to 60 years and taking advantage of the higher burn-up rates of nuclear fuel.
- Development of the final disposal concept for nuclear fuel and acquiring the necessary licences for disposal by Posiva.
- Support to OL3 and OL4 projects and acquisition of the relevant construction and operating licences.
- Maintenance and transfer of nuclear field know-how and training of new experts.

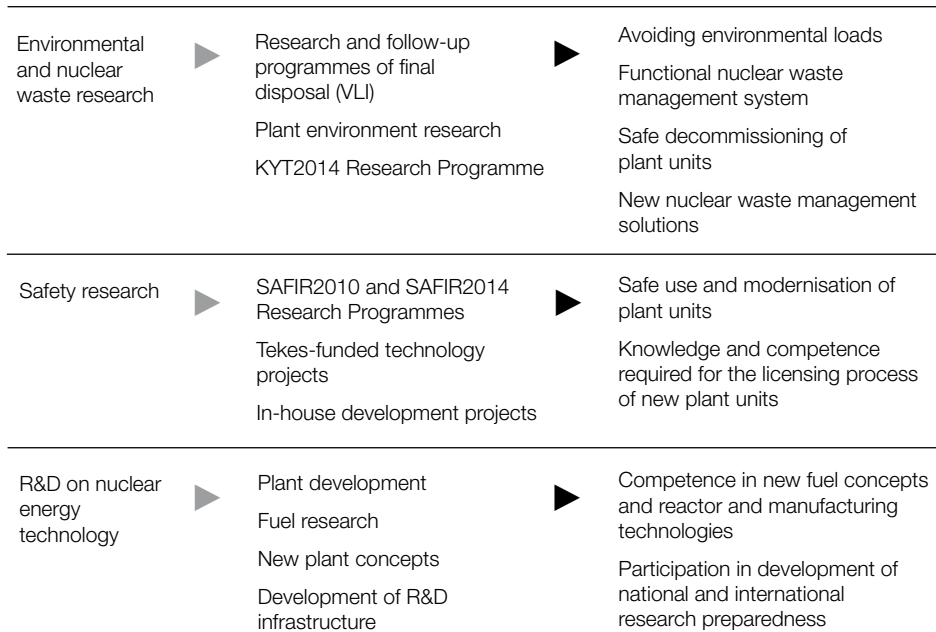
On a larger European and international scale the following challenges also exist:

- Design and construction of new nuclear power plant units increases the need for European regulation. The need for R&D and experts will also increase.
- Addressing the questions related to nuclear waste management and final disposal of spent fuel that still remain open is a key issue with regard to acceptability of nuclear energy.
- R&D and demonstration of fourth generation (Gen IV) nuclear power plant concepts. Novel reactor and fuel technology also requires that the research infrastructure (test reactors, hot cells, etc.) is up to date.

TVO's R&D consists of three areas of activity: research groups on safety, nuclear energy technology, and environmental and nuclear waste research (figure 4.9). The aim of these is efficient exploitation of R&D projects while simultaneously developing experts and encouraging networking and network development.

In the area of environmental and nuclear waste research, the objective is to keep the environmental load caused by the Olkiluoto nuclear power plant at the minimum and to ensure safe final disposal of the operating waste of the plant and spent fuel. The research field of nuclear waste management also includes the decommissioning of nuclear power plant units in the future as they are closed down, as well as treatment and final disposal of waste generated during the operation of nuclear power plants. TVO is also partly responsible for Posiva's research and development work as the liable party for nuclear waste management.

**Figure 4.9.** Structure of TVO's R&D activity.

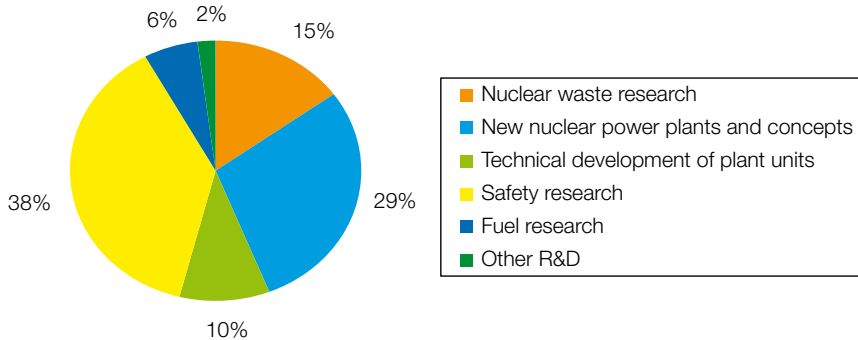


Safety research contributes to ensuring safe and stable long-term operation with high capacity factors of the existing nuclear power plant units. One of the aims is also to ensure the verified safety of the technological solutions for the new nuclear facilities, and acquisition of the know-how required for their forthcoming operating licences. The research is largely based on the national SAFIR2014 programme, and the company also participates in Euratom's SNETP activities at several levels.

In the field of nuclear energy technology, R&D focuses on fuel research in particular both in international projects (OECD/NEA cooperation) and in collaboration with fuel suppliers. The novel technical solutions used in nuclear power plants and in ensuring licensability require R&D projects, which involve both experimental work and modelling. The projects are either TVO's own commissioned research or, typically, joint national projects funded by Tekes. Nordic research cooperation also contributes to meeting these needs, and TVO takes part both in research programmes involving power companies (NPSAG, NOG and Elforsk) and in the NKS programme as a funding partner.

Participation in the development of new concepts and establishment of infrastructure is primarily effected as part of national projects, such as the GEN4FIN network, and VTT's JHR MTR test reactor project financed by Tekes.

**Figure 4.10.** Distribution of TVO research and development activity in 2010, excluding the share of fuel R&D.



The financial distribution of research and development activity funded by TVO among various areas is shown in figure 4.10. The highest expenses derived from nuclear waste management research, the largest portion of which was spent on Posiva’s primary area of operation, in other words research and development of final disposal of spent nuclear fuel. The growth of research expenditure increased further in 2010 as Posiva’s research and development activities expanded.

During 2010, 1.3% of the total funding volume of R&D activity was used for international research, most of which consisted of fuel and safety studies.

#### 4.3.4 Research Activity at Posiva

Research, technical design and development activities (RTD/TKS) at Posiva, jointly owned by TVO and Fortum, aim at final disposal of spent nuclear fuel, expected to begin around 2020. The primary objective of this work is the production of the design basis and designs for the construction of the encapsulation plant and the geological disposal facility, and the construction of these nuclear waste management facilities. In addition to construction of the underground rock characterisation facility ONKALO, the research and development activities include above-ground research, development of encapsulation and final disposal techniques, and design of the encapsulation plant and the repository.

This R&D is based on a ten-year plan (Posiva 2000-14) drawn up in 2000, and on annual nuclear waste management action plans prepared until 2008. Work is carried out both in Finland and in international cooperation, the most extensive of which is the formal cooperation with Sweden’s SKB (Svensk Kärnbränslehantering AB) (see chapter 6).

In accordance with the Nuclear Energy Act, the parties liable for nuclear waste management must submit to the Ministry of Employment and the Economy a report detailing the responsible parties’ plans concerning the implementation of the



measures associated with nuclear waste management and the preparatory work related to these measures. Until 2008 such reports were submitted to the Ministry on an annual basis. However, following the entry into force of the amendment to the Nuclear Energy Act in 2009, the reports must now be submitted every three years and they include a detailed description of the measures to be taken during the next three-year period, as well as an outline of the plans for the three years following.

Posiva's TKS-2009 (TKS = RTD, research, technical design and development) Programme Report comprises a description of the planned waste management measures and their preparation in 2010–2012. Posiva will prepare for the application of a construction licence for a final disposal repository in 2012 in accordance with the decision of the Ministry of Trade and Industry (the present MEE).

The plans for the next three-year period include completion of confirming site investigations concerning the Olkiluoto geological disposal facility; design of the necessary facilities and development of disposal techniques to be used to the level required for the construction licence application; as well as production of a safety case for long-term safety to be attached to the construction licence application.

Alongside studies made in accordance with the reference solution for the disposal system (emplacement of canisters in vertical deposition holes, KBS-3V), the company will investigate the feasibility and long-term safety of the alternative disposal concept for horizontal emplacement (KBS-3H) in collaboration with Sweden's SKB.

The tasks for the TKS-2009 programme period concern three major entities, which include the confirming site investigations concerning the Olkiluoto site; design of the encapsulation plant and the repository for the disposal of spent nuclear fuel; development of disposal techniques for spent nuclear fuel; and the demonstration of the long-term safety of the final disposal of spent nuclear fuel.

#### **4.3.4.1 INVESTIGATIONS FOR SITE CONFIRMATION AT OLKILUOTO**

The accuracy of the description of the repository site features in the eastern part of the investigation area will be enhanced during the TKS-2009 period due to new investigation holes. Additionally, the surveys and studies carried out in the ONKALO underground research facility will expand to the areas surrounding the repository host rock.

Several investigation niches have been excavated in ONKALO to enable studies and tests to be conducted at the disposal depth (see chapter 5). The studies and tests conducted at the investigation site, above ground and in ONKALO, support not only site modelling but also the establishment of features specific to the investigation site and function as a basis for the design of the final disposal facility.

In addition to the surveys, studies and tests conducted above ground and in ONKALO referred to above, the description of the features of the investigation site is materially based on the data produced by the Olkiluoto Monitoring Programme (OMO). With field testing, the programme will also be expanded to the eastern survey area and deeper down in the bedrock as the construction of ONKALO progresses.

The development of Rock Suitability Criteria (RSC) will continue. The development of RSC criteria is among the most significant research carried out within the field of site survey for final disposal; such research has not so far been conducted anywhere else in the world. The RSC criteria take account of rock characteristics with significance for both long-term safety and construction of underground facilities. The goal is to develop practices for the recognition of rock volumes suitable for hosting disposal tunnels, and assessing the suitability of tunnel sections and deposition holes for disposal.

#### **4.3.4.2 THE DESIGN OF THE DISPOSAL FACILITY FOR SPENT FUEL**

The disposal facility for spent nuclear fuel planned by Posiva consists of two nuclear waste facilities: the aboveground encapsulation plant and the underground final disposal repository. In the encapsulation plant, the spent fuel is encapsulated in disposal canisters. The disposal canisters are transferred from the encapsulation plant to the underground disposal facility, which comprises the repository facilities, central tunnels connecting the repository facilities, an access tunnel, a number of shafts, and other underground auxiliary and technical facilities. Additionally, the disposal facility comprises the aboveground buildings serving the operation of the facility.

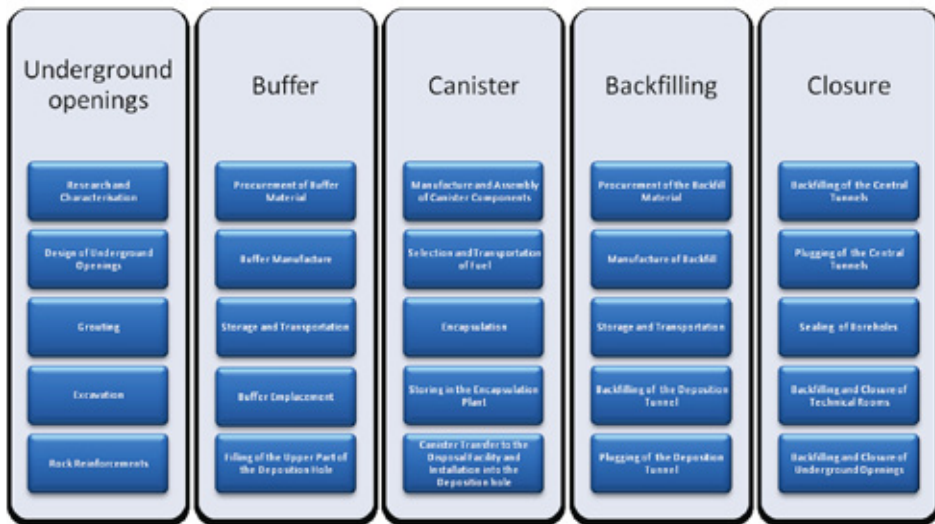
In accordance with the reference disposal concept (KBS-3V), the repository consists of disposal tunnels and deposition holes bored into the floor of the disposal tunnels. During the operation of the repository, more disposal tunnels will be excavated in several stages, some 10-20 tunnels at a time. After emplacement of canisters, the tunnels will be sealed as soon as possible.

The underground rock characterisation facility ONKALO, currently under construction, has been designed in such a manner that it can later operate as part of the repository.

#### **4.3.4.3 DEVELOPMENT OF SPENT NUCLEAR FUEL DISPOSAL TECHNOLOGY**

The spent fuel disposal technology RTD work is divided under “production lines” as shown in figure 4.11.

**Figure 4.11.** Final disposal system presented as production lines describing the various phases of the work. Photo: Posiva



In terms of technology development, the most important production lines are those of buffer and tunnel backfilling. During the next TKS (RTD) period, the focus of both technical development work and the disposal system performance assessments will be on the bentonite buffer. The bentonite buffer development work, for its part, will focus on the design of the solution to be implemented, and the definition of manufacturing and installation methods for the buffer blocks. The development will be coordinated within the framework of the BENTO programme.

The entire bentonite processing chain will be tested and analysed sequence by sequence. The manufacture of buffer components using both uniaxial and isostatic methods, respectively, will progress from small-scale manufacturing tests to actual production processes complying with quality requirements for full-scale blocks. The buffer block serial production processes will be tested by manufacturing blocks for buffer demonstration purposes. Suitable inspection and acceptance criteria for buffer production will be prepared and developed in connection with the manufacturing tests. The preparations for both the small-scale (1:3) and full-scale buffer implementation demonstrations are scheduled to take place from 2010 to 2012.

The canister production line begins from the manufacture of a cast iron insert for the canister, and consists subsequently of the manufacture and assembly of the copper outer shell. While the definition of the canister solution is nearing completion, issues remain open concerning the detailed dimensioning of the canister. The performance of design analyses will be continued in order to solve all questions concerning the loads affecting the canister and canister durability, the maximum

allowed level of material defects and residual stresses in canister components, and criticality safety. Canister research is already nearing completion and the focus is now mostly on the qualification of the inspection methods and quality assurance of canister components and sealing.

The tunnel backfilling production line begins from the manufacturing of backfilling components and comprises installation of the backfilling components and installation of necessary sealing structures.

According to the current basic design the backfilling of the deposition tunnels will be conducted using blocks compacted from Friedland Clay, pellets filling up the space between the blocks and the rock, and a filling for the tunnel floor to be applied separately. Quality assurance processes will be developed for the entire backfilling production line on the basis of the safety significance of the backfilling. Investigations and small-scale testing will be continued in order to determine the properties of the filling materials and factors affecting the performance of the backfilling. The block installation procedure will be tested phase by phase.

#### **4.3.4.4 THE DEMONSTRATION OF THE LONG-TERM SAFETY OF THE DISPOSAL OF SPENT NUCLEAR FUEL**

A safety case will be prepared for the purpose of demonstration of the long-term safety of the disposal of spent nuclear fuel. According to an internationally adopted definition, "safety case" refers to all the technical-scientific documentation, analyses, observations, tests and other evidence that are used to substantiate the safety of disposal and the reliability of the assessments thereof. A summary of the safety case will also be appended to the preliminary safety analysis report (PSAR). According to the 2008 plan the safety case will be produced as several separate reports. The performance targets and target properties defined for the disposal system form one starting point for the safety case. The most central RTD tasks to be completed before the submission of the construction licence application involve the elimination of defects and uncertainties in, for example, initial data, and models that pose a significant potential risk to the reliability of the long-term safety assessments.

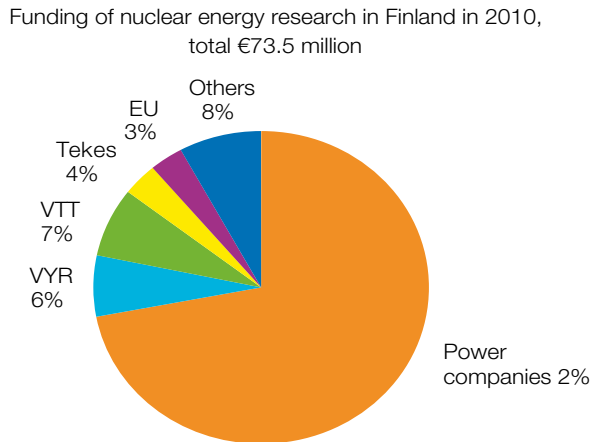
The central RTD task and objective during the next three-year period will be the definition of the initial states of the release barriers (spent fuel, the canister, the buffer, the properties of the surrounding rock, and the interfaces between the disposal system components) in the basic scenario. Another key task will be the definition of allowed ranges of variation for the buffer properties in the anticipated development scenario.

The safety case will yield estimates of the potential radiation impacts caused by disposal, and the probability of such impacts in each scenario. The impact estimates for the first few thousand years will be based on radiation doses received by individuals, while the estimates for the subsequent period will be based on the amounts of activity released from the repository. Posiva is currently developing an Olkiluoto-specific model for the estimation of radiation doses.

## 4.4 Research Funding

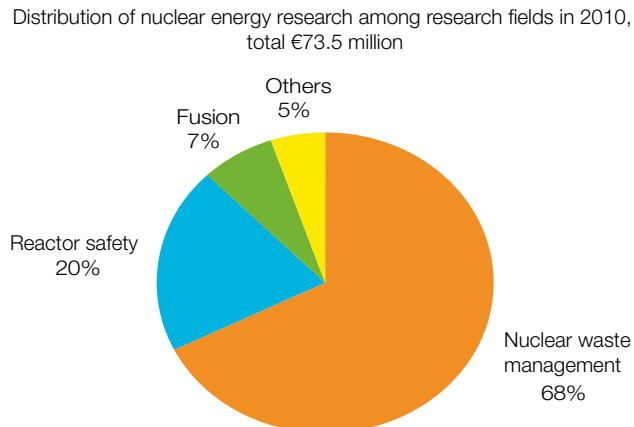
The survey of the Committee for Nuclear Energy Competence in Finland charted the level of funding in 2010. Corresponding surveys have been carried out in 2007, 2003 and 1999. As shown in figure 4.12, the overall nuclear research funding in Finland was 73.5 million euros in 2010. Power companies accounted for 72% of the total. Other major contributors included VTT, VYR, Tekes and the EU.

**Figure 4.12.** Funding of nuclear energy research in Finland in 2010



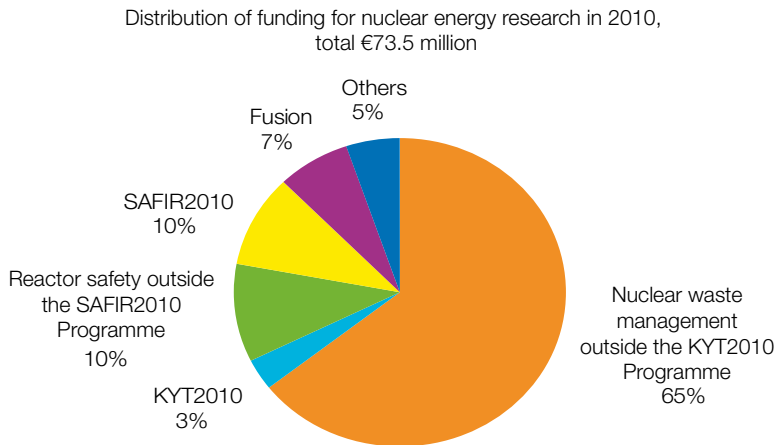
According to figure 4.13, nuclear waste research accounted for 68% of the total, nuclear power plant safety research for 20%, fusion research for 7%, and other research – also including reactor safety research on the new generation or GenIV reactors – for 5%.

**Figure 4.13.** Distribution of nuclear energy research between research fields in 2010



According to figure 4.12, the majority of nuclear waste research was financed by power companies. According to figure 4.14 the proportion of the Finnish Research Programme on Nuclear Waste Management KYT2010 was only 3% of the total volume. With regard to reactor safety, the share of the national SAFIR2010 research programme was 10% of the total volume of funding, and half the entire research volume of nuclear power plant safety.

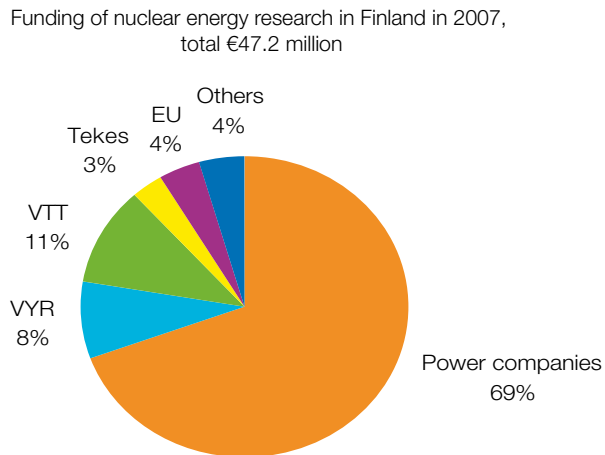
**Figure 4.14.** Distribution of funding for nuclear energy research in 2010



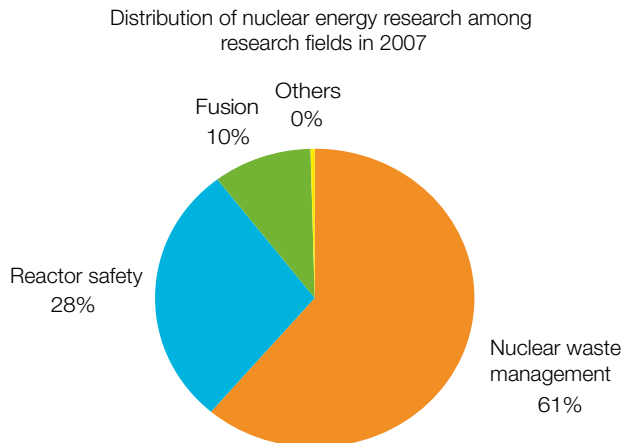
Compared to the situation in 2007, shown in figures 4.15 to 4.17, overall funding for nuclear energy research has grown significantly from 47.2 million euros to 73.5 million euros. In funding of research, the role of power companies has risen from 69% to 72%, and the relative share of VTT, VYR and the EU has reduced when compared to 2007.

In terms of research areas, nuclear waste research has further increased its relative share, and the share of nuclear power plant safety research has fallen from 29% in 2007 to 20% in 2010. The proportion of other research has also grown significantly, safety research on GenIV reactors forming the major part of this research activity. In euro, the amount of nuclear waste research has increased from 28.9 million in 2007 to 49.7 million in 2010, whereas in the field of nuclear power plant safety the growth has been from 13.4 million in 2007 to 14.7 million. In 2011, the VYR funding for research area of nuclear power plant safety increased by slightly over two million euros as a result of the new decisions-in-principle on Fennovoima's and TVO's new nuclear power plants.

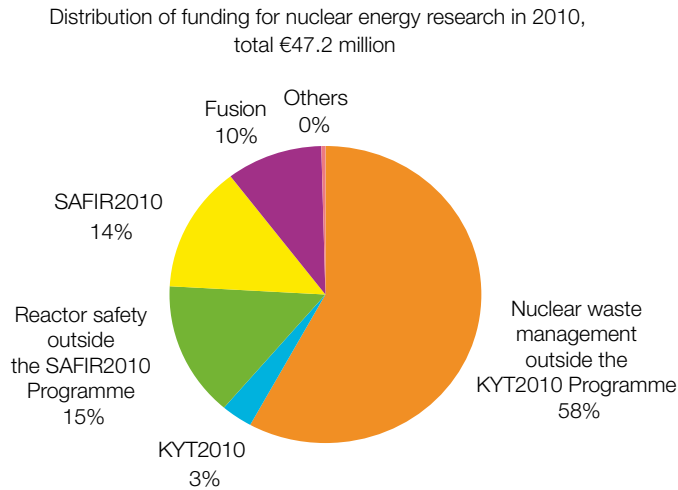
**Figure 4.15.** Funding of nuclear energy research in Finland in 2007



**Figure 4.16.** Distribution of nuclear energy research among research fields in 2007



**Figure 4.17.** Distribution of funding for nuclear energy research in 2007



## 4.5 The Effect of the Fukushima Accident on Research

As a consequence of the Fukushima nuclear power plant accident, the reference and steering groups of the SAFIR<sub>2014</sub> programme have recognised the need for further research in the areas of initiating events, nuclear power plant design, mitigation of the effects of accidents, and fuel life-cycle.

The groups concluded that the occurrence of external natural phenomena requires to be assessed in greater depth. These include phenomena causing exceptionally high sea levels in the Baltic Sea, together with their repercussions; the impact of the atmosphere's current composition on the intensity of weather phenomena; and occurrence of phenomena previously uncharacteristic of Finnish weather patterns, such as ice storms and hurricanes. New information is also needed on combinations of external events, as well as combinations of external and internal events for inclusion in risk analyses of power plants.

It was concluded that the adequacy and scope of the design principles for nuclear facilities must be reviewed at regular intervals. With regard to the impact of earthquakes, initial data affecting the calculation of seismic models, for instance, should be investigated. Research must specify the guidelines and requirements for a measuring system suited for seismic long-term survey of plant sites, and create a clear overall picture of the importance and monitoring of seismic phenomena under Finnish conditions. New information is also needed on the impact of initiating events on nuclear power-plant safety that exceed the design bases for nuclear facilities.



With regard to analysis of reactor accidents, situations in which large amounts of boron or other crystallisable substances have entered the reactor circuit should be investigated. In addition, accidents of long duration pose new kinds of challenges to decay heat removal.

Improved knowledge is required on potential hydrogen formation and transport within plant premises or on the plant site in accidents, in order to plan counter-measures related to hydrogen explosions. Modelling needs to be developed further to take account of events of quite considerable duration. In accidents resulting in a core meltdown, a large number of different fission products may be released from the fuel, depending on the circumstances. A systematic study should be performed covering the release of as large a range of fission products from nuclear fuel as possible, and their transport in the primary circuit and containment building and release into the environment.

It was concluded that in terms of safety research of nuclear power plants, attention should therefore be paid to the overall review of the fuel cycle as part of nuclear power plant safety. A situation involving loss of the cooling water supply for the plant site's spent fuel pools would provide interesting topics for experimental and computational analysis. In addition to cooling-related analysis, there should be competence for the estimation of the behaviour of cladding materials in various stages and situations during storage.

## 4.6 Conclusions and recommendations

No research field can manage for long without the existence of basic scientific research. The Academy of Finland commissioned an international evaluation of energy sector research in Finland in 2006. The evaluation valued the good results of applied nuclear energy research as a factor guaranteeing operability and safety of nuclear power plants. However, one of the central conclusions drawn was that there is very little basic research in the nuclear energy field in Finland. The evaluation urged Finland to increase research infrastructure within the sector. The Academy of Finland has for its part responded to this by including nuclear energy research within the scope of its SusEn 2008–2011 research programme, and by targeting a call for proposals within the field of nuclear energy in 2012–2016, amounting to a total of 2 million euros. Nuclear energy must also be included as an equal applicant in the spectrum of energy research with regard to any future funding provided for basic research.

The maintenance of nuclear safety requires foresight which can be obtained only through research. Research results are exploited continuously for the enhancement of nuclear plant safety and plant operation. Independent Finnish research activity has helped STUK to establish a rapid decision-making process. Furthermore, the load

factors of nuclear power plants have remained high, since existing knowledge has made it possible to carry out the necessary solutions in a reliable fashion.

In terms of nuclear power plant safety, a national research programme is the backbone of national competence. A positive sign is that the funding base of the programme has expanded in recent years due to new decisions-in-principle. However, it must be borne in mind that the real extent of the programme in 2011, when a total of seven reactors are at the design, construction or operation stage, does not correspond even with the situation in the late 1980s, when only four reactor units were in use.

Major contributions are made in Finland in research and development related to the safety of nuclear waste management and the final disposal of spent nuclear fuel in particular. The volume of the national nuclear waste management programme is modest compared to Posiva's research programme. However, the programme plays an important role in the creation and maintenance of complementary know-how, and in research of alternative disposal solutions.

In Finland, the study of fourth generation nuclear facilities is relatively limited due to the scarcity of funding available and the need to concentrate primarily on ensuring the safety of existing facilities. However, the small national research programme has established the framework for national cooperation and limited participation in international research activity.

In relation to fusion research, the national programme has been successfully linked as part of international research activity within the field.

In addition to national programmes, universities and research institutions are also engaged in other significant research activities, most of which are conducted in collaboration with international partners. Some of the research also involves such development of internal strategic competence that is not suited to national or international programmes.

In the research conducted by power companies, the focus is naturally on research aimed at enhancing the safety and cost-efficiency of the companies' own power plants. In the field of nuclear waste management, Posiva's programme is the most significant investment target in terms of nuclear safety research.

It is important that experts within various fields remain in contact with each other. Interactions between physical phenomena or systems can produce novel situations that must not come as a surprise, and no unexplored gaps should remain among various fields of study. The combinations of various fields of science have turned out to be a strength for a small country like Finland, since here individual researchers need to stretch their expertise to cover a more extensive area of research than is generally the case, and interaction within the small research community is lively.

Research scientists can focus profoundly and exclusively on their own research areas. No one person can know the latest achievements within all these areas. The contributions of hundreds or even thousands of domestic and foreign researchers are therefore needed in order to manage the entity.

Research creates new knowledge and fosters new experts. In the area of nuclear safety, the needs are very 'down to earth' and well recognised. However, the striving to achieve something that has never been achieved before, an opportunity to explore the prevailing perceptions from a critical perspective, and an opportunity to fail, are all integral parts of research activity. Research funding and targeting of research should allow for these features that distinguish research from consulting, without which progress stalls and potential new safety hazards, as well as opportunities for enhancing safety, remain unrecognised.

## References/Further information

<http://safir2014.vtt.fi> (The SAFIR2014 research programme website and links to former programmes)

Puska, Eija Karita; Suolanen, Vesa. 2011. SAFIR2010. The Finnish Research Programme on Nuclear Power Plant Safety 2007-2010. Final Report. Espoo, VTT. 578 p. VTT Tiedotteita - Research Notes; 2571 ISBN 978-951-38-7689-0 (softback ed.); 978-951-38-7690-6 (URL: <http://www.vtt.fi/publications/index.jsp>) <http://www.vtt.fi/inf/pdf/tiedotteet/2011/T2571.pdf>

Bruna, G., Rastas, A., Schaefer, A. Evaluation of the Finnish Nuclear Safety Research Program SAFIR2010. Publications of the Ministry of Employment and the Economy. Energy and the climate 51/2010.

<http://kyt2014.vtt.fi> (The KYT2014 research programme website and links to former programmes)

[www.lut.fi](http://www.lut.fi)

[www.aalto.fi](http://www.aalto.fi)

[www.helsinki.fi](http://www.helsinki.fi)

[www.jyu.fi](http://www.jyu.fi)

[www.stuk.fi](http://www.stuk.fi)

Energy Research in Finland 1999-2005, International Evaluation, Publications of Academy of Finland, 14/06, ISBN 951-715-625-1, ISBN 951-715-626-X (pdf), Edita Prima Oy, Helsinki 2006. [http://www.aka.fi/Tiedostot/Tiedostot/julkaisut/14\\_06%20Energi-aalan%20arviointi.pdf](http://www.aka.fi/Tiedostot/Tiedostot/julkaisut/14_06%20Energi-aalan%20arviointi.pdf)

[www.vtt.fi/nuclear](http://www.vtt.fi/nuclear)

[www.fortum.com](http://www.fortum.com)

[www.tvo.fi](http://www.tvo.fi)

[www.fennovoima.fi](http://www.fennovoima.fi)

[www.posiva.fi](http://www.posiva.fi)

Posiva Oy. TKS-2009 Nuclear Waste Management at Olkiluoto and Loviisa Power Plants - Review of Current Status and Future Plans for 2010-2012.

Posiva Oy. 2011. Nuclear Waste Management at Olkiluoto and Loviisa Power Plants. Overview of activities in 2010.

Posiva Oy. 2011. Annual Report 2010.

# 5 Research Infrastructure

This chapter describes the Finnish research infrastructure available to sector actors that is related to research on nuclear reactor types in Finland in the design, construction or operation phases. Nuclear fuel research is not addressed in this chapter as such, but references to its organisation are made in connection with presentation of the international infrastructure available for research. Participation in international cooperation is described in closer detail in chapter 6.

Since the structural and operational safety of nuclear power plants requires not only computational verification but also experimental checking, there is a need for up-to-date research capabilities fulfilling the requirements of both existing and future power plants. In addition to describing infrastructure related directly to safe use of nuclear power plants, this chapter also provides a review of research on nuclear sector automation, safety arrangements and nuclear material regulation, as well as research capabilities that support the ageing management of the plants and storage and final disposal of fuels. The chapter describes not only experimental capabilities but computational modelling and simulation preparedness that also contributes to overall experimental infrastructure.

When the research on the power plants in operation or under construction is combined with their long service life and the subsequent decommissioning period, as well as the final disposal of fuel, the time span for research infrastructure after commissioning a new plant is at least 100 years.

On the basis of the Fukushima accident, safety functions must be developed further and preparations made for rare initiating events and combinations of events. Special attention must be paid to storage of spent fuel at the plant site.

To enable the requirements described above to be met and to exploit international experimental capabilities, Finland must possess sufficient infrastructural preparedness for its own experimental and computational activity, as well as for the maintenance and enhancement of national competencies.

## 5.1 Experimental Facilities and Equipment and Software Tools

This chapter is based on information provided by Finnish actors concerning the nuclear sector infrastructures, equipment and software tools used for nuclear research in research institutions and universities. Information on supplementary capabilities in other organisations has also been collected for the report. Account has been taken of the information acquired by the conducted survey.

Research infrastructures that fall into one of the following categories have been included in the review:

- nuclear-energy-specific
- additional strong need in nuclear energy research
- otherwise linked to nuclear energy.

Research facilities and equipment directly linked to use and safety of nuclear energy are mainly possessed by VTT and universities. Research on final disposal of spent fuel is conducted by Posiva, VTT, the Geological Survey of Finland and B+Tech. STUK's in-house research is mainly connected with regulation and supervision of radiation and nuclear materials. Research related to final disposal of operating waste is conducted by companies responsible for the final disposal of nuclear waste from the plants in operation. These companies also take advantage of the capabilities provided by research institutions.

### 5.1.1 Reactor Physics and Dynamics

Reactor physics and dynamics are key competencies needed by nuclear power plants for ensuring efficient and safe operation. VTT has traditionally had strong computational competence within this area. This nuclear-specific topic is supported by research and infrastructure related to fission cross sections and determination of the decay properties of fission products, described in chapter 5.1.2.

#### **Reactor Physics**

VTT has created and acquired an extensive range of computer software tools, and also maintains competence in the conducting of analyses related to stationary reactor physics needed in Finland with a view to safe and efficient use of nuclear power plants. The software tools consist of both internationally sourced and independently developed codes. New fuel and reactor types and new modes of utilising fuel, such as constant efforts for higher burn-up levels, require further development and verification of calculation models and codes. Criticality safety also becomes emphasised in such cases. The results of stationary programmes are also needed as initial data for reactor dynamic safety analyses. International cooperation is the prerequisite of reactor physical research.

The Serpent code is the latest significant addition to software tools within the field of reactor physics. Developed in Finland, the code has attracted a large number of international users. The objective was to create an efficient research tool, based on continuous-energy Monte Carlo codes, that specialises in transport and burn-up calculation applications at fuel rod bundle level, such as generation of homogenised multi-group constants used for reactor simulation calculations.

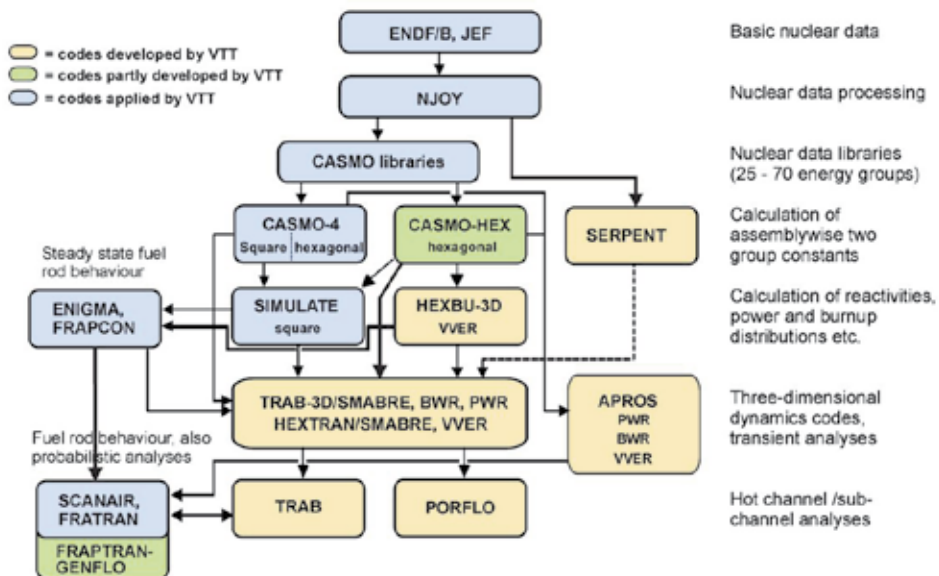
#### **Reactor Dynamics**

VTT has been developing independent reactor dynamics software for nuclear power plant safety analyses in transient and accident situations since the 1970s. The TRAB, TRAB-3D and HEXTRAN software have been successfully utilised for safety analyses

of domestic and foreign power plants. Recently such codes have also been transferred to APROS system code core models. Fluid dynamics simulation methodology has also been developed alongside reactor dynamics software, the latest tool being VTT's own 3D flow simulation code PORFLO. The research has also constantly approached the topics of fuel investigation. Figure 5.1 shows the reactor dynamics software tools at VTT's disposal and demonstrates the safety analysis calculation chain. The latest pieces added to the code chain are a calculation system for the assessment of fuel rod failure and development of uncertainty methods to complement reactor dynamics calculations.

Keeping reactor dynamics software at an internationally competitive level requires constant research and development. In addition to R&D, it is necessary to verify the new models through experimental techniques and comparisons against the results generated by other similar codes. For this reason, participation in international cooperation within the area of reactor dynamics takes place primarily within the OECD and AER Working Groups dealing with VVER reactors, and through benchmark exercises. Development of internal software has also been found to be the best way of familiarising young researchers with the topic.

**Figure 5.1.** VTT's reactor dynamics calculation software and the reactor physics and fuel analysis codes related to the analyses.



## 5.1.2 Fuel Research

### Fission Research at the Accelerator Laboratory of the University of Jyväskylä

There is a strong need in nuclear research for determination of cross-sections and decay characteristics of fission products (fission yield, decay heat, beta decay delayed neutrons). The Accelerator Laboratory of the Department of Physics at the University of Jyväskylä (JYFL) has used several modern techniques of nuclear physics for determining these characteristics. The laboratory's two cyclotrons and one direct-current accelerator, as well as the versatile research facilities for radioactive radiation and materials research, provide an excellent framework for research and review projects related to radiation and nuclear safety, and to nuclear energy.

In the early 1980s the department developed a separation technique for radionuclides based on the ion guide method, in which a mass separated ion beam of high ion-optical quality is produced from primary ions generated by nuclear reaction. The method is equally suited for study of fusion or fission reactions. With regard to fission reactions, the ion guide method has some interesting applications related to nuclear energy research.

**Figure 5.2.** The science campus of the University of Jyväskylä. The Department of Physics is on the left. (Photo: Jussi Jäppinen)



Use of the ion guide enables measurement of independent fission product cross sections. Three ion guide characteristics are exploited in the process:

- The generation mechanism of the ions extracted from the ion guide, ionisation in the nuclear reaction, is independent of the chemical properties of the isotopes to be separated. The fission yield can be measured for the isotope of any element. Fission reaction produces isotopes of more than 40 elements that can all be separated using the ion guide technique.
- The time available for ion processing is only a few dozen milliseconds. The yield can also be determined for very short-lived isotopes. It is therefore possible to measure not only mass distributions but direct fission yields.
- The ions extracted from the ion guide are direct fission products. The number of ions is directly proportional to independent fission yield. No correction factors are needed to account for accumulation of long-lived isotopes.

Using the ion guide of the JYFL Accelerator Laboratory, fission yields have been measured for fission of  $^{238}\text{U}$  and  $^{232}\text{Th}$  induced by 20–40 MeV proton, deuteron, alpha particle and neutron. In a typical measuring process, a magnetic isotope separator is utilised to identify the fission products on the basis of atomic mass, and the yields have been determined using gamma spectrometry.

In the early 21st century a Penning ion trap (JYFLTRAP) was built in connection with the JYFL isotope separator intended primarily for very precise atomic mass measuring of isotopes, see figure 5.3. The trap can also be employed as an isotope separator with a high mass resolution capacity.

The Penning trap can be exploited for direct measuring of fission yields. Almost all fission-generated isotopes can be identified unambiguously on the basis of their mass, without having to wait for their radioactive decay. The capacity of the Penning trap to separate isotopes, or even isomers, at very high resolution facilitates preparation of very pure samples. These samples make it possible to perform more precise measuring than before of certain phenomena of importance to reactor engineering. These phenomena are the decay heat caused by the radioactivity of fission products, and beta radiation-delayed neutron decay.

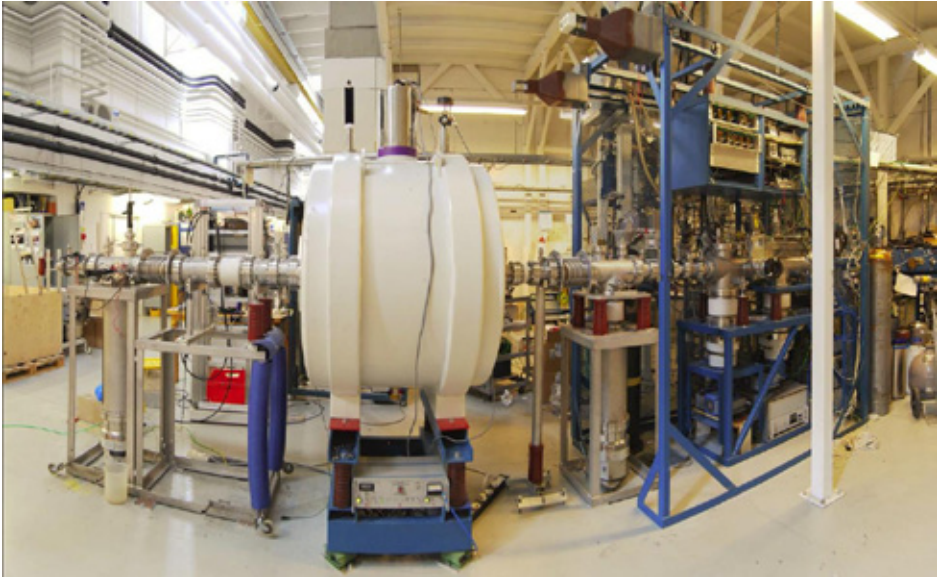
The decay heat in nuclear reactors is caused by energy released by radioactive decay of fission products. This energy can amount to up to eight per cent of the reactor's full power. It had not been possible to simulate the behaviour over time of such release of energy after the reactor shutdown at sufficient accuracy on the basis of known fission yield distributions and decay properties of radioactive isotopes. The method considered the best for measuring total decay energy is called Total Absorption Gamma Spectroscopy (TAGS or TAS), in which the total amount is measured of gamma radiation released as the nucleus splits. The necessary samples can be prepared with the help of the Penning trap, in which case the measurement accuracy is very high.

During 2011, the mass separation apparatus based on ion guide technology and the attached Penning trap were moved to the new MCC30/5 accelerator of the JYFL Accelerator Laboratory. There are plans for using the very intense proton beam produced by the new accelerator in a new manner in fission research by building a



neutron conversion target station. This research is associated with fourth generation reactors in particular.

**Figure 5.3.** The superconducting Penning trap mass spectrometer of the Accelerator Laboratory at the University of Jyväskylä.



### **Fuel Research in Support of Power Plant Operation**

The operation of nuclear power plants requires research on industrial fuels and their structures, which in turn calls for special research capabilities and competencies. Actual nuclear fuel research is conducted primarily through international cooperation, since Finland does not have national experimental capabilities for active fuel materials. Participation in international research activities is described in chapter 6. In Finland, the research capabilities related to fuel cladding and other structural fuel bundle materials are centralised at VTT.

Examples of research needs and methods associated with fuel research are as follows:

- fuel characterisation during manufacture (fuel manufacturers: visual, NDE, mechanical and microstructural characterisation);
- computational analysis of fuels: the necessary software tools, validation materials and competence;
- non-destructive fuel inspection (NDE methods in/out hot cell: dimensional accuracy, surface flaws, volumetric inspection, inspection of fuel pellets);
- destructive fuel inspection (hot cell strength, impact durability, hardness, fracture mechanics, metallography, ceramography, etc.);
- fuel damage research (hot cell NDE, microscopy and microanalysis);

- research of new fuel grades (fuel and cladding) (test reactors and hot cells with corrosion research and microanalysis capabilities);
- research and characterisation capability required by increased burn-up (plant, test reactor, hot cell);
- capability for reactivity-initiated accident (RIA) investigation and test reactor facilities (HALDEN, CABRI, JHR MTR); and
- infrastructure and testing capabilities required by interim fuel storage and identification.

### 5.1.3 Thermal Hydraulics

#### **Need for Thermal-Hydraulics Research**

The nuclear power plant safety systems are designed on the basis of thermal-hydraulic analyses. Assessment of nuclear power plant safety requires continuous application of thermal-hydraulic calculation methods. Experimental data is needed for the validation of calculation methods. Thermal-hydraulic tests are nuclear-energy-specific measurements performed using testing facilities simulating nuclear power plant operation. The rapid development of calculation methods sets new requirements for both the accuracy and the quantity of experimental data used for validation purposes. The prerequisite for the validation of 3D flow models is access to measuring facilities where the distribution of flow rates, temperatures and steam void fraction in the testing devices can be defined with adequate accuracy.

Many new nuclear power plant concepts use passive safety systems (systems whose operation is independent or minimally dependent on active components), for instance to ensure reactor cooling in different transient and accident situations. To ensure the operation of passive systems, the development of software models needs to be backed up by experiments in which the impacts can be modelled of, for example, non-condensable gases in various situations. Passive systems must also be tested in integral test facilities in order to verify the computational results.

Experiments are necessary in order to ensure the correct heat transfer and fluid flow characteristics of various power plant systems. The results of the experiments can be exploited either directly or by employing calculation software for test data analysis and conversion to full plant scale. Experimental capabilities must also be available for investigation within reasonable time of problem situations occurring in nuclear facilities in operation. Particularly the passive emergency cooling systems to be introduced in the new nuclear power plants require experiments that will ensure operability of these systems under any circumstances.

In Finland, nuclear power plants must be designed such that provisions are made for severe reactor accidents. However, the severe accident management strategies of the new power plant alternatives vary. In other words, in Finland there is a need for independent evaluation of the special features of severe accident management for the purposes of the licensing process of the new plants.

The essential target of severe accident management is to stabilise and cool the molten core material into a solid form. Independent validation of a new type of solution requires computational tools and suitable experimental study, by which the viability of heat transfer from the core catcher to its surrounding coolant can be verified experimentally.

In many new plant types, decay heat is removed from the containment building in severe accidents by using passive (operating on natural circulation) decay heat removal systems. It must be possible to verify the functionality of such solutions in severe accident conditions. Factors that may hamper operations include the accumulation of non-condensable gases in the system and the attachment of aerosols created in a severe accident to the surface of the heat transfer device. Research into the passive decay heat removal systems of containment buildings is closely linked to the computational (CFD) and experimental methods being developed in the research area of thermal hydraulics.

Participation in international experimental programmes gives Finnish actors access to the results of valuable experiments. Participation can be ensured by means of in-house experimental activity, either by using in-house prior experimental data as an instrument of exchange or by using in-house experimental facilities for participation in such programmes.

### **Current Status of Thermal-hydraulic Experimental Activity**

Experimental research on nuclear power plant heat transfer and fluid dynamics has continued in Finland for more than 30 years. Practically all domestic thermal-hydraulic testing for nuclear power plants is performed at the Lappeenranta University of Technology (LUT). Maintaining the experimental competencies has always been, and still remains, a challenge for LUT. The amount of research and technical personnel participating in the experimental activity and analyses is at a critical level. Furthermore, there are growth pressures within the sector, since the advanced measuring systems to be commissioned also require new personnel resources to allow full-scale exploitation.

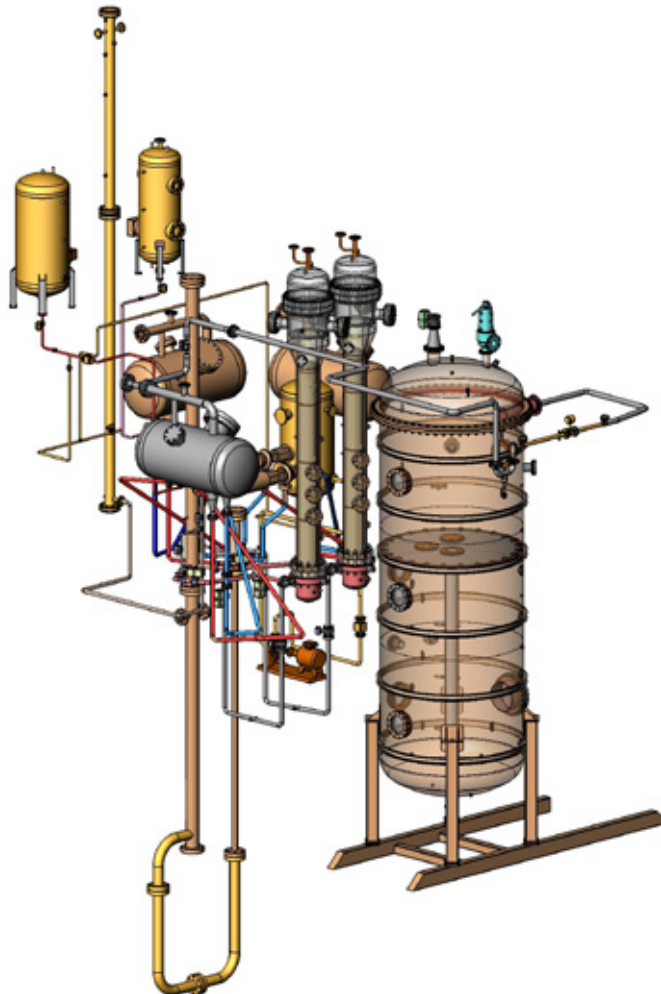
### **The Existing Test Facilities, LUT**

The PACTEL test facility, one of LUT's old integral test facilities still in use, was designed to model the Loviisa nuclear power plants. It is still the largest test facility in the world for modelling the VVER-440-type reactor. Since commissioning in 1990, some 250 separate experiments have been performed at the facility. The facility has later been upgraded with higher horizontal steam generators. In addition to national research, the facility has also been utilised for international projects. The facility enables studies of plant transients starting from almost full primary operating temperature of the plant, although the maximum operating pressure is 8.0 MPa. However, in practice, this does not limit the use of the facility.

For the purposes of EPR investigation, the PACTEL facility was complemented with vertical steam generators, the structure of which, when considering the limitations of scale and the laboratory premises, is as close as possible to that of EPR steam generators. One of the first experiments performed at the PWR PACTEL facility was used as transient data for calculation of an international blind benchmark.

The study of condensation pool phenomena in the context of boiling water reactors was initiated with an open POOLEX test facility, and its successor PPOOLEX is modelling both the dry well and the wet well phenomena of BWR containment under prototypical pressure. The results obtained at both test facilities have been widely used for development both of containment and of CFD codes.

**Figure 5.4.** The placement of PACTEL, PWR PACTEL and PPOOLEX test facilities at the research laboratory of Lappeenranta University of Technology.



LUT's experimental research capabilities also facilitate construction and operation of separate test facilities. The latest examples include testing devices for determining the heat transfer coefficient for the pressure vessel wall in connection with unintentional flooding of the reactor shaft; study of how insulation wool caught in the containment sump behaves in the emergency cooling circuit (figure 5.5); and investigation of the gas tightness of the float ball of the hydroaccumulator in connection with accumulator injection.

**Figure 5.5.** A full-scale filter element in LUT's containment sump experiment. The insulation wool in the circuit had accumulated in the filter element during the experiment. (Photo: Jani Laine).



### **Thermal Hydraulics in Severe Accidents**

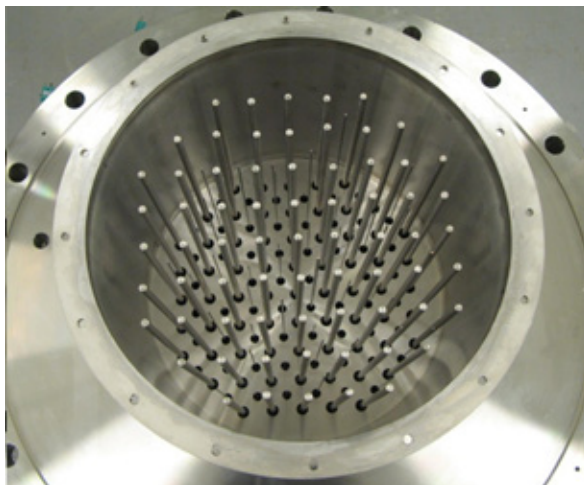
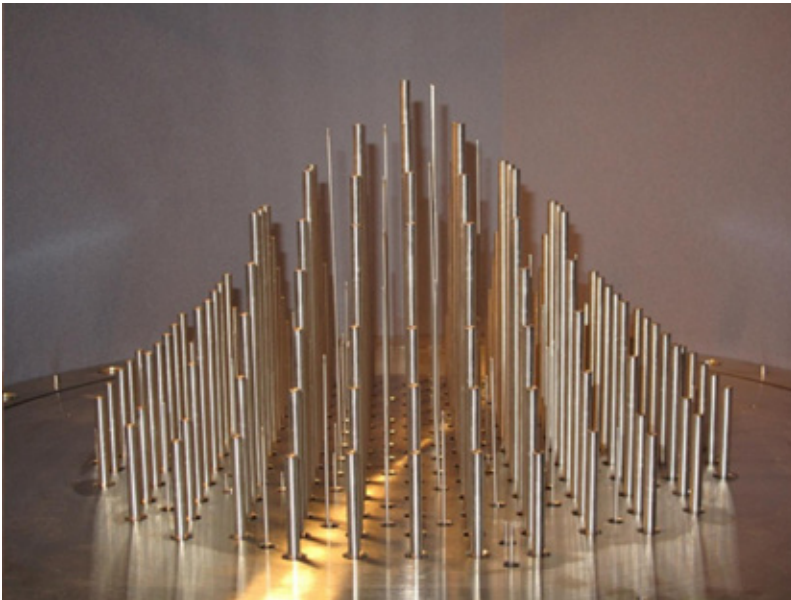
Flooding of the lower dry well of the containment building and cooling of the core material that has solidified into a particulate state on the bottom of the lower dry well is an important part of severe accident management strategy in Finnish and Swedish boiling water reactor power plants. Experiments have been performed exploiting VTT's COOLOCE (Coolability of Cone) facility to study the coolability of particle bed formed of core debris, see figure 5.6. COOLOCE experiments are used to investigate the effect of particle bed geometries by comparing the dryout power of conical (heap-like) and cylindrical particle beds. The objective is to take more precise account of the shape of the particle bed potentially forming in an accident. In addition, the test results are utilised for validation and development of software for coolability modelling.

In COOLOCE experiments, the coolability is determined by measuring the dryout power leading to local dryout of the particle bed (the dryout heat flux). This takes

place by monitoring the temperature of the test bed or heap, where the criterion used for dryup is increase in the temperature from the saturation temperature.

Decay heating power is simulated in the test facility by power transformers with a maximum output of 50 kW. The volume of test heaps is approx. 20 litres and the particle material consists of small, ceramic beads. In the facility assembly, the former STYX device has been used as far as practicable, but the particle bed section of the facility including the heaters and pressure vessels was fully modernised in 2009–2010.

**Figure 5.6.** The particle bed heating system of the COOLOCE facility and the thermocouples for determining the dryout power. The photos show the conical geometry (top) and cylindrical geometry (bottom).



### **Examples of Research Projects**

Along with national projects, LUT participates in international research projects that take advantage of the results of the experiments performed using its own test facilities.

The national research programmes and projects include SAFIR2014 and the NUCPRI and NETNUC projects of the Academy of Finland, while the major international projects are the EU projects NURISP and THINS and the Nordic NORTHNET. VTT also participates in the EU project SARNET in the field of severe accident research.

### **Software Used in Thermal-hydraulic Research**

Analysis software is used for the design of thermal-hydraulic test facilities and experiments, which in turn helps to develop the software itself. The key system software tools employed in Finland include APROS and TRACE, and versions of CATHARE2 and ATHLET codes are also available.

CFD tools, such as Fluent, CFX, Star-CD, NEPTUNE CFD, TransAT, open code software OpenFOAM, and VTT's own PORFLO, are also being exploited to an increasing extent. The development of own codes needs to be supported by experimental activity with sufficiently extensive instrumentation. The generally available test result data are often unsuited for the validation of CFD model codes.

The codes used for containment building modelling include APROS and CFD codes, as well as the CONTAIN code, while the GOTHIC code is also used in the Nordic cooperation context.

In addition to PORFLO, other thermal-hydraulics software tools used for severe accident analysis include MELCOR, MEWA, CORQUENCH and APROS-SA codes.

## **5.1.4 Inspection of Reactor Circuit Structures and Materials**

Safe use of nuclear reactors is heavily based on familiarity with the material properties and manufacturing techniques, as well as knowledge of their ageing behaviour. This presupposes experimental material research and introduction of new research methods. A major part of the material research is nuclear-specific, since the conditions, operating loads and material solutions used for research require familiarity with the test facilities and equipment and their definition.

### **Ageing Research of Reactor Materials and Damage Investigations**

Competence in material engineering plays a key role in ensuring safe operation of nuclear power plants throughout their life cycle. The current material engineering competence has developed according to the changing needs of the life cycles of the existing power plants. After ensuring structural integrity, phenomenon-based embrittlement research, environmentally assisted crack growth and propagation research, and establishment of experimental capabilities, the focus has shifted

with the ageing of the nuclear power plants to management of structural safety of the reactor circuit and ageing management. The objective of material engineering competence is reliable prediction of the progress of thermal ageing and of time-dependent damage mechanisms – such as radiation embrittlement, creep, corrosion and crack growth and propagation – in the power plant materials and structures over the planned lifetime of the plant.

The material engineering issues related to construction and future operation of new nuclear power plants, together with the needs of the existing ageing power plants, including the decommissioning of the plants and final disposal of spent fuel, will pose new challenges for the national competence in material engineering.

The management of structural safety and ageing of a nuclear power plant is based on identification of damage mechanisms, detection of damages and assessment of failure risks. Factors affecting the damage mechanisms and failure probability include the metallurgic structure (manufacturing and welding techniques, thermal and radiation ageing), environmental effect (pressure, temperature and water chemistry) and mechanical loads (thermal hydraulics and structural analysis). The management of structural integrity can be ensured by correct timing of non-destructive inspections and monitoring measures. The assessment of eventual failure risk is based on exploitation of the methods and analysis models of fracture mechanics.

From the national perspective, a significant research topic related to structural safety and ageing has been radiation embrittlement of the pressure vessel at the Loviisa nuclear power plant. To control radiation embrittlement the pressure vessel was successfully heat annealed, after which radiation embrittlement has been further monitored with help of special monitoring programmes. As concerns the new nuclear power plants under construction, monitoring programmes for radiation embrittlement of pressure vessels will already be drawn up while they are at the construction stage. Another research subject of national importance has been environmentally assisted crack growth under primary water circuit conditions. Even though stress corrosion of stainless steel in oxygenous water is currently a relatively well known phenomenon, improved knowledge of phenomena related to modernisation, power upgrade and lifetime extension of nuclear power plants is of central importance in the management of structural safety and ageing. In addition, it must be taken into account that the power plants under construction use new building materials and water chemistries that are not employed in the reactors currently in operation in Finland.

The future of nuclear energy is based on finding sustainable and acceptable solutions to environmental, efficiency and safety issues related to nuclear power plants. In the design of the new third generation reactor concepts emphasis has been placed on safety factors, while in the forthcoming fourth generation reactor concepts closed fuel cycles enable enhanced usability of fuel, reducing the amount of high-level waste needing final disposal. In the future, nuclear power based on fusion reaction may offer an acceptable solution, especially in terms of environmental issues. The



common feature of future nuclear power concepts is that their feasibility is based on the extended service lives of structural materials in particularly demanding nuclear power plant environments. Even though different reactor concepts have their individual special features, in terms of material engineering it should be noted that high temperatures, intense neutron radiation, and in-service loads define the rate of ageing and degradation and the employable inspection methods, which are often the same for all reactor concepts.

### **Current Status of Materials Research**

The present Finnish nuclear energy research infrastructure related to material engineering has evolved over more than 30 years from capabilities created for ensuring nuclear power plant safety and structural integrity. Finland has invested in experimental research of lifetime management, and in this connection VTT has accumulated significant competencies and infrastructure in fracture mechanics methodology and analyses, environmentally assisted cracking, water chemistry and NDE. In Otaniemi VTT maintains hot cell facilities and autoclaves that enable the study of low-level radioactive structural materials in environments simulating reactor conditions. Also placed in connection with these facilities are the NDE research devices used in assessment of the structural integrity of components by versatile non-destructive methods.

Apart from competencies in material engineering, VTT has also acquired strong expertise in the area of research equipment development. The sales and marketing of autoclaves and electrochemical tools based on VTT's R&D has been outsourced to Cormet Oy. In addition, VTT has developed pneumatic loading devices for mechanical stress and fracture mechanics testing and corrosion measuring in various simulated LWR and SCW environments and test reactor core environments. VTT also has capabilities for designing and building medium-size-scale test facilities for the needs of nuclear engineering experiments, such as LISSAC (pressure vessel head model specimen tests), STYX (particle bed coolability tests) and HECLA (thermo-chemical interaction between metallic melt and concrete).

VTT's material engineering research preparedness has been further developed for the needs of Gen IV and fusion research programmes. In the area of Gen IV, VTT participates in the material and research equipment development of SCWR (Super Critical Water Reactor) and LFR (Liquid Lead Reactor) concepts in particular.

In fusion research, VTT participates in experiments in first wall materials and materials irradiated in test reactors, as well as development of related equipment.

Material research linked strongly to nuclear energy is also conducted in various universities, such as Aalto University, Lappeenranta and Tampere Universities of Technology, and the University of Oulu.

In order for VTT's hot cell and autoclave research and other experimental nuclear research (radiochemistry, nuclear waste chemistry, filtration research and experimental fusion material research) to continue, these research areas

require urgent modernisation of their premises and partially also of their research equipment. Due to its notable costs, the development plan drawn up by VTT has been under deliberation at the national level for some time.

### **Examples of Research Projects**

VTT participates in several international research projects. The EU Framework Programmes in particular focus on large international Gen IV and Fusion projects, and participation in these makes it possible to increase research volume in such a manner that national targets can also be met.

National research programmes

SAFIR<sub>2014</sub>, KYT<sub>2014</sub>

NETNUC project within the Academy of Finland's SusEn programme

JHR MTR cooperation, the FUSION programme

International research programmes

EC Seventh Framework Programme projects GETMAT, PERFORM60, LONGLIFE and MATTER

NULIFE-NoE

OECD Nuclear Energy Agency's Halden Reactor Project.

## **5.1.5 Radiochemistry**

### **Laboratory of Radiochemistry of the University of Helsinki**

The Laboratory of Radiochemistry is one of the nine Department of Chemistry divisions of the University of Helsinki and the only unit of general radiochemistry in Finland. The nuclear research conducted at the laboratory is divided into three areas. The largest research area is the migration and retention of radionuclides dissolving from spent nuclear fuel in ground and bedrock. The second area is the development of inorganic ion exchangers for the purification of nuclear waste effluents. The third area is environmental radioactivity, involving the study of the behaviour in the environment and food chains of radionuclides originating from nuclear and mining operations.

The Laboratory of Radiochemistry research facilities include several class C radionuclide laboratories and two class B laboratories. The unit does not have a class A laboratory (hot cell laboratory), nor will such a laboratory be built. In spent nuclear fuel research, however, some use would probably be made of the class A laboratory of the VTT Centre for Nuclear Safety, being planned for Otaniemi. Unlike most European and U.S. universities, the Laboratory of Radiochemistry of the University of Helsinki is capable of processing practically all radionuclides, including transuranium elements. The processed amounts are small, however.

The Laboratory of Radiochemistry has a large variety of modern tools for detecting and measuring radiation, including 3 gamma spectrometers, 2 gamma counters, 4

liquid scintillation counters, 30 alpha spectrometers, and a whole body counter for measuring radioactivity within the human body. There is unique equipment for determination of rock porosity that can show the rock's pore structure and distribution on the desired plane surfaces; this technology is also currently being transferred to France as part of an EU project. The laboratory also has two nitrogen atmosphere glove boxes, facilitating study of the behaviour in deoxygenated environments of redox-sensitive radionuclides, and in a carbonate-free atmosphere of radionuclides forming carbonate complexes in liquids.

The Laboratory of Radiochemistry has one quadrupole ICP mass spectrometer that can be used for elemental analysis, such as determination of uranium and thorium contents. An ICP-OES will also be acquired in the near future for the purposes of elemental analysis. The laboratory uses its HPLC equipment for differentiating various shapes of radionuclides, i.e. speciation analysis. Researchers can also employ the high resolution magnetic sector ICP-MS equipment of the Geological Survey of Finland (GTK) in their studies. The Laboratory of Radiochemistry has a cyclotron used primarily for production of short-lived radionuclides as radiopharmaceutical tracers, although it can and has been used for production of radionuclides for nuclear waste research. The laboratory also has a particle size/zeta potential analyser for colloid research.

## 5.1.6 Structural Research

Structural safety relates to nuclear power plant buildings and engineered construction elements. Knowledge of the behaviour of the structures and structural components must be solid when designing, constructing or maintaining nuclear power plants. The need for structural inspections in nuclear research is great.

### IMPACT Test Facility at VTT

Figure 5.7. IMPACT test facility at VTT



VTT's IMPACT test facility is located in an underground research hall at Otaniemi, Espoo. The apparatus is used for producing experimental data on the behaviour of reinforced concrete structures under impact loads. The impact load is generated by accelerating a missile such that it hits a vertical concrete wall at the desired speed. The impact force caused by the missile can be measured when the missile is projected against a "force plate" instead of the wall.

It is presently possible to accelerate a missile weighing approximately 50 kg in such a manner that it hits the wall at the maximum speed of 170 m/s.

The test wall is mounted in a support frame that limits the span length to 2 metres and maximum thickness to 0.5 metres. The wall can be supported in one or two directions and can also be pre-stressed.

Measured quantities during testing include:

- impact speed of the missile;
- missile speed after penetrating the test wall;
- wall deflection;
- strains in rebars;
- strains on concrete surface;
- tensile forces in pre-stressed bars in case of pre-stressed walls;
- support frame reacting forces;
- liquid dispersal indicators and droplet sizes both for flying and fallen drops, if the missile contains water;
- the impact is videotaped using three high-speed cameras; and
- impact forces when using a "force plate" instead of the wall.

### **VTT's Earthquake and Vibration Testing Facility**

VTT has a hydraulic vibration table suited for vibration testing of small structures and electronic devices where large movements and low frequencies are required – see figure 5.8. A single run tests axial reciprocating movement in one direction only; items must be turned on the vibration table to test impacts in other axial directions. For vertical direction, in which the weight of the item may affect the result, the facility features a separate wall mounting. A pre-calculated free-form drive signal for the hydraulic actuator can be entered into the device in advance. This signal is typically an earthquake signal, a vibration signal caused by an aircraft impact, or some other required test signal.

Separate software tools can be used for example to calculate the drive signal corresponding to the acceleration response spectrum, and the corresponding response spectrum can also be calculated on the basis of the acceleration rates measured for the test item. The test standards generally employed include the GR-63-CORE for telephone devices and CEY/IEC 68-2-57, as well as earthquake signal standards drawn up by STUK regarding nuclear power plants located in Finland. During testing, the quantities that can be measured on the test item include

acceleration, displacement, stresses and forces. In addition, the test can be recorded by normal video and by a high-speed video at 1000 fps.

**Table 1.** Properties of the hydraulic vibration table.

Operating principle	Hydraulic single-axis vibration table
Max. stroke	420 mm (+- 210 mm)
Frequency range	0–20 .. 30 Hz
Max. actuator speed	1.3 m/s
Max. test item size	Width approx. 2 m, depth 1 m, height 2.5 m
Max. test item weight	Approx. 500 kg (depending on the test signal)
Sensors	16 channels, additional channels available
Analysis software and data acquisition board	LabView NI PCI MIO-16-4

**Figure 5.8.** VTT's hydraulic vibration table for earthquake testing.



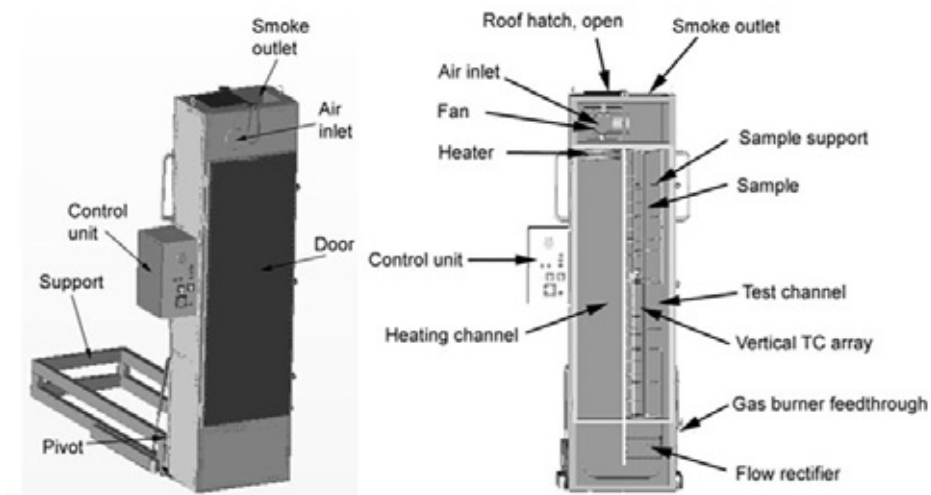
### **Flame Spread Measuring Facility at VTT**

VTT has developed both its experimental and computational capabilities in relation to fire safety of new nuclear power plants. A new experimental apparatus was developed in connection with the OL3 unit for studying the fire behaviour of modern electric cables. The apparatus can be used for measuring flame spread on cable surfaces in various temperature environments – see figure 5.9. In addition, test instrumentation for solid material experiments includes a cone calorimeter. The

services of VTT and Aalto University's chemistry departments have been exploited in small-scale materials testing (TGA, DSC).

Once the renovation of VTT's fire laboratory has been completed, larger samples can also be burned while simultaneously performing mass change and temperature measurements. However, the intensity of fire can be measured only from relatively small (less than 300 kW) fires in the SBI facility. For the purposes of computer simulations required for fire safety and aircraft impact analyses VTT has access to a computing cluster of 180 CPUs.

**Figure 5.9.** Flame spread measuring facility.



### 5.1.7 Behaviour of Fission Products in Accidents

When the containment building functions as designed, the fission product releases from the power plant to the environment remain relatively small even in a severe reactor accident. However, early or large releases are possible in containment bypass sequences. Fission product chemistry varies according to conditions determined by the release path and accident scenario, implying that fission product migration has to be modelled both in aerosol, gas and liquid forms when assessing bypass releases.

Finland currently performs high-standard experimental research on fission product release and chemistry. Test facilities built by VTT have been used for investigation of iodine and ruthenium transport in the primary circuit and retention on primary circuit surfaces, as well as generation of iodine in elemental form during irradiation. Other experiments have studied oxidation of iodine in containment and the effect of painted containment building surfaces on release of iodine.

The tightness of the containment building in severe accidents depends for its part on the durability of the sealing materials used for penetrations. Finland must

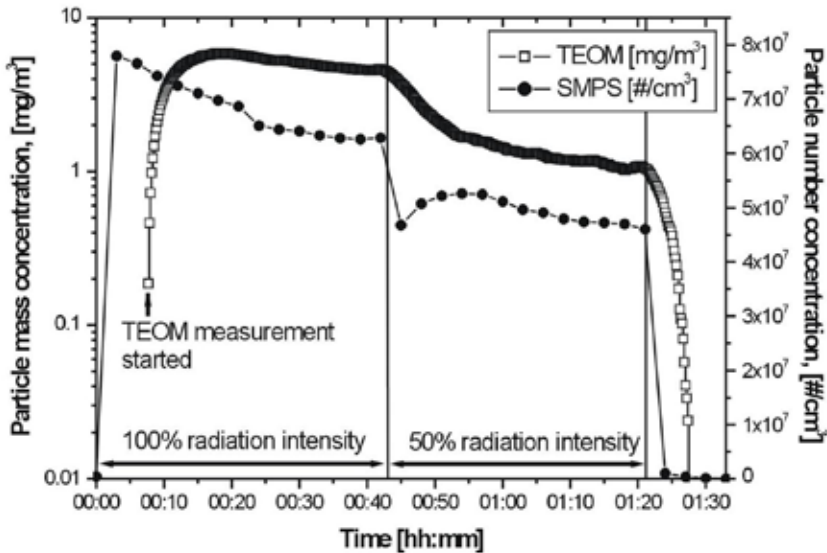
have the capacity to investigate sealant materials in circumstances corresponding to severe accidents (radiation, temperature, pressure).

### **EXSI Facility**

The EXSI experimental facility built at VTT is one of the latest additions to the research tools of fission product chemistry and release. The facility can be used for performing experiments in both primary circuit and containment environments. The apparatus enables measurement of the properties of fission products in aerosol form, such as size distributions and mass concentrations, and analysis of the elemental composition, structure and shape of particles. In addition, the facility enables identification of gaseous fission product compounds and measuring of their concentrations. It is also possible to measure, for example, the effect of different surfaces, types of radiation and gas mixtures on fission product behaviour. The facility and its automated sampling system are unique in the research field of fission product release. VTT has also manufactured a similar type of sampling device for IRSN's CHIP test facility, which investigates the reactions of gas-phase iodine.

So far VTT's EXSI facility has been exploited for investigation of radiolytic oxidation of gaseous organic and inorganic iodine in a containment building environment. Gamma, beta and UV(c) irradiation has been used in the experiments. Figure 5.10 shows an example of measuring results when gaseous organic iodine was exposed to UV(c) radiation in air. The experiment measured, for example, mass and quantitative concentrations of the iodine oxide particles formed as the radiation intensity was changed. Iodine chemistry has also been investigated in primary circuit environments. The high-temperature experiments studied, for example, the impact of different surfaces (such as steel and oxide) and other fission product and control rod materials on iodine release.

**Figure 5.10.** The figure shows graphs demonstrating the measured quantitative and mass concentrations of iodine particles as a function of time. In this experiment gaseous organic iodine was exposed to UV(c) radiation in air. Under irradiation, part of the gas was oxidised and formed aerosol particles. The mass concentration of the particles was measured with TEOM and the quantitative concentration with SMPS. Both concentrations increased as radiation intensity increased. The measurements were made using the EXSI facility at VTT.



### DIANA Facility

In severe accidents, aerosol particles are retained on containment building walls through various mechanisms depending on, for example, the size of the particles and flow conditions. One such poorly known mechanism is turbulence in natural circulation flow. This phenomenon can be modelled accurately by means of Direct Numeric Simulation (DNS) and Large Eddy Simulation (LES), but experimental data required for validation of the codes has not previously been available.

VTT has at its disposal a high resolution Particle Imaging Velocimeter (PIV) for severe accident analysis. The velocimeter can be used for accurate measuring of gas and particle movement in the natural circulation flow that emerges in the space between the hot wall and the cold wall. Initially, the results of these experiments will be used for the validation of DNS and LES models. It is also possible from these models to derive correlations demonstrating particle retention for more traditional CFD (Computational Fluid Dynamics) computation. With the growth of computer efficiencies, CFD computation is used increasingly for nuclear facility accident modelling.



## 5.1.8 Probabilistic Risk Analysis (PRA)

### Need and Current Status

In the evaluation of nuclear facility safety, deterministic accident analyses and probabilistic risk analyses (PRA) are used side by side so that the methods complement each other. PRA utilises computing codes developed specifically for this purpose. According to official regulations the licence applicant should take part in conducting the design phase PRA and the efforts to complement it during the construction phase, and ensure that PRA is performed and maintained during operation of the nuclear power plant. PRA computing codes are used not only in nuclear power plants but also in STUK's regulatory activities, and in VTT's research and development work and assignments.

The research and development of probabilistic risk analysis began in Finland in the 1970s, when VTT initiated a review and development of calculation and analysis methods for system reliability; the acquisition of necessary statistical and other data; and particularly application of these methods to reliability analyses of the nuclear power plants to be procured for Finland. The calculation methods and tools have developed significantly over the past decades.

Since the late 1980s the Radiation and Nuclear Safety Authority (STUK) has made major contributions to the development of a PRA tool of its own. The SPSA/FinPSA tool developed by STUK is used by TVO. Fortum, on the other hand, is using the Risk Spectrum PSA professional tool, which is one of the most widely used items of PRA software in the world. VTT uses both PRA tools for its own applications.

A topical issue in the near future is how to organise the maintenance and further development of the SPSA/FinPSA tool.

### Examples of Research Projects

VTT conducts research related to PRA development and application, for instance under the SAFIR2014 programme, and particularly in Nordic collaboration (NPSAG). Participation in EU-ASAMP2 and work in NEA's WGRISK working group can be mentioned with regard to international projects.

## 5.1.9 Infrastructure of Nuclear Waste Research

Three main phases can be detected in the organisation of nuclear waste management: nuclear waste processing, interim storage and final disposal. The research on nuclear waste management and the research infrastructure focus on the study of low-level (LLW) and intermediate-level (ILW) operating waste and decommissioning waste, and the investigation of spent nuclear fuel and its final disposal in the various main phases of nuclear waste management.

TVO and Fortum see to the organisation of all measures related to processing and final disposal of low- and intermediate-level operating waste and decommissioning

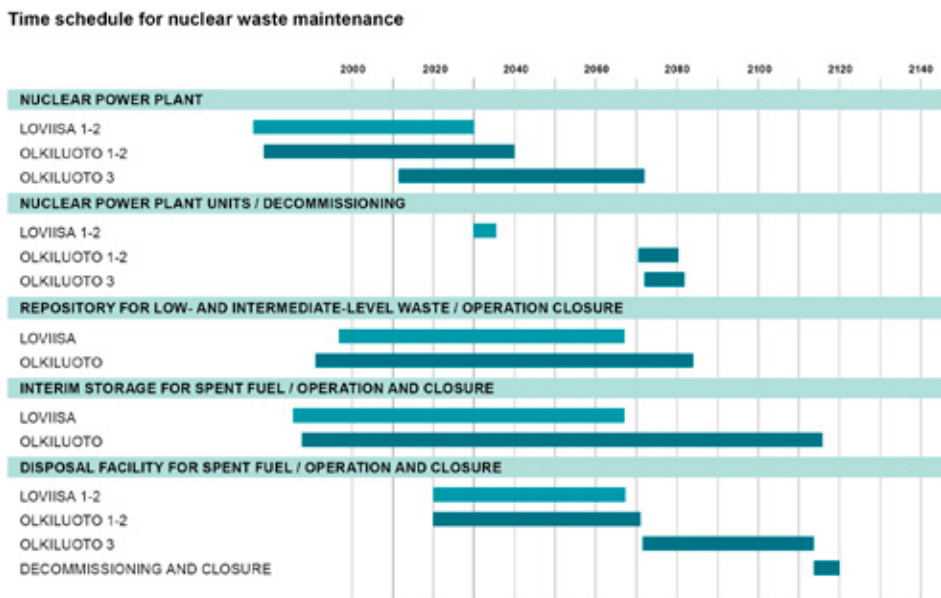
of their respective nuclear power plants. Both power companies have final disposal facilities for operating waste at the nuclear power plant site.

Research and development aimed at final disposal of spent nuclear fuel is performed by Posiva, owned jointly by TVO and Fortum, and the public KYT<sub>2014</sub> research programme administered by MEE. Posiva will later take care of construction and operation of an encapsulation plant and a repository for spent nuclear fuel.

Along with the Radiation and Nuclear Safety Authority (STUK), the KYT<sub>2014</sub> research programme is also responsible for production of research data related to regulatory functions, consisting of modelling and computation of different processes and related experimental research. The participants include Aalto University, the Geological Survey of Finland (GTK), the University of Helsinki, the University of Eastern Finland, the University of Jyväskylä, Ludus Mundi Oy, Numerola Oy and VTT.

The implementation schedule for nuclear waste management strategies of the nuclear power plants in operation and under construction is shown in figure 5.11.

**Figure 5.11.** The implementation schedule for the nuclear waste management strategies of the nuclear power plants in operation and under construction (Posiva 2009).



## Research Infrastructure for Disposal of Spent Nuclear Fuel

The following organisations in Finland possess research software, test equipment and underground research premises for research into final disposal of spent nuclear fuel:

- VTT (research capabilities for usability and lifetime management of materials, incl. NDT, and capabilities for the characterisation of bentonite)
- The Laboratory of Radiochemistry of the University of Helsinki,
- The Department of Physics at the University of Jyväskylä (tomography and flow laboratories)
- B+Tech (bentonite laboratories, research software and instrumentation)
- Posiva.

In addition, research laboratories of non-nuclear-specific organisations, such as Patria Aviation's EB welding equipment, can be used for nuclear waste management research.

Posiva, through a cooperation agreement, has the opportunity to exploit the encapsulation laboratory of Swedish SKB (Svensk Kärnbränslehantering AB), located in Oskarshamn, the underground research facilities of Äspö Hard Rock Laboratory (HRL), and SKB's bentonite laboratory located in Äspö. For individual cooperation projects Posiva also has access, for example, to the Grimsel rock laboratory in Switzerland.

For the purposes of confirming site investigations Posiva has built an underground rock characterisation facility, ONKALO, for collection of accurate data with a view to detailed design of the geological repository, and for assessment of related safety and construction engineering solutions – see figure 5.12. ONKALO facilitates testing of disposal techniques under realistic conditions. The construction of ONKALO was initiated in June 2004. The final disposal depth of 420 m has been reached during the ongoing construction phase. Two separate tunnels will also be excavated to a demonstration facility located on this level for studying both actual final disposal and the related modes of operation. The excavation at the depth of 437 m of technical auxiliary facilities needed for the operation of the repository was completed at the end of 2011. Research has been carried out at ONKALO since the beginning of the excavation process. Four research tunnels (research niches) have been excavated from the ONKALO access tunnel below the depth of 300 m for carrying out buffer, rock mechanics, hydrological and hydrochemical studies under conditions equivalent to those of final disposal.

**Figure 5.12.** ONKALO, the underground rock characterisation facility at Olkiluoto, Eurajoki. Aboveground structures of the Olkiluoto research site in summer 2007. On the left, entry of the ONKALO access tunnel, a building for tunnel technology, and a storage and maintenance hall. The ONKALO facility reaches a depth of 420 m. (c) Posiva Oy. Photo: Helifoto.



**Figure 5.13.** Posiva Oy's site investigation. Core drilled samples taken of the Olkiluoto bedrock, and other core samples collected for final disposal site investigation, are mapped and processed in the research hall located at the Olkiluoto research site. In the picture, processing of core drilled samples in 2007. (c) Posiva Oy. Photo: Sari Ojala.



Own patented research devices have been developed in connection with Posiva's site and ONKALO area investigations, including a PAVE device for collecting pressurised groundwater samples, and Posiva's Flow Log range of measuring devices (PFL DIFF and PFL TRANS) for groundwater flow measurements. In addition, charge potential measuring is applied in the Flowlog device in a novel manner. At the Olkiluoto site and in its immediate vicinity there is also an extensive microseismic monitoring network (18 measurement stations) and four forest-intensive monitoring plots related to biosphere description and assessment studies.

As well as access to the SKB encapsulation laboratory devices, Posiva has ultrasound inspection equipment of its own for the purposes of non-destructive inspection (NDT) of copper canisters. This equipment is located at the VTT premises in Otaniemi, Espoo. Posiva also has NDT inspection software licences for ultrasound and X-ray inspection devices.

In the course of several years VTT has invested systematically in research on coupled processes in the near-field environment of the final disposal facility, both experimentally and by modelling. The reason for this is that immediately after the closure of final disposal facilities several thermal, hydrological, chemical and mechanical gradients will prevail simultaneously in the conditions of the near-field environment. Coupled thermal-hydrological-chemical (THC) processes linked to the bentonite buffer have constituted a particular object of research. Young researchers have been trained as experts within the field in connection with the contributions made to coupled process research.

VTT has long experience in the use of controlled atmosphere glove boxes, which can simulate the anaerobic or reducing conditions of the final disposal facility. Six controlled atmosphere glove boxes are currently available for nuclear waste management research, using Ar atmosphere (previous use of N<sub>2</sub> atmosphere led to difficulty in controlling potential microbial activity). VTT has acquired high-resolution ICP-MS equipment for demanding analysis of low elemental concentrations. Research conducted into controlled atmosphere glove boxes has concerned, for example, leaching of uranium fuel in different conditions, and cement-bentonite interaction. VTT has just completed the design and testing of prototype equipment for studying the cementing action of bentonite. Cementing refers to sedimentation of dissolved compounds (silicon and aluminium) in bentonite, which reduces its swelling pressure and capacity.

VTT's test equipment is utilised for Posiva's research programme, the KYT2014 research programme and some EU research projects. VTT is currently involved in two nuclear waste management research projects with EU funding: CROCK (Crystalline rock retention processes) and REDUPP (REDucing Uncertainty in Performance Prediction, concerning the dissolution rate of spent nuclear fuel). The third project, BELBaR (Bentonite Erosion: effects on the Long-term performance of the engineered Barrier and Radionuclide transport concerning phenomena reducing the safety performance of bentonite release barriers), is at the negotiation stage. The KYT2014

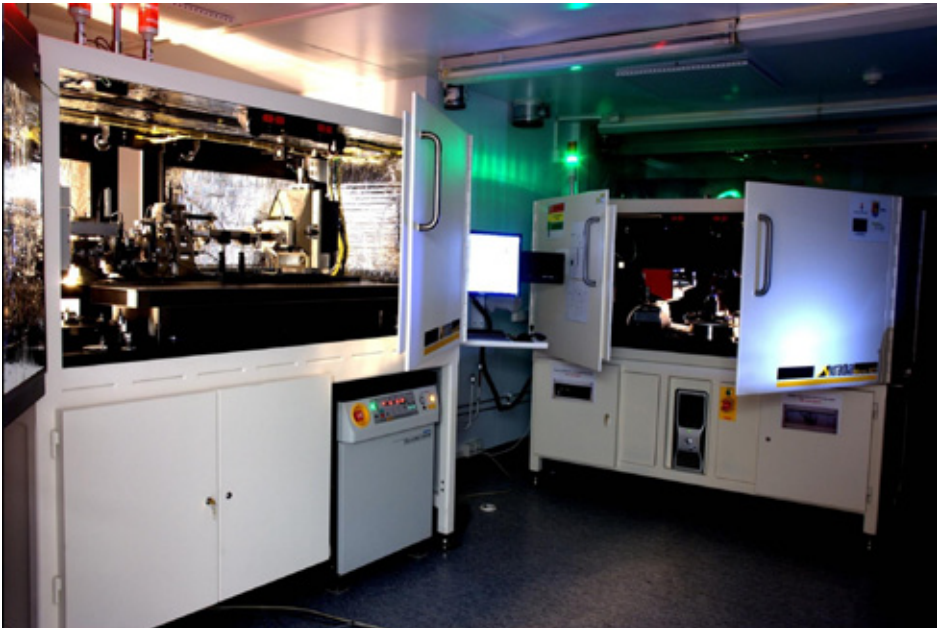
programme's BOA project (assessment of bentonite buffer properties) in particular is making a systematic review of the usability of the experimental methods available to the research consortium for investigation into bentonite microstructure. The BOA consortium consists of VTT (project coordinator), the Geological Survey of Finland (GTK), the Department of Physics at the University of Helsinki, the Department of Physics at the University of Jyväskylä, Ludus Mundi Oy and Numerola Oy. The microstructure research is closely associated with research into coupled processes, since a reliable image of the bentonite buffer structure is a prerequisite of reliable assessment of bentonite buffer processes.

B+Tech Oy specialises in experimental research and modelling of EBS (engineered barrier systems) components used for final disposal, particularly bentonites and other types of swelling clay, as well as design, manufacture, quality assurance and supply chain management from producers to end users. B+Tech Oy has currently three separate laboratory premises. One of these investigates chemical, mineralogical and physical properties of bentonite in a "traditional laboratory scale", conducting experiments such as swelling investigations on bentonite in pressure cells with inner diameter ranging from 24 to 100 mm, and chemical interaction tests. In addition, B+Tech Oy has two laboratories for larger-scale experiments and testing. Examples of such testing include thermal-hydrological-mechanical experiment related to saturation of the bentonite buffer in a test cell 35 cm in diameter and 80 cm in length. Furthermore, B+Tech has capabilities for studying mechanical clay properties using traditional geotechnical research methods, such as oedometer tests.

The Laboratory of Radiochemistry of the University of Helsinki, conducts research on the migration and retention of radionuclides leaching from spent nuclear fuel in bedrock and ground – see chapter 5.1.5. The research includes the use, for example, of equipment for determining rock porosity that can reveal pore structure and distribution.

The Tomography Laboratory of the Department of Physics at the University of Jyväskylä (figure 5.14) has three X-ray tomography devices with resolutions ranging from approximately 20 micrometres to 50 nanometres, together with the necessary sample processing equipment. Tomography imaging is used, for example, for structural analysis of bedrock samples, and study of the hydromechanical properties of bentonite. The flow laboratory has equipment for investigation of migration phenomena (flows and diffusion) in bedrock and bentonite, and for oedometric measurement of bentonite. The laboratory also has equipment for measuring the conductive porosity of rock samples (pycnometer). The particular objective of experimental research conducted at the Department of Physics at the University of Jyväskylä is to produce data on structural parameters, particularly those affecting migration, as well as to be employed for the purposes of modelling methods developed or being developed for assessment of the properties of matrix diffusion and the bentonite buffer.

**Figure 5.14.** A view of the Tomography Laboratory of the Department of Physics at the University of Jyväskylä. On the right, the Xradia MicroXCT 400 microtomography system and, on the left, an Xradia NanoXCT nanotomography device.

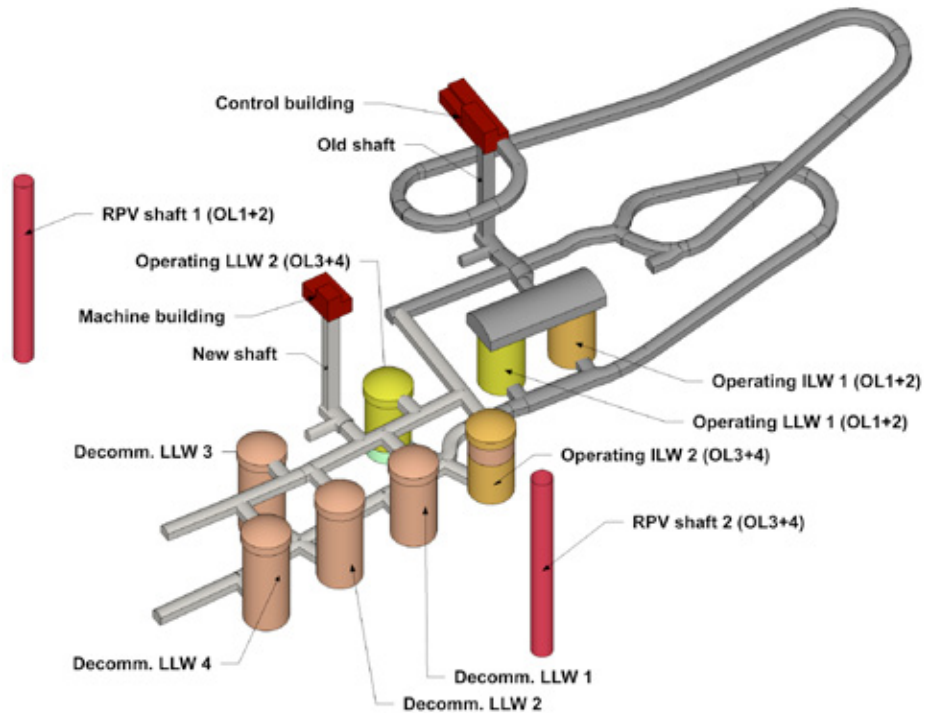


### **Research in the Underground Repository for Operating Waste (VLJ Repository) at Olkiluoto**

The use and expansion, as well as forthcoming closure, of the underground repository for operating waste (VLJ Repository) require continuous monitoring and research work. In-service monitoring is effected by means of rock mechanical, hydrological and geochemical measuring. Post-closure behaviour of the waste and long-term durability of the structures will be investigated through separate test series to be carried out with pilot scale equipment, and through long-term experiments in the bedrock. All experimental activities were moved in 2010 to the premises of the underground VLJ Repository.

The general structure of the underground repository for operating waste, the VLJ Repository, at Olkiluoto is shown in figure 5.15. The facility consists of an aboveground control room building, access tunnel, excavation tunnel, shaft, low-level waste silo (LLW silo), intermediate-level waste silo (ILW silo), a hoisting hall above the silos, and auxiliary facilities.

**Figure 5.15.** Structure of the VLJ Repository and planned modifications. The section of the VLJ Repository currently in use (Operating LLW 1 and Operating ILW 1) consists of two silos. Two new silos (Operating LLW 2 and Operating ILW 2) will be constructed during the operation of OL3 and OL4. At the decommissioning of nuclear power plants, separate vertical silos (Decomm.) will be built for the final disposal of decommissioning waste and reactor pressure vessels.



The in-service rock mechanical and hydrological monitoring of the VLJ Repository will be implemented in accordance with the bedrock research and monitoring programme drawn up for 2006–2017. This programme will ensure verification of the data for the safety analysis of the VLJ Repository and monitoring of the stability of the bedrock during the in-service period. The results of rock mechanical and hydrological monitoring of the VLJ Repository will be monitored annually:

- The bedrock stability has been monitored since the early stages of the excavation for the VLJ Repository by continuous rock mechanical measuring.
- In spring 1993, ten test bolts were installed in the VLJ Repository research tunnel for the purpose of investigating the corrosion rate of bolts to be used for rock reinforcement. The purpose of the experiment is to obtain knowledge of the corrosion resistance of galvanised rock reinforcement bolts. On the basis of results so far the corrosion rate has been found to be negligible.



- Hydrological monitoring of the VLJ Repository is implemented by observing, with the help of pumps and weir monitoring, the volume and quality of seepage water pumped out of the facility. Long-term monitoring results show that the total amount of seepage water is on the decline.
- Air quality is also studied in the VLJ Repository. The monitoring includes radon, temperature, humidity and CO<sub>2</sub> levels. In addition, the exhaust air from the underground facility is monitored for radioactivity.

A separate test facility has been built into the VLJ Repository for simulation of the post-closure situation in the intermediate-level waste silo (ILW silo), when the entire underground facility has been closed and has filled up with water. This gas generation experiment has been employed since 1997 for the study of microbiological degradation of low-level waste in disposal conditions. The experiment involves the waste being sealed into steel barrels and packed into a concrete box, which is then placed inside a 20 m<sup>3</sup> test tank filled with water.

This experiment will provide information on the volume and rate of gas generation from operating waste, and increase knowledge of the impact of microbial activity on the degradation process in disposal conditions. The transfer of radioactivity from the waste barrels into the surrounding water is also monitored. The results have been employed for the safety analysis of the VLJ Repository, which requires information on the gas generation rate of operating waste. In the long run, the gas generation rate has ranged from 60 to 90 dm<sup>3</sup>/month, an order of magnitude lower than estimated in the original safety analysis.

TVO and Fortum Power & Heat Oy launched a joint project in 1997 to investigate the long-term behaviour of concrete structures, to be conducted at the research facility of the VLJ Repository. On the basis of the experiment, assessments will be made on the long-term behaviour of concrete on the solubility and migration of radionuclides in disposal conditions, and on degradation of concrete in groundwater conditions similar to the in-service conditions. The goal is to determine the most durable concrete compositions under prevailing conditions that would fulfil the 60-year service life requirements set for the VLJ Repository. Data are also produced for the modelling of long-term durability of concrete.

The most significant damage mechanisms of concrete include carbonation, degradation, and the post-closure corrosion of steel in concrete caused by aggressive groundwater ions.

### **Research Infrastructure for Operating Waste**

The starting point for safety requirements concerning nuclear waste management is the capability to keep the waste isolated from living nature. The final disposal of nuclear waste is designed such that the safety of final disposal will not require supervision. TVO was granted permission to build a final disposal repository for operating waste (VLJ Repository) at Olkiluoto in 1992. Preparations are now being made for the needs of the new OL<sub>3</sub> and OL<sub>4</sub> power plant units. Both the final disposal

activities and their expansion call for establishment of a systematic research programme and its implementation.

Apart from spent nuclear fuel the operation of nuclear power plant units also generates low-level (LLW) and intermediate-level waste (ILW). Waste is generated during maintenance and repair work, and includes a variety of materials (plastics, paper, metals, wood, and materials used for various types of personal protective equipment). Waste is also generated in different water treatment systems (ion exchange resins and condensates from evaporation processes). Typically, the annual amount of waste generated during the operation of current plant units is from 100 to 200 m<sup>3</sup>.

### 5.1.10 Human Factors Research

The establishment of nuclear engineering infrastructure can also be justified, at least in an indirect manner, by arguments arising from the starting points of behavioural and sociological sciences. The first of these is associated with the basic fact that safe and efficient production of nuclear energy requires high-standard techno-scientific knowledge and theoretical, experimental and computational practices. International standards demand that each country engaged in nuclear power production develop and constantly maintain such competencies. Attending to these is part of good safety culture within this field of activity. Research – and particularly experimental activity, by which new knowledge is actively generated – is an important prerequisite for the acquisition of competence, for scientific education, and for the maintenance of the necessary standard of knowledge. The results of internal research activities are also essential for developing long-term and in-depth cooperation with international scientific and commercial actors.

Another justification for the need of nuclear engineering infrastructure, arising from the perspective of social and behavioural sciences, is that research facilitated by such infrastructure is closely linked with the competence for, and interest in, creating concept designs for new nuclear power plants. Concept design produces conceptualisations and basic outlines for nuclear and process technical solutions, on the basis of which future nuclear power plants are subsequently designed in closer detail. The starting points for management of the whole process are determined in the conceptualisation phase.

It would be important in the review of design principles to define quantities that will have an impact on the manageability of the system when it is being used in various phases of its life cycle. For example, the complexity of the system, or the temporal properties of its process events, are factors with essential impact on the manageability of the system. Decisions are made on the basis of these concerning the division of duties between automation and man, the quality and quantity of expertise required for various duties, and several issues related to cooperation. Multidisciplinary and integrated design produces a final product that rests on a safer

foundation. Design practices aimed at generating such planning can be established through experimental activity that reviews the basic phenomena and operation principles of nuclear facilities and of research environments that support such work.

The planned research infrastructure is most closely linked to the behavioural scientific research and development activity in the field of nuclear energy in the respect that it could offer opportunities for experimental research, development and testing of control room or other similar control centres or complex manipulation equipment taking advantage of virtual reality and other simulation techniques. The key actor in this area of research is the OECD Halden Reactor Project's (HRP) HAMLAB, in whose future-oriented research activities Finnish researchers of human factor issues have been involved. No other opportunities for participation in future development of control rooms and equipment have so far presented themselves. Attention was paid to the need of such experimental and more futuristically-oriented research in the international evaluation of the former SAFIR programme.

### **5.1.11 Accreditation in Automation and Information Technology**

The application of information technology has expanded to almost all equipment. In the future, IT competence will become emphasised in the design, construction and operation of nuclear facilities. This means exploitation of competence in programmable safety automation in all phases of the life cycle of a nuclear facility, as well as in design, manufacture, operation and decommissioning of various types of equipment. The short lifetime of new technologies compared to the safety technologies employed earlier gives rise to new challenges.

Finland lacks national infrastructure at present that would facilitate wide-ranging national evaluation of compliance with regulations concerning automation. This does not concern nuclear engineering competence alone, but also applies to conventional technologies. This competence area has connections not only to nuclear energy, but also to other industrial competencies. At the beginning of 2010 a new approach was adopted in the EU with an aim of achieving a single European internal market with regard to inspection bodies. As a result, the directives are drafted at a level setting only the general requirements necessary for protection of health and safety, while the more detailed technical requirements are set by the EN standards related to the directives. In Finland, the requirements of the directives have been incorporated into Government decrees.

Closer supervision of accreditation bodies and accredited inspection organisations is also related to the new approach in the area of traditional technologies. In the future, accreditation of inspection bodies requires essential standards of the field. These amendments also have an effect on the direction in which STUK's supervisory practices will be developed in the future.

In connection with the revision of STUK's YVL guides, the use of inspection organisations will also be expanded to cover areas other than pressure vessels. It is essential, with a view to implementation of the reform, that Finland establish an adequate infrastructure consisting of qualified inspection bodies and laboratories supporting their work. This kind of competence also has extensive applications outside the nuclear technology field, and plays an important role with regard to national competitiveness.

The laboratories supporting the work of inspection bodies must be actors at the international level and their number should be sufficient in all fields of technology. Areas of specialisation still lacking modern laboratories of international standard include information technology, data security, and fuel and material engineering.

There is a great need for research related to modern, software-based automation. This is not limited to nuclear facilities, but applies to other critical areas of infrastructure, such as energy distribution and other production facilities (e.g. food industry) of vital significance in emergency situations.

Ensuring functioning capacity requires both competence and experimental and research infrastructure. Currently, Finland does not have the appropriate experimental and research infrastructure for conducting objective testing within the field of automation technology.

## 5.2 Emergency Preparedness, Radiation Protection

STUK's Radiation Biology Laboratory conducts research on the biological effects of ionising and non-ionising radiation (mainly mobile phone radiation) and health hazard mechanisms. The particular research subjects include low-dose risks, individual sensitivity, indirect effects on cellular level, and reconstruction of radiation dose in humans (biological dosimetry). The laboratory has equipment for exposing tissues and cells to radiation, and devices and techniques for observing the effects of radiation, including microscopes, computer software and protein analysis equipment necessary for the analysis and imaging of cells and tissues. The methods of biological dosimetry are based primarily on microscopic analysis of biological markers emerging in blood lymphocytes.

The laboratory has at its disposal techniques for both short-span (exposure measuring) biological dosimetry and long-term reconstruction of radiation dose. The routinely used method, analysis based on dicentric chromosomes, is used for dose reconstruction in overexposure and actual accident cases, and is also provided as a service to customers. The minimum whole-body dose that can be detected using this method is approximately 100 mGy of low energy ionising radiation. The laboratory's capacity for rapid dosimetry measurements (the "triage" test method) is approximately 60 cases per week. Long-term biological dosimetry is based on analysis of stable chromosome aberrations, and is used in cases or populations in

which the exposure has taken place a long time ago or has been chronic – such as inhabitants and cleaning workers of Chernobyl, and nuclear power plant employees – and can detect doses of a few hundred mGy.

## 5.3 Testing and Inspection Facilities

### 5.3.1 Dosimetry Laboratory of the Radiation and Nuclear Safety Authority (STUK)

The task of STUK is to maintain the national measurement standards for radiation. In accordance with legislation, the scope of STUK's responsibility includes the measured quantities of ionising radiation and the non-ionising measured quantities relevant with a view to radiation protection. The ionising radiation quantities include absorbed dose, kerma (kinetic energy released in matter) and dose equivalent. Measurement standards are also maintained for other dose quantities with relevance for measuring activity, such as measured quantities of brachytherapy, and dose quantities of beta radiation and neutron dosimetry. In terms of calibration and measuring services for dose quantities, the primary customers include STUK units engaged in supervision of radiation use and biological research, university hospitals, nuclear facilities, and manufacturers and importers of irradiation equipment and radiometers. A list of key irradiation equipment used for production of calibration and irradiation services is provided in the following.

The overall area of laboratories dedicated for measurement standards operations is approx. 230 m<sup>2</sup>, divided into three irradiation rooms and one common control room for controlling the irradiation equipment. The radiation shielding walls are made of 70–120 cm thick concrete. The shielding ensures both measuring technical reliability and radiation protection of employees. The irradiation rooms are equipped with mechanically opened doors and extensive safety equipment for prevention of accidental exposure or unintentional use. The rooms feature standard air conditioning for keeping temperature and humidity within the desired range.

Gammabeam X200 (installed in spring 2011) is the latest addition to the measurement standards laboratory equipment, and this <sup>60</sup>Co irradiator also produces the highest dose rate available; the activity of the radiation source is 400 TBq – see figure 5.16. In the calibration geometry of radiotherapy dosimeters, the dose rate produced by the device at 10 x 10 cm<sup>2</sup> field size is approximately 1.5 Gy/min at one metre from the source.

**Figure 5.16.**  $^{60}\text{Co}$  gamma irradiator GBX200 with 400 TBq radiation source activity.



The Revolver irradiation device is used mainly for calibration and inspection of radiation protection meters. The device has eight separate gamma radiation sources ( $^{137}\text{Cs}$  and  $^{60}\text{Co}$ ) with various activity levels. The sources can be brought to the irradiation station one at a time, in which case the device emits a radiation beam with a circular cross-section. Air kerma rates at the distance of one metre are 0.7–140 mGy/h ( $^{137}\text{Cs}$ ) and 6–410 mGy/h ( $^{60}\text{Co}$ ). In addition to source selection, the dose rate can be controlled by adjusting the distance of the irradiation point from the source; distances up to 10 m can be used. Both the Revolver and Gammabeam irradiators are mounted on rails and can therefore be used in any of the irradiation rooms.

Seifert ISOVOLT HS X-ray equipment can be used for calibrating dosimeters used in X-ray diagnostics, radiation protection, and radiotherapy. The equipment is designed particularly for extended irradiation periods. Two separate X-ray tubes, with operating voltages ranging from 5 to 160 kV and from 5 to 320 kV respectively, have been connected to the Seifert ISOVOLT HS high voltage generator; the maximum output power is 3 kW. The energy distribution of photons emitted by the X-ray equipment is controlled by filters placed in the radiation beam, thus producing different radiation spectra. The dosimeter laboratory uses the ISO Narrow, ISO H, BIPM, RQR, RQT, MAM and DAP radiation spectra.

The diagnostic X-ray equipment (the CPI Indico 100 high-voltage generator and Comet DI 10 HS 22/52-150 X-ray tube) is used, for example, for irradiating biological samples, inspection of STUK's in-house radiation meters, and calibration of X-ray tube voltmeters. The device is mounted on a ceiling rack, which allows relatively free direction of the irradiation beam. The operating voltage range is from 40 to 150 kV, while the maximum output is 50 kW (100 ms exposure). At longer exposures, the maximum output is significantly lower. Two different focus sizes can be used for the X-ray tube.

## 5.4 Standardisation, Development of Competence

Standards form part of the regulatory framework in an ever larger area of application. The decree-level regulations only list the essential safety requirements in general terms, and the technical requirements are obtained from the standards related to the regulation in question. This is strongly visible in the EU area, where at the beginning of 2010 a "New Approach" was adopted in areas covered by ten Traditional Approach directives. These Traditional Approach directives cover pressure vessels, machinery, hoisting devices, and electrical and automation equipment, for example. The level of requirements established by them is the basic level of safety, on top of which the detailed regulations concerning nuclear technical devices will be set. For some devices in lower categories of safety the Traditional Approach requirements are sufficient in themselves.

The safety requirements concerning nuclear facilities are being harmonised, and their requirement standards will be stricter than before. In May 2011, the IAEA adopted new safety standards for nuclear facilities. These standards are consistent with the new safety requirements set by the Western European Nuclear Regulators' Association (WENRA). The requirements demand that in the design of any new nuclear facilities provisions are made not only for design basis accidents but also for so-called beyond design basis accidents which cover, for example, extreme weather phenomena and other rare external events, as well as reactor core melt. Such situations should be dealt with so that there is no need for emergency evacuation measures and that long-term environmental effects would be limited to the nuclear power plant site.

Finland has kept a low profile with regard to participation in standardisation activities related to use of nuclear energy. The fact that Finland does not have any manufacturing industry or equipment suppliers in the field has been regarded as valid justification. However, the establishment of a new type of binding effect on standards applied to traditional industry no longer provides support for this kind of justification, since in practice standards form part of the regulatory framework.

The facility and system level requirements are set by the IAEA Safety Standards and national nuclear safety regulation, which in Finland refers to the YVL

guides. Participation in standardisation activity means influencing the kind of detailed requirements set for nuclear facility systems, structures and equipment. Standardisation work also has – to use a nuclear technology term – a large “cross section”, because in global standardisation activities Finland has one vote, the same as any big country producing nuclear power plants.

Standardisation work translates into development of competence, and those participating in this activity can effectively forecast future changes.

With a view to technical development within the field, initiation of the drafting of different types of Best Available Technology (BAT) reports is of primary importance. These reports provide a review of the current state of technology, and background information on the activities of inspection bodies and licence holders, as well as authorities. The actual process of drawing up these reports enhances competence within the area covered by each report. A similar procedure is in use in several fields of traditional industry where application of BAT technologies is required.

Accordingly, Finland should expand the organisation of standardisation work and drafting of BAT reports to cover a wider range of nuclear technical applications. The activities of the working groups of the Mechanical Engineering and Metals Industry Standardisation in Finland (MetSta) or groups chaired by the Finnish Standards Association (SFS) would be applicable to several product groups, but the nuclear technical standardisation activities should also be expanded further and made more systematic.

## 5.5 Planned National Infrastructure

### 5.5.1 VTT Centre for Nuclear Safety

A major part of VTT’s nuclear engineering research is conducted in the premises located at 3 Otakaari in Espoo. The main research topics are the characterisation and fracture mechanics of active structural materials (hot cell), radiochemistry, final disposal of nuclear waste, dosimetry and other nuclear technology experimentation, first wall material research for fusion reactors, and iodine filter testing. The modelling personnel for nuclear waste research and fusion reaction also work in the same premises, and the operations of the research reactor FiR 1 are supported by the house. The premises were built in the 1970s specifically to meet the needs of nuclear technology, but the overall condition of the premises, space solutions badly suited for present operations, and a general lack of space have given rise to surveying the potential for new premises. The equipment, particularly that used for hot cell activities, is also in need of modernisation.

Over the past few years VTT has commissioned surveys concerning transfer of these activities to other premises, until a decision was made to conduct a thorough investigation into construction of a new building and modernisation of research equipment. On the basis of the conclusions drawn in the Senate Properties space



requirement and project plan, drafted in collaboration with VTT, the primary alternative was to place the abovementioned experimental facilities and operative personnel, together with the personnel engaged in computational nuclear safety assessment – some 150 people in total – in the same premises, which would be built on Kivimiehentie at Otaniemi, Espoo. The factors in favour of the location include synergies with other VTT research facilities, and the vicinity of Aalto University and other actors within the field.

Attention has been paid in the design of the premises to adaptability and ease of maintenance. A further aim is to make provision for new experimental research needs that cannot be known at this point. The overall living area of the premises in the primary alternative is approximately 4,500 m<sup>2</sup>, with a gross area of some 8,400 m<sup>2</sup>. The building expenses at 2010 cost level would amount to approximately 25 million euros, in addition to which outfitting of the hot cell facility would require a further 8–10 million euros. The higher-than-normal building expenses of the experimental facilities are due to the radiation safety requirements. Efforts will be made to design the premises for several decades of use, corresponding to the currently known duration of the Finnish nuclear energy programme.

The time of construction of new infrastructure with regard to research premises is about 4 years from the construction decision. The plan is to acquire most of the equipment for the hot cell facilities, the actual hot cells, manipulators and research equipment in advance, so that operations could be moved from the old to the new premises without major disruptions. The goal is to move other experimental research equipment from the existing premises mainly as they are.

The reform of the research infrastructure will also lead to significant recruitment and training needs of new personnel. VTT is already making major investments in this area of operations and will increase its contribution as the project progresses. VTT intends to provide services for key national actors in particular, but efforts will also be made to increase international activities as the market situation allows.

In discussion involving nuclear field actors conducted under the steering of the Ministry of Employment and the Economy, decisions were made to cover the additional costs primarily from the research allocations of the State Nuclear Waste Management Fund (VYR), which will need to be temporarily increased through amendments to the nuclear energy legislation. However, a significant part of the additional costs will need to be covered by VTT by means of more efficient and increased research activities. The scientific steering of the project has been linked to the National Nuclear Power Plant Safety Programme (SAFIR2014).

In the meantime, while this report was being written, VTT has made a preliminary construction decision on the Centre for Nuclear Safety.

## 5.5.2 LUT

Construction of new laboratory premises for Lappeenranta University of Technology's (LUT) nuclear-related heat transfer and fluid dynamics research has been completed, which also enables the construction of new experimental facilities requiring substantial vertical space. The former laboratory premises, which are practically fully taken up by PACTEL, PWR-PACTEL and PPOOLEX experimental facilities, are also still in use.

The experimental capabilities of LUT will be further improved by the acquisitions of, for example, PIV equipment, and an up-to-date high-speed camera. The range of other measuring instrumentation has also been supplemented, with a view to using them flexibly with various research facilities. These supplementary acquisitions were facilitated by infrastructural funding from the Academy of Finland and the SAFIR<sub>2014</sub> research programme. Further efforts will be made over the coming years to ensure that research tools offer increasing versatility and remain up-to-date, with the aim of producing high-level research data for developing CFD software models, for example, particularly for nuclear power plant applications.

When required, LUT also has competence in rapid development and production of separate effect test facilities, and this opportunity has been exploited by authorities, power plants and plant suppliers in their R&D projects and safety assessments.

**Figure 5.17.** The new laboratory hall of heat transfer and fluid dynamics at the Lappeenranta University of Technology for nuclear-energy-related experimental research. Photo: Timo Mikkola.



## 5.6 The International Infrastructure Available for Finland

Finland has several links to international research projects and facilities in the area of nuclear power plant safety research. One such example is the OECD's Halden research reactor, facilitating participation in international fuel and reactor materials research and man-technology-organisation research. The hot cell facilities of Studsvik Hot Cell Laboratory are exploited for the Cladding Integrity Project (SCIP). The numerous OECD/NEA experimental projects take advantage of research facilities worldwide.

CEA has four experimental facilities in Cadarache, France, for investigating severe accident phenomena on real reactor materials. VULCANO equipment is able to melt up to 100 kg of corium and study molten core interaction with concrete, for example, or the spreading of corium in the core catcher. The KROTOS facility is dedicated to studies in steam explosion phenomena. The COLIMA (a few kilograms) and VITI (max 0.1 kg) facilities have been built for studying physical and chemical properties of molten materials and measuring aerosol release. The facilities in Cadarache are also available for Finnish users. Using the VULCANO facility, VTT has performed one EU- and SAFIR-funded experiment on molten core interaction with EPR concrete. CEA will be an even more important cooperation partner in the future due to the Jules Horowitz Materials Testing Reactor (JHR) currently being built in Cadarache.

### **Jules Horowitz Materials Testing Reactor (JHR)**

Under VTT steering, Finland participates in the design and implementation of the new Jules Horowitz nuclear reactor intended for European material research. The purpose of JHR is to replace ageing research reactors and create investigation preparedness for future nuclear reactor technologies. The JHR reactor will be constructed in Cadarache, France between 2008 and 2015. The power of the reactor will be 100MW. The reactor is commissioned by the French research organisation CEA (Commissariat à l'énergie atomique et aux énergies alternatives). VTT is part of the international consortium that is producing research instrumentation for the reactor in a so-called 'in-kind' project. The other research parties in the consortium are CIEMAT (Spain), SCK (Belgium), NRI (Czech Republic), DAE (India) and JAEA (Japan). Other participants include EdF and AREVA from France, Vattenfall from Sweden, and the European Commission.

The Finnish in-kind contribution will be implemented as a Tekes project with funding from Tekes and VTT, as well as contributions from Teollisuuden Voima, Fortum, Fennovoima and Posiva. In addition, Oxford Instruments Analytical will take part in the project in terms of instrumental design, with VTT as a supplier, and the Radiation and Nuclear Safety Authority (STUK) as the expert organisation of the Ministry of Employment and the Economy.

VTT will supply measuring instrumentation for the reactor worth 10 million euros at the 2005 currency rate. The plan is to design and supply three measuring device entities in collaboration between VTT and CEA:

1. Underwater gamma spectrometry and X-ray radiography systems in both the reactor pool and the spent fuel storage pool. These are some of the key JHR measurements to be made for obtaining data on burn-up and radioactivity levels of various types of fuels. The purpose of the measurements is to investigate the behaviour of fuels in a certain kind of construction intended, for instance, for future reactors, or the generation of radioactive degradation products in fuel.
2. Gamma spectrometry and X-ray radiography systems in the hot cells. Similar measurements are made in the hot cell facility to those in the reactor pool, but in the hot cell it is possible to study single fuel rods instead of fuel rod bundles.
3. Mechanical loading device for material property studies in the reactor core. The servo-pneumatic mechanical loading device enables mechanical material studies in the reactor core under the influence of radiation. This will provide information about the effects of radiation on the durability of materials, which is critical information with a view to reactor and reactor components design and assessment of power plant ageing.

The systems to be delivered will be designed in collaboration involving VTT, CEA and the subcontractors selected by each organisation. The technical contents of the in-kind delivery were fixed and the preliminary design made during the first phase of the in-kind project - the feasibility phase - which was implemented in 2008-2011. The next phase of the project - the design phase - including the final technical design of the systems, will be executed in 2011-2013. The manufacture, testing and mounting of the systems in the reactor will take place between 2013 and 2015.

A major part of the design and manufacturing work will be subject to an international tendering process. The goal is to include Finnish suppliers in the in-kind delivery as far as applicable, although the French nuclear safety regulations to be applied to the project may have an influence on the willingness of Finnish actors to participate in the tendering process.

Finland will have access through this participation to two per cent of the reactor's research capacity and to research programmes of the consortium. Participation in projects such as this improves the competitiveness of Finnish nuclear energy technology and gives Finnish actors access to knowledge that would otherwise be unavailable to them.

Fuel research presupposes both suitable test reactor preparedness and hot cell facilities suitable for the investigation of fuels. From the Finnish perspective, the nearest such test reactor is located in Halden, Norway ([www.ife.no/hrp](http://www.ife.no/hrp)), although this facility lacks hot cell capabilities. Fuel rods under study must therefore be transported to hot cell facilities in Studsvik, Sweden ([www.studsvik.se](http://www.studsvik.se)), for example, or to similar research laboratories available elsewhere. Fuel research requires special

capabilities and competencies from hot cell facility protection and analysis devices. There are no plans to build such capabilities in Finland due to their extremely high price and relatively small national demand. Networking with international research institutions is a good solution, and also feasible because investigation of fuel samples can thus be effected in a systematic manner. Issues related to transport of fuel samples have also been solved. France, Germany and Switzerland also have reasonably good capabilities for fuel research. The cost of fuel research is high, and leads in most cases to a larger consortium being put together for research projects, including the involvement of fuel manufacturers.

## 5.7 Recommendations

National research activity related to the use of nuclear energy and relevant competence is an essential basis for the safe use of nuclear energy.

The development of national capabilities and their sufficiently extensive exploitation calls for long-term planning and engagement, as well as adequate knowledge of the field and international cooperation. With regard to the development of capabilities, national coordination improves the opportunities for their versatile use.

Research programmes and large research projects with various actors support coordination efforts and establish a natural framework for further development.

Reform of the ageing research infrastructure requires significant national contributions. The most critical situation is the current state of VTT's nuclear engineering research premises and facilities, where immediate steps need to be taken in order for these operations to continue.

Additional investments in experimental research infrastructure will ensure that Finland will be able to react rapidly to potential problem situations. Internal research will supplement the internationally accessible research data and make it possible to give own contributions to ensuring the operability and development of safety systems.

International cooperation requires sufficient resources and adequate research-orientation. However, international cooperation is crucial with a view to research, since with the help of such activity it is possible to expand competencies and research capabilities and gain access to significant research results. International cooperation is also a way of ensuring that the standard of national competencies remains sufficiently high, and that access is secured to information on the latest opportunities and research needs.

Research capabilities and competencies also constitute the basis for the research services needed at the national level for the purposes of the use and modernisation of nuclear facilities and construction and licensing of new power plants. In other words, the national features and requirements should be taken into account to a sufficient extent in the development of research capabilities.

# 6 Finnish Participation in International Research Activities

## 6.1 Objectives and Extent of Participation

Finland participates in international research activity on a relatively broad front. In a small country, not all research can be conducted independently, nor would it be practicable. Test facilities used for nuclear power plant safety research are so large that it would be unreasonable to expect any one country to build such facilities on its own. It also includes facilities owned by one big country that are, however, used for extensive international test programmes and that other, typically small member states can use for their own testing purposes (“transnational access”).

Participation in international research activity and research networks offers Finnish nuclear field actors an effective opportunity to become a part of the Nordic, European and global research and training community, as well as access to the latest research information and research infrastructures.

Finns are valued cooperation partners in the abovementioned networks. The financial and personnel resources required by research are so massive that it would not be possible to obtain the desired outcomes by acting alone, or at least not within the current schedule. The value of international research has been recognised, and Finns are also acting as important contributors in the new European research and technology platforms SNETP (nuclear energy), IGD-TP (nuclear waste management), and the technology and research groups of radiation protection EURADOS, MELODI, NERIS and Radioecology Alliance, covering the various fields across the entire nuclear energy sector.

Regarding Finnish participation in international research activity within the field of nuclear power plant safety, the volume and significance of OECD/NEA and EU Euratom projects is by far the greatest.

The volume of Nordic NKS projects is small in comparison with both the international projects mentioned above and also with typical projects included in the national programmes.

In IAEA cooperation, the main focus is on participation in various working groups and committee activities. OECD/NEA also has committees and working groups of various types.

The significance of technology and research communities in international research cooperation is growing strongly, and is expected to generate a rise in the volume of international nuclear energy cooperation to a totally new level compared to the present Euratom Fission Programme’s annual budget of some 50 million euros.

Universities and research institutions also have bilateral cooperation agreements, some of which are mentioned here as examples, where they have been publicly

announced. It must be noted that a large share of bilateral agreements, particularly involving companies, is confidential and will not be discussed in this context.

There are several taskforces and committees of various kinds in the projects of all stakeholder groups. These will not be presented in detail in the following. The list of international contacts in the field of nuclear power plant safety, maintained for the SAFIR2010 programme annual reports, recognised 22 OECD/NEA committees and working groups in addition to actual projects, three Generation IV International Forum working groups, five IAEA committees or working groups, 16 EU and Euratom committees or working groups, and some 70 other committees, working groups or other international contacts.

## 6.2 OECD/NEA Projects

The Organisation for Economic Cooperation and Development (OECD) is an intergovernmental organisation of industrialised countries, with the Nuclear Energy Agency (NEA) acting as one of its agencies. The membership of the organisation, based in Paris, France, consists of 30 countries.

Table 6.1 lists the most significant OECD/NEA research projects currently involving one or more Finnish organisations. One project is currently being implemented in the field of nuclear waste management and one in the area of radiation protection. Most of the projects in table 6.1 are related to nuclear power plant safety research, and VTT is engaged in them as an official contracting partner that reports to other national stakeholders. In the MEE authorisation to participate, most of these projects have been attached to a SAFIR2014 programme research project, where the parties participate not only in follow-up but also, for example, in benchmark calculations, and the reporting to other national stakeholders is implemented through the research programme. The participation fees for these projects come either directly from the MEE, from VYR funding or from some other power company funding, while VTT contributes to funding of the follow-up process. In a typical OECD/NEA project, experiments are made in massive test facilities and the participants use the test results for the development and verification of their internal calculation methods.



**Table 6.1. OECD/NEA projects**

Area	Abbreviated name	Topic	Finnish participating organisations	SAFIR2014 reporting
Radiation protection	WPMM PRD	Radiation damage	VTT	No
Nuclear waste	Sorption project III	Sorption of radionuclides in bedrock	Posiva/University of Helsinki, Laboratory of Radiochemistry	No
Nuclear safety	BIP-2	Behaviour of fission products	VTT	Yes
Nuclear safety	Halden (several projects)	Fuel, materials, control room and human factors	VTT, power companies	Yes
Nuclear safety	IAGE	Ageing of concrete structures	VTT	Yes
Nuclear safety	IRIS Benchmark	Construction safety	VTT	Partly
Nuclear safety	PKL-2	Thermal hydraulics	VTT	Yes
Nuclear safety	PRISME	Fire safety	VTT	Yes
Nuclear safety	ROSA-2	Thermal hydraulics	VTT	Yes
Nuclear safety	SCIP-II	Fuel cladding	VTT	Yes
Nuclear safety	SERENA-2	Severe accidents	VTT	Yes
Nuclear safety	SETH-2	Severe accidents/hydrogen management	VTT	Yes
Nuclear safety	THAI-2	Severe accidents (project not yet initiated)	VTT	Yes

Several database projects with Finnish involvement are also implemented within OECD/NEA. These are compiled in table 6.2. The projects collect information on various nuclear power plant incidents and component failures. The information collected is typically confidential. In most of these projects the official Finnish contracting party is STUK. Power companies providing their own information for the databases also have access to the data. As a general rule, the access of research institutions to the data is determined on a case-by-case basis.

**Table 6.2. OECD/NEA databases**

	Abbreviated name	Topic	Finnish participants	SAFIR2014 reporting
Nuclear waste management	TDB	Thermo-chemical database	Posiva	No
Nuclear safety	COMPSIS	Operating experience concerning computer-based systems important to safety	STUK, power companies	Partly
Nuclear safety	FIRE	Fire safety	STUK	Partly
Nuclear safety	ICDE	Common cause failures	STUK, power companies	Partly
Nuclear safety	ISOE	Information systems and radiation doses	STUK	Partly
Nuclear safety	OPDE	Pipe failures	STUK/ VTT, power companies	Partly
Nuclear safety	SCAP	Stress corrosion cracking and cable ageing	STUK, power companies	Partly
Nuclear safety	EXFOR	Neutron and charged-particle reactions	VTT	No
Nuclear safety	NEA Data Bank	NEA computer software	VTT	Partly
Nuclear safety	ICSBEP	NEA criticality safety evaluation database	VTT	Partly

There are also several committees operating under the auspices of OECD/NEA which may have several subgroups working under them. Table 6.3 lists the key committees with Finnish participation.

In the area of nuclear waste management, OECD/NEA has various types of cooperation groups operating under the Radioactive Waste Management Committee (RWMC). The most important of these include the Forum on Stakeholder Confidence (FSC), the Integration Group for Safety Case (IGSC) and the Working Party on Decommissioning and Dismantling (WPDD). In terms of nuclear power plant safety, CNRA, CSNI, NDC and NSC have several working groups. The Finnish participants in the OECD/NEA working groups are MEE, STUK, VTT, Posiva, Fortum and TVO.

**Table 6.3. Key OECD/NEA committees with Finnish involvement.**

Area	Abbreviated name	Topic	Finnish participants	Number of working groups
Nuclear safety	SC	NEA Steering Committee	MEE	0
Nuclear waste management	WPDD	RWM Working Party on Decommissioning and Dismantling	TVO, Fortum, STUK	0
Nuclear waste management	RWMC	Radioactive Waste Management Committee	MEE, STUK, VTT, Posiva	3
Nuclear safety	CNRA	Committee on Nuclear Regulatory Activities	STUK	4
Nuclear safety	CSNI	Committee on the Safety of Nuclear Installations (CSNI)	STUK, VTT	8
Nuclear safety/ Radiation protection	CRPPH	Committee on Radiation Protection and Public Health	STUK	0
Nuclear energy	NDC	Nuclear Development Committee	MEE, STUK, Fortum, GTK	4
Nuclear safety	NSC	Nuclear Science Committee	STUK, VTT	5
Nuclear safety/ Radiation protection	ISOE	Information System on Occupational Exposure	STUK	0

In addition, OECD/NEA may initiate new separate projects within certain areas, such as separate technical databases; organise benchmarking projects serving the purpose of computer software verification; and convene data exchange and development committees within various fields, the results of which are disseminated as OECD publications ([www.nea.fr](http://www.nea.fr)).

## 6.3 EU Euratom Projects

Finnish participation in EU fusion research is described in chapter 4.1.3. Finland has long traditions in participation in Euratom projects, dating back to the Fourth Framework Programme.

Finnish organisations are currently participating in 36 Euratom fission projects in progress or in negotiation phases under the Seventh Framework Programme.

The projects are divided as follows:

Area	Number of projects	Participating organisations
Radiation protection	9	STUK
Nuclear waste management	10	Posiva; VTT; University of Helsinki, Laboratory of Radiochemistry
Nuclear safety	15	VTT, LUT, University of Jyväskylä, University of Helsinki, Aalto
Other nuclear energy related fields	2	University of Helsinki, Laboratory of Radiochemistry; University of Jyväskylä, Department of Physics

The Euratom projects identified in the survey held by the Committee for Nuclear Energy Competence in Finland are listed in table 6.4. The Euratom budget for fission-related research is only around 50 million euros, including management of radioactive waste, radiation protection and the safety issues of both the present and the new generation Gen IV reactors. In other words, the projects are typically quite small in relation to the number of the partners involved, especially in terms of the safety of the existing power plants.

Experience shows that the project schedules have also been difficult to predict, and adaptation of projects to other schedules and requirements, especially the VYR funding conditions, has been found difficult. In terms of administration, therefore, the projects have generally been kept separate from national research programmes. Owing to the confidentiality clauses of the projects and their separation from national information forums, only a limited amount of people have been informed about the work carried out within these projects and the results obtained, compared to OECD/NEA projects, for example. Administrative information about the ongoing project entities has spread somewhat through the national Euratom project reference group, but no information has been available on the substance of these projects.

**Table 6.4.** EU Euratom Fission projects with Finnish involvement.

Area	Abbreviated name	Topic	Finnish participants	Coordinator
Other nuclear energy	ANDES	Research on the properties of nuclear energy related cores	University of Jyväskylä	CIEMAT, Spain
Radiation protection	DETECT	Design of optimised systems for monitoring of radiation and radioactivity in case of a nuclear or radiological emergency in Europe	STUK	SCK-CEN, Belgium
Radiation protection	DoReMi	Low Dose Research towards Multidisciplinary Integration	STUK	STUK, Finland
Radiation protection	EPI-CT	Epidemiological study to quantify risks for paediatric computerised tomography and to optimise doses	STUK	CIDRC, France
Radiation protection	EpiRadBio	Combining epidemiology and radiobiology to assess cancer risks in the breast, lung, thyroid and digestive tract after exposures to ionising radiation with total doses in the order of 100 mSv or below	STUK	HMGU, Germany
Radiation protection	NERIS-TP	Towards a self sustaining European Technology Platform (NERIS-TP) on Preparedness for Nuclear and Radiological Emergency Response and Recovery	STUK	KIT, Germany
Radiation protection	NOTE	Non-targeted effects of ionising radiation	STUK	STUK, Finland
Radiation protection	STAR	Strategic Network for Integrating Radioecology	STUK	IRSN, France
Radiation protection	CARDIORISK	The mechanisms of cardiovascular risks after low radiation doses	STUK	TUM, Germany

Radiation protection	RENEB	European network of biological dosimetry	STUK	BfS, Germany
Nuclear waste management	BELBaR	Bentonite Erosion: effects on the Long term performance of the engineered Barrier and Radionuclide Transport	Posiva, VTT	SKB, Sweden
Nuclear waste management	CROCK	Crystalline rock retention processes	Posiva, VTT	KIT, Germany
Nuclear waste management	First-Nuclide	Fast/Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel	Posiva, TVO	KIT, Germany
Nuclear waste management	FORGE	Fate of repository gases	Posiva	BGS, UK
Nuclear waste management	LUCOEX	Large Underground Concept Experiments	Posiva	SKB, Sweden
Nuclear waste management	MoDeRn	Monitoring Developments for safe Repository operation and staged closure	Posiva	ANDRA, France
Nuclear waste management	PETRUS II (EFTS)	Towards a European Training Market and Professional Qualification in Geological Disposal (EFTS)	Posiva, Aalto	INPL, France
Nuclear waste management	ReCosy	REdox phenomena Controlling Systems	Posiva; University of Helsinki, Laboratory of Radiochemistry	KIT, Germany
Nuclear waste management	REDUPP	REDucing Uncertainty in Performance Prediction	Posiva, VTT	SKB, Sweden
Nuclear waste management	SecIGD	Secretariat of Implementing Geological Disposal Technology	Posiva	Posiva, Finland
Nuclear safety	ASAMPSA2	Advanced safety assessment methodologies, PSA	VTT	IRSN, France
Nuclear safety	ERINDA	European Research Infrastructures for Nuclear Data Applications	University of Jyväskylä	Dresden, Germany
Nuclear safety	HARMONICS	Software reliability	VTT	VTT, Finland
Nuclear safety	HPMC	Monte-Carlo reactor core analysis	VTT	DNC, Netherlands
Nuclear safety	GETMAT	Gen IV and transmutation materials	VTT	MPI, Germany
Nuclear safety	MATTER	Materials testing	VTT	ENEA, Italy
Nuclear safety	MULTIMETAL	Multimetal components	VTT	Areva, France
Nuclear safety	LONGLIFE	Irradiation embrittlement effects on reactor pressure vessels	VTT	KIT, Germany
Nuclear safety	PERFORM60	Prediction of the effects of radiation for reactor pressure vessel and in-core materials using multi-scale modelling	VTT	EdF, France
Nuclear safety	NULIFE	Nuclear plant life prediction	VTT	VTT, Finland
Nuclear safety	NURISP	Nuclear Reactor European Simulation Project - 2	LUT, VTT	CEA, France
Nuclear safety	SARNET-2	Severe accident research network	VTT	IRSN, France
Nuclear safety	SCWR	SCWR Fuel Qualification Test	VTT	CVR, Czech Republic

Nuclear safety	STYLE	Structural integrity for lifetime management, non-RPV components	VTT	Areva, France
Nuclear safety	THINS	Thermal hydraulics of innovative reactors	LUT	KIT, Germany
Training	CINCH	Review and planning of education in nuclear and radiochemistry	University of Helsinki, Laboratory of Radio-chemistry	CTU, Czech Republic CUT, Sweden MSU, Russia ENSCP, France NRI, Czech Republic NNL, UK
Training	ENEN-III	European training scheme for nuclear engineering	LUT, Aalto	CEA/INST (ENEN Association), France

With regard to research on radiation protection, the main emphasis of projects is on health effects of radiation. Radiation supervision and preparedness for radiation hazards and accidents are also among the research topics.

In nuclear waste management, the research subjects include spent nuclear fuel, repository conditions for final disposal, engineered release barriers and natural analogues research into these, monitoring, and various large-scale demonstration projects. In addition, in the area of nuclear waste management, co-funding from the EU Framework Programme is used for building up the training scheme for geological disposal in PETRUS II (see chapter 3.5) and to set up the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP).

In the area of nuclear safety research, the projects cover the entire field of nuclear safety. However, the focus of Finnish participation is clearly in material research projects.

## 6.4 Other EU Projects

Projects listed in table 6.5 were identified as other EU nuclear energy projects related to fission research. These typically concern training or severe accident experiments.

**Table 6.5. Other Euratom fission projects with Finnish involvement.**

Area	Abbreviated name	Topic	Finnish participants	Coordinator
Radiation protection	MULTI-BIODOSE	Biological dosimetry	STUK	SU
Radiation protection	CEEPRA	Preparedness for radiation hazards and accidents	STUK	STUK, Finland
Radiation protection	Metrometal	Metrology	STUK	CIEMAT, Spain
Nuclear waste management	Posinam/Marie Curie IAPP	Development of methods for rock pore space investigation	University of Helsinki, Laboratory of Radiochemistry	ERM, France HYDRASA, France BRGM, France STUK, Finland
Nuclear safety	Phebus FP	Severe accidents	VTT	CEA, France
Nuclear safety	ISTP	International Source Term Program/Severe accidents	VTT	IRSN/CEA, France
Other: Nuclear physics research	ENSAR	FP7/Integrating activity	University of Jyväskylä	GANIL

## 6.5 Nordic Nuclear Safety Research Programme (NKS) Projects

The research projects listed in table 6.6 were identified in the Committee for Nuclear Energy Competence in Finland survey. These projects are typically quite small, and in the field of reactor safety, for example, often constitute part of a larger national SAFIR2014 programme project.

**Table 6.6. NKS projects with Finnish involvement.**

Area	Abbreviated name	Topic	Finnish participants	Coordinator
Radiation protection	BIONCA	Biological dosimetry	STUK	STUK
Radiation protection	PIANOLIB	Dosimetry	STUK	SSM
Nuclear waste management	Radwaste	Development of radiochemical analytical methods for measuring radionuclides in nuclear waste	University of Helsinki, Laboratory of Radiochemistry	DTU, Denmark
Nuclear safety	ENPOOL	Thermal hydraulics	LUT, VTT	NORTHNET
Nuclear safety	MOREMO, SADE	Safety culture	VTT	
Nuclear safety	AIAS	Iodine behaviour	VTT	Chalmers University of Technology

STUK is involved in radiation protection projects. The Laboratory of Radiochemistry of the University of Helsinki is engaged in the NKS Radwaste II project, which is a continuation of the project initiated in 2009. The project develops analytical methods for radionuclides difficult to measure in nuclear waste. The VTT projects fall within the scope of 'traditional NKS cooperation', including safety culture, thermal hydraulics and severe accidents.

## 6.6 IAEA Projects

No actual IAEA research projects were identified in the Committee for Nuclear Energy Competence in Finland survey, but the emphasis in IAEA activity was on participation in various committees and working groups.

**Table 6.7.** The key IAEA working groups.

Area	Abbreviated name	Topic	Finnish participants	Coordinator
Nuclear safety	INSAG	High-level safety targets	STUK	IAEA
Nuclear safety regulation	RCF	Regulator-to-regulator forum, regulatory control of nuclear facilities	STUK	IAEA
Nuclear safety	NERS	Cooperation organ of small countries	STUK	IAEA
Nuclear safety regulation	CCS	Safety standards	STUK	IAEA
Nuclear power plant safety	NUSSC	Safety standards	STUK	IAEA
Supervision of nuclear waste and nuclear materials	WASSC	Safety standards	STUK	IAEA
Radiation safety	RASSC	Safety standards	STUK	IAEA
Transport supervision	TRANSSC	Safety standards	STUK	IAEA
Nuclear safety	IRS	International incident reporting system, operational experience	STUK	IAEA
Nuclear and radiation safety	INES	Nuclear and radiological event scale	STUK	IAEA
Nuclear and radiation safety	IRSRR	Incident reporting system for research reactors	STUK	IAEA
Nuclear safety	PRIS	Nuclear power reactor information system	STUK, TVO, Fortum	IAEA
Nuclear safety	GNSSN/NNRP	National Nuclear Regulatory Portals of the Global Nuclear Safety and Security Network	STUK	IAEA
Nuclear and radiation safety	DIRATA	Database on discharges of radionuclides	STUK	IAEA
Nuclear safety, development of competencies		HR activity	MEE, STUK	IAEA



Safeguards for nuclear waste and nuclear materials	CEG	Radioactive waste	STUK	IAEA
Safeguards for nuclear waste and nuclear materials	ASTOR	Geology	STUK	IAEA
Safeguards for nuclear waste and nuclear materials	GEOSAF	Safety of geological final disposal	STUK	IAEA
Safeguards for nuclear waste and nuclear materials	EMRAS II	Radioecology	STUK	IAEA
Safeguards for nuclear waste and nuclear materials	PRISM	Final disposal of radioactive waste	STUK	IAEA
Nuclear power plant safety	IGALL	Ageing management for nuclear power plants	STUK	IAEA
Nuclear and radiation safety	ITDB	Security arrangements, illicit trafficking in radioactive materials	STUK	IAEA
Nuclear safety regulation	NFCIS	Nuclear fuel cycle	STUK	IAEA
Supervision of nuclear waste and nuclear materials	NEWMDP	Nuclear waste	STUK	IAEA
Nuclear and radiation safety	DRCS	Radioactively contaminated sites	STUK	IAEA
Safeguards for and oversight of transport of radioactive materials	EVTRAM	Events in the transport of radioactive material	STUK	IAEA
International Seismic Safety Centre	ISSC	Nuclear facilities and seismology	STUK	IAEA

In the area of nuclear waste management, STUK and Posiva have participated in the activities of IAEA's various technical meetings and working groups. International development work and exchange of information associated with nuclear waste management takes place in the working groups operating under both the Nuclear Security Fund (NSF) and the division of Nuclear Fuel Cycle & Waste Technology (NEFW). The topics of technical meetings have included fuel issues, safeguards, cost control, training and nuclear knowledge management. The purpose of the technical meetings is to develop IAEA's guidelines related to nuclear safety, and the target of working-group-style networks is to transfer information in the form of training and cooperation projects from more experienced nuclear-energy-user countries to those beginning to use nuclear energy in the fields of operation needed for the peaceful use of nuclear energy.

## 6.7 Other International Projects

A certain number of other international projects were also identified in the Committee for Nuclear Energy Competence in Finland survey, examples of which are given in table 6.8. When reflected against reviews made in connection with nuclear safety

research programmes, for example, it can be concluded that these projects represent only a fraction of other international projects.

**Table 6.8.** Examples of other international projects.

Area	Abbreviated name	Topic	Finnish participating organisation	Coordinator
Nuclear waste management	Grimsel	Test site investigations 2003–2013	University of Helsinki, Laboratory of Radiochemistry, Posiva	Nagra/GTS, i.e. Grimsel Test Site, Switzerland
Nuclear safety	ARTIST2	Fission product release	Fortum, VTT	Paul Scherrer Institute (PSI), Switzerland
Nuclear safety	JHR	Jules Horowitz Reactor Project – e.g. development of measuring technology for the project	VTT	CEA, France
Other	EERA Nuclear materials	GenIV materials	VTT	KIT, Germany
Other	US-NRC-PARENT	Residual stress	VTT	NRC, USA

The largest of the projects listed above is the JHR project. This is not an OECD/NEA or EU project, but a separate international consortium with minor EU contribution.

Posiva is also engaged in other large international nuclear waste management projects. The largest of the ongoing single projects is the Greenland Analogue Project (GAP). In addition, Posiva participates in the following Grimsel (Switzerland) Phase IV Test Site projects: Long-term Cement Studies (LCS), FEBEX, and Colloid Formation and Migration Project (CFM). Posiva is also involved in a smaller multinational research project investigating clay natural analogues in Cyprus.

Posiva participates in the Technical Evaluation Forum (TEF) within the framework of international technical cooperation carried out at SKB's Äspö Hard Rock Laboratory (HRL), while both Posiva and VTT have participated in Äspö International Task Forces.

## 6.8 Technological Platforms and Research Communities

International cooperation in technology and research is growing strongly and reaching a position alongside traditional co-funded research. Research consortiums pool their resources and target their activities according to a common research agenda. The Euratom programme provides strong support for establishment of technical platforms and research communities.

## 6.8.1 Radiation Protection

Cooperation communities in technology and research in the area of radiation protection include EURADOS, MELODI, NERIS and the Radioecology Alliance. All involve the participation of STUK. Of this list, EURADOS (European Radiation Dosimetry Group, [www.eurados.org](http://www.eurados.org)), established in 2001, has been operating the longest. Currently the EURADOS group consists of 57 institutions (voting members) and 200 scientists.

The MELODI (Multidisciplinary European Low Dose Initiative), dedicated to investigation of low dose risks, was established in 2010. STUK was one of the 15 founding members (see [www.melodi-online.eu](http://www.melodi-online.eu)). The NERIS Platform (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery) was also established in 2010 with an aim of promoting preparedness for nuclear or radiological emergency situations. The platform consists of 37 organisations, and STUK acts as the first chair of the organisation. The establishment of an European research community within the area of radioecology – the Radioecology Alliance – is also in preparation. The European Commission finances the development of MELODI and Radioecology Alliance through Network of Excellence projects.

## 6.8.2 Nuclear Waste Management

In 2009, ten European nuclear waste management organisations (Andra, Covra, Enresa, Nagra, NDA, ONDRAF/NIRAS, Posiva, PURAM, RAWRA, and SKB) and a ministry from Germany (BMW i – Federal Ministry of Economics and Technology) established a technology consortium of geological final disposal. The above also constitute jointly the executive group of the technology platform. The purpose of IGD-TP (Implementing Geological Disposal of Radioactive Waste Technology Platform) is to promote research into geological disposal and the joint implementation of development and demonstration projects in collaboration with other research stakeholders. In addition, the technology platform intends to promote knowledge and competence transfer between various actors representing the industry, the Commission (DG TREN/RTD, SNETP) and authorities (ministries, regulating authorities and technical support organisations).

The IGD-TP vision is that by 2025 the first geological repositories for spent nuclear fuel and other high-level waste are operating safely in Europe. In order to realise this vision the technology platform has committed itself to supporting confidence-building in the safety and implementation of geological disposal solutions. The benefits from IGD-TP are not limited to safe implementation of the first repositories, but extend to support of longer-term waste management programmes. The state, implementation schedules and challenges of final disposal differ among most of the countries that have a nuclear waste management programme. Sweden, Finland and France are some years ahead of others in the implementation and licensing of final disposal facilities.

On the basis of the technology platform's vision, a joint Strategic Research Agenda (SRA) was completed in summer 2011 and its Deployment Plan (DP) is currently in preparation. The Strategic Research Agenda defines the common research areas for licensing and implementation of geological disposal solutions. In order for the first geological repositories for spent nuclear fuel to be operating by 2025 as intended, those participating in the technology platform have defined the following as the common key topics of research, development and demonstration activities: scientific and technical foundations for long-term safety case; waste forms and their behaviour; demonstration of technical feasibility and long-term performance of repository components; development strategy of the repository; safety of construction and operations; monitoring the impact of final disposal; and the decision-making process for site selection, including stakeholder participation.

Cooperation among the waste management programmes, advancing in different stages of repository implementation and according to their own schedules, is an integral part of IGD-TP activity. The collaborative work between waste management organisations and the active participation of various stakeholder groups in the drafting of a joint Strategic Research Agenda has already benefited all parties involved. Detailed exchange of ideas has increased mutual understanding among the different waste management programmes, and produced added value for compiling the research agenda. The current goal is to promote implementation of the research agenda, which aims to pool personnel resources and funding in a more effective manner throughout Europe in support of the implementation of the platform's vision.

The European Commission supports the secretariat of this technology platform through a Seventh Framework Programme project for 2010 and 2011. Nordic cooperation on geological disposal also continues within the IGD-TP, since the secretariat of the technology platform is located at SKB in Sweden, and the European Commission's secretariat project is coordinated from Finland by Posiva Oy. In other respects, members of the IGD-TP executive group are responsible for the funding of the platform. The technology platform already has more than 80 participants from different parts of Europe. Finnish participants in addition to Posiva include VTT, Aalto University and Saanio & Riekkola engineering consulting company.

### **6.8.3 Nuclear Safety**

The Sustainable Nuclear Energy Technology Platform (SNETP; <http://www.snetp.eu>) was established in September 2007. There are currently some 80 European actors participating in SNETP activities representing, for example, nuclear energy industry, research institutions, higher education institutions, and the technical support organisations of nuclear safety authorities. The Finnish participants in the SNETP technology platform are VTT, TVO, Fortum and Lappeenranta University of Technology.

SNETP's objective is to promote research, development and demonstration projects related to nuclear fission technology in order to achieve the goals specified in the Strategic Energy Technology Plan (SET-Plan), particularly those related to reduction of greenhouse gas emissions. SNETP's specific goal is to promote the safety of fission technology and to ensure its technological competitiveness by 2020. The goal by 2050 is to prove the feasibility of new technologies based on a new generation (Gen IV) of fission reactors by means of demonstration facilities built to promote the achievement of sustainable development targets. Another aim is to expand the operation range of power plants based on fission technologies to cover cogeneration of process heat and hydrogen alongside power production.

By 2011, three task forces had been set up under SNETP, two of which are already active:

- **ESNII** - European Sustainable Nuclear Industrial Initiative for demonstration of Gen IV reactor technologies (Tekes coordinates Finnish participation)
- **GenII/III** activity will be organised into a **NUGENIA** community (Euratom's Nulife and Sarnet networks and ETSON cooperation), which has an agenda with seven topic areas. More detailed descriptions have already been drafted for each area:
  1. Fuel, waste management (all but Geological Disposal) and dismantling
  2. Integrity assessment and ageing of Structures-Systems-Components
  3. Plant safety and risk assessment
  4. Severe accidents
  5. Core and Reactor performance
  6. Innovative Gen III designs
  7. Harmonisation
- **Cogeneration** cooperation is still at the planning stage; the goal is coordination of R&D in support of cogeneration of hydrogen and heat.
- The **Fukushima** task force set up under SNETP has drawn up a programme for a research agenda, and the intention is to put that into practice in the GenII/III task force.

Other goals for SNETP cooperation include development of concepts for advanced light-water reactors, fast reactors based on closed fuel cycles, and reactors operating at very high temperatures, particularly for process industry needs. In addition to developing these basic concepts, the technology platform has an overall goal of developing technologies generally suited for R&D of different concepts. Included among such targets are development of innovative structural materials and fuel types; reactor design; development and application of simulation models and test equipment to support safety, material selection and fuel development; general development of R&D infrastructure; and development of nuclear safety regulations.

Another community that can be regarded a cooperation community in technology and research, in addition to those presented above, is the VMK cooperation forum

that originally started as unofficial and temporary cooperation among research institutions and power companies of countries using VVER technologies, and which has continued for more than 30 years. In the 1990s it was consolidated into an Atomic Energy Research (AER) association, and over the years organisations other than those conducting research on or exploiting VVER technologies have also joined. The AER has several permanent and active scientific working groups and an annual seminar, and organises international benchmarking projects in the same manner as OECD/NEA, focusing mainly on VVER reactors.

## 6.9 Major Bilateral Agreements between Organisations

Universities and research institutions also have bilateral cooperation agreements, some of which are mentioned here as examples, where they have been publicly announced. It must be noted that a large share of bilateral agreements, particularly between companies, are confidential, and will not be discussed in this context.

Examples of bilateral agreements include the agreements, for example, of Aalto University and Lappeenranta University of Technology with the ENEN Association, and the cooperation agreements of the University of Jyväskylä with Brookhaven National Laboratory in the U.S. and the RIKEN Institute in Japan. VTT has several bilateral cooperation agreements with such partners as CEA and IRSN, France, PSI, Switzerland, JRC and separate agreements with US NRC concerning CAMP, CSARP and PINC cooperation. In these VTT acts as a contracting partner that disseminates information to other Finnish organisations.

The Swedish nuclear waste management organisation SKB (Svensk Kärnbränslehantering AB) is making preparations for the licensing of a final disposal repository within the next few years side by side with Posiva, and the companies will largely base their applications for an operating licence on similar technical plans and safety cases. This has been possible owing to an agreement, signed in 2001 and continued in 2006, on extensive research and development cooperation covering the final disposal technologies and related safety research in their entirety. The agreement is Posiva's most important international cooperation agreement concerning research and development in the field of nuclear waste management.

Currently, Posiva is involved in some 20 cooperation projects based on this bilateral cooperation agreement, some of which are multinational. In all, approximately 140 cooperation projects have been implemented since 2001. A cooperation agreement has also given Posiva an opportunity to exploit the Äspö Hard Rock Laboratory, the bentonite laboratory located at the same site, and the Oskarshamn canister laboratory (see also chapter 5).

## 6.10 Functionality and Development Needs of International Research Cooperation

International cooperation in the nuclear energy sector is a necessity. In a small country, not all research can be performed independently, nor would it be practicable. Nuclear power plant safety research requires experimental facilities of such magnitude that it would be unreasonable to expect any one country to build them on its own. In order to gain maximum benefits from research projects it is advisable to participate actively, for example by performing benchmark calculations. This, on the other hand, requires funding for the work performed, in addition to the participation fee and the funding needed for monitoring of the project. The OECD/NEA projects are generally regarded as advantageous, and the information gained through them worth the investments made. However, the available funding (VYR funding and organisations' internal funding) limits the opportunities for participation.

In order to obtain international research results and attract projects that Finnish actors could exploit, it is also important that Finland has its own research contributions to offer in return. Such contributions have included self-developed computing codes, calculation and measuring data, and opportunities offered to international research groups to use test facilities developed and built in Finland in co-financed projects.

In Euratom reactor safety projects, Finland is typically involved as a minor partner. This ensures access to information about the project, but gives little opportunity for active influence on how the project is targeted. However, one must often stay involved in these projects, because absence would become too costly if one wants to keep abreast of the latest developments. Furthermore, the internal synergy of these projects is often lower than that of OECD/NEA projects, and each partner 'does what it would do anyway'. The few projects coordinated by Finland are naturally an exception, since in these Finland can significantly influence the direction of the project.

In Euratom projects in the areas of radiation protection and nuclear waste management it is typical that the number of partners is smaller than in nuclear safety research, and the projects are found to match better with our own needs.

Compared to the abovementioned projects, Nordic cooperation under the auspices of NKS is small in volume, but often forms a springboard to more extensive international contacts. Nordic cooperation facilitates more extensive surveys related particularly to the boiling water reactors in use in Finland and Sweden, as well as observation of northern conditions in safety investigations, assessments of the operations of various organisations, and environmental surveillance. Nordic cooperation can be further developed and strengthened in the context of safety research concerning the use of nuclear energy.

The expectations for cooperation in technology and research are high, but the new consortiums are just in the process of initiating their activities.

The committee and working group activities are largely financed by the organisations themselves. The important task forces and committees largely define the direction of research, as well as the methods and research equipment required. The number of committees was not surveyed for the purposes of the competence study, but on the basis of samples from other sources it can be concluded that committee work consumes important resources, but the results are often limited to carefully filed travel reports.

Topics considered important include maintenance of opportunities for teacher and student exchange, encouragement to participate in exchange programmes, and ensuring financing opportunities for the maintenance of international networks and the building of new networks (also securing research and basic and further training opportunities for groups of students and researchers, instead of individual researchers and students only).

A major part of international cooperation is confidential and, during the project and for a specified period afterwards, only the participating organisations have access to the results of the project. This limits dissemination of information on such projects in national forums. Confidentiality requirements must be followed closely in order to maintain one's reputation as a reliable research partner. The different forms of international cooperation that came up in this study, and the large number of such contacts, would speak for a need to conduct similar regular surveys concerning international cooperation, so that the entire national research field would be aware of the involvement of all parties and of whom to consult when considering new cooperation options.

Fennovoima decided in 2011 to build its nuclear power plant in Pyhäjoki municipality, located in Northern Ostrobothnia. Fennovoima's nuclear power plant unit Hanhikivi 1 will be constructed on Hanhikivi peninsula on the coast of Bothnian Gulf.





# 7 The Opportunities for Finnish Industry to Participate in the Forthcoming Large Nuclear Power Plant Projects

## 7.1 Introduction

During preparation of the latest decisions-in-principle concerning Fennovoima and Teollisuuden Voima's nuclear power plants and their parliamentary ratification, unanimous and broad consensus prevailed in Finland on the desirability of having as large a share as possible of the construction of the forthcoming nuclear power plants given to Finnish industry. However, due to the nature of nuclear power plant projects, the Finnish contribution to the plant delivery would be primarily subcontracting to large international nuclear technology and project suppliers. In industrial circles this opportunity has already been acknowledged, and preparations for future projects have been launched on various fronts, as described in closer detail below.

This chapter focuses on such national industrial activities that can be expected to have realistic opportunities for participating in nuclear power plant projects to be launched in Finland or neighbouring countries during this decade.

The chapter consists of three sections. The first addresses the typical structure of large nuclear power plant projects, which provides the framework for potential steps to be taken by the national industry. The same section also describes the new opportunities for providing services for actors within the sector that are opening up along with the development of the regulatory operations. The second section describes the industrial efforts made so far, especially the FinNuclear cooperation and the nuclear energy branch group of the Federation of Finnish Technology Industries. The third section describes the (present and potential future) regional initiatives of nuclear power plant localities.

## 7.2 The Nature of Large Nuclear Power Plant Projects

Nuclear power plant projects are very large industrial projects that involve high quality standards and extensive involvement by authorities. A typical price range estimate for a nuclear power plant is from 4 to 6 billion euros, and the duration of the construction process on the basis of experience from past decades, counting from the beginning of the actual plant construction, is from 6 to 10 years. Due to the large size and long duration of the projects, the commercial risks are also substantial.

In the planning of such projects, therefore, appropriate business risk management with maximum functionality is one of the key selection criteria, both for the actors involved and the supply models.

The following recurring features have been observed in the nuclear power plant projects implemented over the past decades:

- The suppliers are typically large consortiums with a few main technology suppliers and primary contractors.
- The main suppliers and primary contractors use substantial subcontracting, which can consist of relatively long chains.
- The main suppliers, primary contractors and subcontractors procure materials, equipment and services.

A nuclear power plant project can be implemented in many ways, starting from a 'turnkey delivery' model, in which the supplier consortium delivers a fully completed facility on the appointed site. The other extreme is the separate procurement model, in which the developer orders the facility in small parts from various actors and manages the implementation process itself. Even in projects implemented using the separate procurement model, the trend has been towards larger and larger partial deliveries, meaning that the practical differences between the various implementation models are reducing. Regardless of the implementation model, some preparatory processes need to be carried out at the plant site. These include preparation of the plant site, road construction, water supply, sewerage and building site power supply, all of which the plant developer can procure itself. Naturally, in large deliveries the suppliers also source materials, equipment and services regionally.

In individual nuclear power plant projects, the structure of the delivery evolves in the course of procurement negotiations between the buyer (owner) and the plant supplier candidates. The definition of the project structure involves several commercially, technically and administratively sensitive points that cannot be addressed in detail in this context.

It is likely that even in the forthcoming Finnish nuclear power plant projects, Finnish subcontractors sell their services related to plant delivery directly to the plant suppliers. The owner's share of the project is typically limited to the parts outside the actual power generation facility, such as construction of other facilities and buildings on the plant site. This kind of conventional earth-moving, road construction, house building, and other infrastructure construction is needed both at new and existing plant sites. However, the share of this kind of building activity is much bigger at the new sites (e.g. residential areas and visitor centre) than at the existing sites.

In addition to actual nuclear power plant projects, there are also other nuclear energy related projects implemented in Finland, including construction of Posiva's final disposal facility and extensive modernisations of the old nuclear power plant units. Projects such as these also offer participation opportunities for Finnish service providers and suppliers.

In a globalised world, it is likely even in the future that there will be a foreign labour force participating in the nuclear power plant projects, regardless of the delivery model and composition of supplier consortiums. Therefore it would make compliance with the Finnish practices easier if official regulations concerning company obligations, taxation of contract workers, for example, were made available in English.

## 7.3 Expert Services Required by the Authorities and Licence Holders

STUK and the licence applicants and holders under its supervision need different kinds of technical and expert services, which require in-depth expertise in the relevant fields of technology. These include:

- transient and accident analyses required for safety assessment (e.g. inspection of the dimensioning of safety systems);
- type-approval of equipment;
- analyses and expert statements required in various fields of technology;
- inspection and testing of equipment and structures pursuant to YVL guides; and
- evaluation, auditing and certification of operation processes and methods.

The inspections required in various fields of technology in nuclear power plant projects have been specified in the YVL guides. The extent of inspection is determined on the basis of nuclear technical safety classification of the subject in such a manner that the more significant the subject, the more supervision and inspections are conducted.

For some considerable time, particularly in the field of electrical and automation technology, the requirement has been that all devices important to safety are type-approved. The type approval process is laborious and time-consuming. The process includes different kinds of testing, inspection and evaluation activities, and the party performing these activities must be a third party independent of equipment suppliers and authorities, with proven qualifications for the task.

Since the beginning of the 21st century STUK has been outsourcing its inspection activities, particularly as concerns structures and equipment with minor importance to safety. This has provided new business opportunities for inspection bodies operating in Finland. A significant proportion of nuclear power plant process equipment fall into this safety class. With pressurised water reactors, for example, the share of pressure vessels in the plant falling into safety classes 3 and 4 can be well over 50 per cent. In other words, in quantitative terms there can be a remarkable amount of equipment for inspection in the lower safety classes, especially if the class “not safety classified” (no nuclear safety significance) is included.

Standard practices for inspection organisation activity have been established with regard to nuclear power plant pressure vessels. STUK-approved inspection

bodies are already performing inspections of pressure vessels and other structures assigned to safety class 3 or lower. Typical services provided by such third parties include inspection of designs (structural design) concerning equipment prior to manufacturing; supervision of manufacturing and of the qualifications required; structural inspections after component manufacture and installation; and supervision of various trial and testing measures related to different phases of production.

STUK is currently in the process of revising its YVL guides, in which context the intention is to further expand the use of STUK-approved and -supervised inspection bodies. With the reform, STUK will transfer to third parties more of the inspections - of mechanically engineered equipment and steel and concrete structures, for example - that it used to perform itself. The consequent expanded use of inspection bodies gives STUK an opportunity to focus its inspection resources on the evaluation of conformity to the regulations of safety class 1 equipment and structures, and to concentrate on safety supervision of facilities.

The approval process and operational supervision of inspection and testing bodies will be described in the forthcoming new YVL guide YVL E.1. A company intending to acquire inspection body status must meet the requirements set by the Nuclear Energy Act and Decree and the YVL guides, including accreditation by the Finnish Accreditation Service (FINAS) or similar organisation.

In addition to supervision conducted by Radiation and Nuclear Safety Authority (STUK), other authorities, such as the Finnish Safety and Chemicals Agency TUKES and local and regional rescue and environmental authorities, also participate in the evaluation of nuclear power plant projects and may need special expert services to perform their work.

## 7.4 Own Activities within the Industry

### 7.4.1 FinNuclear Association

FinNuclear Association is a national association with the aim of bringing together the versatile competencies of the Finnish nuclear energy sector and other actors having capabilities suited for the field, so that Finnish actors would attract more trade within a business sector that has worldwide significance. The association has 40 member organisations.

The association was established on 4 March 2011 in continuation of the FinNuclear programme that involved ten driver companies in 2009-2010, including Dekra Industrial, Fennovoima, Fortum, Hollming Group, Kraftanlagen Arge OL3, Outokumpu, Pöyry, Telatek, Teollisuuden Voima, Wärtsilä, the Federation of Finnish Technology Industries, and Finnish Energy Industries. In addition, the Finnish Nuclear Suppliers' Group of the Federation of Finnish Technology Industries, described in the next chapter, is linked to this activity. Similar national nuclear energy sector associations

include Foronuclear in Spain and Nuclear Industry Association in the UK. In the future, the FinNuclear Industrial Support Unit operating within Prizztech Oy may be developed into a service provider attached to the association.

Prizztech Oy's FinNuclear Unit is responsible for the practical operations of the association. The unit provides branch-specific support services and takes organisational steps to improve the preparedness of supplier companies for operating in the nuclear energy sector.

Examples of practical FinNuclear activity measures implemented for enhancing the participation preparedness of Finnish industry between 2009 and 2010 include:

- Networking events of various kinds, such as Meet the Vendor type events, in which power plant suppliers and Finnish companies can network
- Common stands at international nuclear sector events
- Lectures
- Maintenance and expansion of the contact network
- Company coaching
- The centralised sector-specific portal [www.finnuclear.fi](http://www.finnuclear.fi), monitoring of the sector and news service (once a month)
- Database presenting the network of Finnish experts [www.finnuclear.fi/](http://www.finnuclear.fi/) directory and the annual printed version of the database

Figure 7.1. A database presenting Finnish nuclear sector experts.



A company coaching concept consisting of training modules, targeted for subcontractors in particular, has been established in collaboration with power companies. Its contents and mode of operation are shown in figure 7.2. In addition, FinNuclear Association also organises other training sessions directed at suppliers. NQA training will be organised in autumn 2011, for example.

Figure 7.2. FinNuclear Training consisting of modules.

The infographic features a blue header with a white square icon and the text 'FinNuclear'. Below this is a blue rounded rectangle with the title 'Business Coaching' in white. The main content is divided into three orange sections, each containing a module description. At the bottom, a white rounded rectangle contains the website URL 'www.finnuclear.fi/training' in blue text.

## ■ FinNuclear

### Business Coaching

Basic knowledge on the nuclear energy sector for companies aiming to enter the business area.

Module 1:  
An overview of the nuclear energy sector.  
Fortum, Espoo

Module 2:  
Quality assurance and management systems in the management of nuclear power plant projects.  
Fennovoima, Vantaa

Module 3:  
Acting as a supplier for nuclear facilities in operation and nuclear power plant projects.  
TVO/TVONS, Olkiluoto

[www.finnuclear.fi/training](http://www.finnuclear.fi/training)

There are plans for extensive development of the activities. A process will be established for assisting companies to qualify as suppliers, which will help companies to prepare, for example, for audits conducted by power plant suppliers and contractors. In addition, efforts will be made with the assistance of the FinNuclear network to define business entities within the nuclear sector – as well as the companies involved – that would offer Finnish actors long-term business potential, and even export opportunities, through which Finns could be involved in the process throughout the lifetime of nuclear facilities, from design and construction through to maintenance and decommissioning. During 2011, extensive development projects were initiated in relation to development

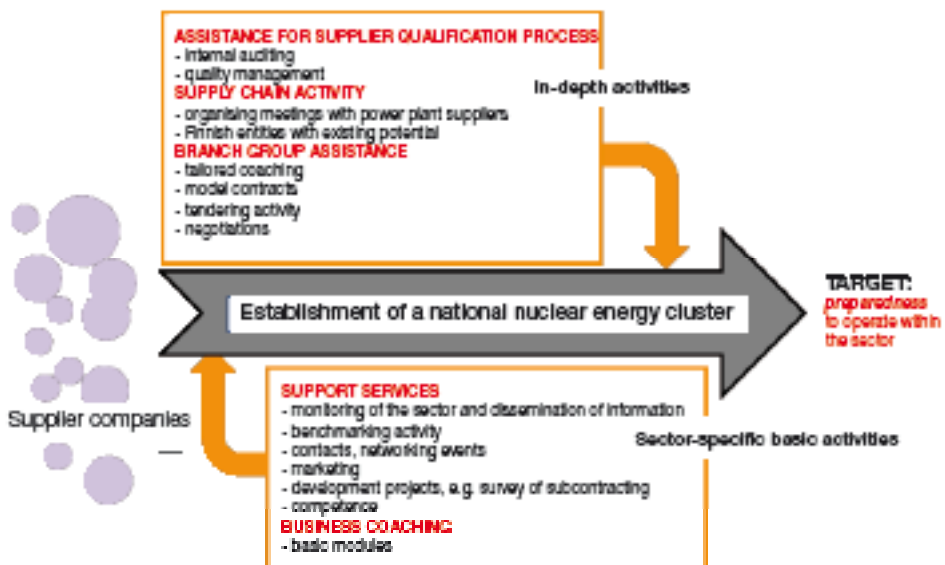
and preparation of sector-specific consortiums for those FinNuclear members willing to join the activity, with the service unit acting as a catalyst.

There are plans for establishment of a multi-year programme for versatile development of the national nuclear energy cluster and branch, which would also need public sector support (e.g. MEE and Tekes).

Such a starting point is further supported by the fact that the importance of FinNuclear activity for Finnish suppliers with regard to the future national nuclear power plant projects was referred to in the Commerce Committee of the Parliament of Finland’s memorandum of summer 2010 before ratifying decisions-in-principle for construction of new nuclear reactors.

The chart in figure 7.3 summarises the role of FinNuclear activity in building up the Finnish nuclear energy cluster.

**Figure 7.3.** The FinNuclear concept for enhancing national nuclear sector subcontracting activities.



#### 7.4.2 Finnish Nuclear Suppliers’ Group of the Federation of Finnish Technology Industries

The purpose of the Finnish Nuclear Suppliers’ Group is to promote the competitiveness of Finnish nuclear energy sector suppliers by increasing cooperation within the sector and encouraging networking among companies. The key content of the branch group’s activity consists of expert seminars, business coaching, training of professional employees, exchange of experiences, international cooperation, participation in fairs, common publications, and company networking events.

The fact that Finland has no manufacturing of heavy nuclear power plant components, such as reactor pressure vessels, steam generators, steam turbines or large generators, has a significant bearing on the task description of the branch group. On the other hand, the implementation of annual maintenance and inspection of the power plants is mostly effected by Finnish crews. Finnish companies also supply machinery, equipment, structures, components, systems and services for modifications and repairs implemented alongside the annual maintenance and inspection. The implementation of demanding modernisation and power capacity upgrade projects, in particular, has developed the competencies of Finnish companies.

The decision was taken to establish the branch group within the Federation of Finnish Technology Industries, since it already had some 30 similar branch groups and associations operating in various fields of technology. Membership of the branch group does not presuppose membership of the Federation of Finnish Technology Industries, and therefore many companies from outside the sector, construction industry for example, have joined the group. Since the beginning of 2011 design and consulting companies not previously involved in the activities have started to join the Federation of Finnish Technology Industries.

The goal of the branch group is to improve the competitiveness of the member companies by creating business networks and by acting as a lobbyist for nuclear energy sector suppliers. Drafting of recommendations for contract strategies plays a central role in the establishment of business networks.

Finnish companies were not granted as many supplier contracts for the Olkiluoto 3 project as might have been suggested by the level of Finnish competence and the wide range of the Finnish offering. The key objective of the branch group is to coach providers of Finnish competencies for future nuclear power plant projects. This would be for the domestic projects at first, naturally, but in the future also with a view to international projects. The Finnish Nuclear Suppliers' Group focuses on improving the competitiveness of companies supplying equipment, components, systems and services. The practical work has been organised in such a manner that the Federation of Finnish Technology Industries commissions the desired services from the FinNuclear project as provided by the agreement made with PrizzTech Oy. This method avoids overlapping of functions and ensures efficient dissemination of information.

### **7.4.3 Construction**

In the Olkiluoto 3 project, Finnish construction sector companies failed to attract subcontracting contracts for major subsystems. An important goal within the field, therefore, is improving the competitiveness of the sector and enhancing its opportunities for participating in the future power plant projects. Companies preparing the new nuclear power plant projects have conducted negotiations,



for example, with the Confederation of Finnish Construction Industries RT and Rakennusliitto (the Finnish construction trade union) concerning ways of improving the competitiveness of Finnish companies and employees, and the preconditions for ensuring more extensive participation than before in nuclear energy sector projects. The organisations within the sector have expressed their strong commitment to enhancing the opportunities of Finnish companies and employees for participating in nuclear sector projects.

One way of improving the competitiveness of the field is to ensure the functionality of the Finnish labour market system as part of the preparation phase of the projects. Efforts towards this end include enhancing the cooperation among nuclear sector companies, construction sector companies, labour market organisations and the authorities. In addition, on the basis of experience gained in the Olkiluoto 3 project, Finnish construction sector companies have invested in the development of such competencies and systems that will help them enhance their capacity to attract major subcontracting contracts in the future nuclear power plant projects. Further efforts to improve their chances are made by establishing business networks and enhancing cooperation among the companies in the field.

## 7.5 Activities of Regional Trade and Industry in Nuclear Power Plant Localities

### 7.5.1 Pyhäjoki/Northern Ostrobothnia/Northern Finland

The strong shared will of Northern Finland to promote new investment in the region has been an important factor in the preparation of Fennovoima's nuclear power plant project. The cooperation has been further enhanced by the long experience gained by the alternative plant site regions in working with industrial and energy sector companies.

At the beginning of October 2011 Fennovoima decided to build its nuclear power plant unit Fennovoima-1 at Pyhäjoki. In February 2012, the plant unit was given the name Hanhikivi-1 after the location of the site. At the construction stage the project will employ thousands of people in Finland, representing an enormous challenge and opportunity for the entire northern part of Finland. Regional development centres, chambers of commerce, and trade and industry have been actively involved from the very beginning of the project, cooperating locally, regionally and nationally with various actors. Information has also been obtained from Olkiluoto and the surrounding region.

The development centres of Raahen region and Kemi-Tornio region drafted a survey at the beginning of 2011 on the regional economic impacts of the project and the steps taken in the region in preparation for the project. These surveys are available in Finnish at <http://www.fennovoima.fi/tiedotteet/ajankohtaista/selvitykset-pyhajoen-ja-simon-seutukunnista-valmistuneet>.

Substantial preliminary work has been performed in these regions in terms of various projects and initiatives, to be actuated once the plant site location has been selected. Preliminary plans for increasing the quality and quantity of services, for example, and for developing the infrastructure, have already been finalised. With a view to the progress of Fennovoima's project, it has been extremely important that the municipalities and inhabitants of Northern Finland, particularly those in the environs of the plant site, have been positively inclined from the very beginning towards such a major project as a nuclear power plant.

### **7.5.2 Olkiluoto/Satakunta Region**

In addition to TVO and Posiva, there are several service providers in Olkiluoto that implement, for example, complex material, equipment, design, installation, maintenance and support service acquisitions. A regional Olkiluoto working group has been established with the aim of enhancing cooperation among these actors, the trade and industry of Satakunta region and the public sector, and to strengthen provincial cooperation. The parties involved include: TVO; Posiva; the municipality of Eurajoki; the cities of Rauma and Pori; chambers of commerce; the Regional Council; the Centre for Economic Development, Transport and the Environment; the University Consortium of Pori; Satakunta University of Applied Sciences; Prizztech Oy/FinNuclear; and representatives of various enterprises. The Olkiluoto working group continues the tradition of regional cooperation dating back several decades.

The regional actors have initiated various development projects in order to support the actors at Olkiluoto. One example of this is the Pori Regional Development Agency Ltd, known as POSEK, which has also launched an Olkiluoto contact project. The key objective is to enhance the provision of Pori region services for companies operating at Olkiluoto and for other international companies. The intention is to organise and coordinate the region's public and private services aimed at international actors into an entity that is available on a one-stop-shop basis. This will enhance their use and accessibility.

The goal is to increase significantly the regional impacts of the Olkiluoto service entity, to enhance the attractiveness of the region, and to improve its operating conditions as an implementation area for major projects. The project also aims to attract local companies to subcontractor networks and to reinforce services supporting the operating conditions of local businesses (e.g. Pori airport and flight connections).

Although the key target groups are the companies and personnel of the companies involved in the ongoing Olkiluoto 3 and the future Olkiluoto 4 project, this initiative will establish a permanent complete service structure that can be adapted to any international investment or project to be implemented in the region.

### 7.5.3 Loviisa/Uusimaa

Loviisa nuclear power plant has well established relations with the companies in the surrounding area. These play a major role, for example in the annual maintenance and inspection. Typically some 60 to 80 companies and 600 to 900 outside employees participate in the annual maintenance of Loviisa 1 and 2 power plant units. Most of these companies come from the eastern Uusimaa and Kymenlaakso areas.

The Loviisa 3 project that was discontinued after the negative decision-in-principle in 2010 would have had a significant impact on the trade and industry in the region. Because of this, contacts were actively pursued during project preparation with entrepreneurs in the surrounding area, who were kept informed about the progress of the project through, for example, the Entrepreneur Association of Loviisa Region, and the Kymenlaakso Chamber of Commerce.

## 7.6 Conclusions and Recommendations

The activities described in this chapter show that Finnish trade and industry is making active preparations for the forthcoming nuclear power plant projects in Finland. Fennovoima and TVO, the companies preparing the projects, have also expressed their wish to involve as much Finnish industry and services in the project as possible. Since Finland lacks domestic nuclear power plant suppliers, the nature of the participation of Finnish companies in the construction projects associated with the new nuclear power plants would be mostly subcontracting and provision of services. Services are needed by all parties involved in the nuclear power plant project: the power company in charge of the project, the main suppliers implementing the project and their subcontractors, as well as the supervising authorities.

The government on its part can contribute to enhancement of the opportunities of Finnish industry for participating in future projects by supporting education and training concerning the special features of nuclear energy activities targeted at companies. The major reforms under way in the official practices of Finnish nuclear safety supervision play a part in increasing this need for education and training.

Foreign labour force will continue to participate in the nuclear power plant projects, regardless of the delivery model and composition of supplier consortiums. Compliance with Finnish practices would thus be easier if official regulations concerning company obligations, such as taxation of contract workers, were made available in English.

To ensure the smooth implementation of future projects, it is important that sufficient resources for official functions related to the projects are also allocated at the regional authority level.

# 8 Situation Regarding the VTT Research Reactor (FiR 1)

Since the early stages of nuclear energy activity in Finland the research reactor (FiR 1) has played a central role as a research and training resource with various applications. The organisation responsible for initial use of the research reactor was the reactor laboratory of the Department of Applied Physics at Helsinki University of Technology (TKK, current Aalto University). When TKK was brought under the Ministry of Education the reactor operations and personnel were transferred to VTT, effective from 1 July 1971. The access rights of organisations outside VTT - i.e. higher education institutions - to the research resources provided by the research reactor were also assigned in connection with the transfer. Operations over the past decades have become more and more diversified from the early activities that focused on reactor technology and reactor physics. The changes in the administrative structure and applications also require reassessment of funding arrangements.

## 8.1 Introduction

An important initial step in creating a national research environment related to nuclear energy was the decision taken at the turn of the 1960s for Finland to acquire a research reactor. The Triga Mark II-type research reactor (FiR 1) was purchased from General Atomics in the United States and commissioned in summer 1962. Responsibility for the operational activities associated with a key national research resource, i.e. the research reactor, was assigned at the time to the Department of Applied Physics at Helsinki University of Technology (TKK). A key objective set for use of the research reactor at that point was to make preparations for creating versatile nuclear sector competencies, which would be important in the future when procuring, planning, constructing, granting licences for or using commercial nuclear power plants.

During the same period, when Finland made the decision to procure and build the first nuclear power plant at Loviisa, decisions were also taken on expanding and organising national nuclear energy research. Research in various topical fields was placed primarily in either existing or new VTT research laboratories. The VTT Reactor Laboratory was established to take charge of the use of the research reactor. The responsibilities for acquisition and maintenance of the competence required for the operation of the test reactor, formerly borne by TKK, were transferred by decision of the Government (41/480/71 of April 1971) to the VTT Reactor Laboratory with effect from 1 July 1971. The access rights of higher education institutions (TKK in particular) to the special resources provided by the research reactor were assigned at the same time. In the early decades the reactor was exploited for training

and research supporting Finland's national nuclear power programme, industrial assignments and medical applications.

In connection with the amendment of the Nuclear Energy Act in 1987, VTT was assigned the additional duty of ensuring that plans for nuclear waste management and decommissioning regarding the research reactor are made, and later also implemented. The expenses arising from these duties are nevertheless covered by the State, so that basic funding from the National Nuclear Waste Management Fund required for the research reactor was at that time allocated in two parts by means of separate appropriations included in supplementary state budgets. The Nuclear Waste Management Fund funding for FiR 1 has also since been increased.

Until the end of the 1980s the main uses of the research reactor were closely linked with the use of nuclear energy, charting of natural resources, and the use of radioisotopes in industry and medicine. In 1991 VTT and MAP Medical Technologies Oy took the initiative to launch development of opportunities for Boron Neutron Capture Therapy (BNCT). The purpose of the research project was to develop equipment, a treatment station and the necessary auxiliary services required for BNCT routine treatment practices connected with the FiR 1 research reactor. The Finnish BNCT project has been - and remains - a cooperation project involving several institutes. In the early stages financing was provided by Tekes, the Academy of Finland, the Hospital District of Helsinki and Uusimaa/Helsinki University Central Hospital (HUS/HUCH), VTT, the University of Helsinki and the EU.

Radtek Oy was established in 1994 to commission the basic components for the treatment station with funding from SITRA - the Finnish National Fund for Research and Development, and Tekes. Since then Radtek Oy operations have been terminated and the company's share of the activity transferred to VTT. All in all, VTT since 1990 has invested enormously in the development of BNCT treatment and the BNCT irradiation station. These investments and collaboration with other Finnish partners and sponsors have resulted in the creation of a BNCT treatment station to match any in the world. In due course NC-Hoito Oy (Boneca Oy from 2002) was established to develop the treatment concept and to administer treatments. The current shareholders of the company are Sitra, Clinical Research Institute HUCS Ltd and VTT Ventures Oy.

## **8.2 Research Relying on the Research Reactor and Future Prospects**

### **8.2.1 BNCT Research and Service**

The basic commodity produced by the FiR 1 research reactor is neutron radiation, which can be exploited further to generate nuclear reactions and to produce radioactive isotopes. The primary fields of use include radiotherapy, research, education and isotope production. The research reactor retains strong links to the

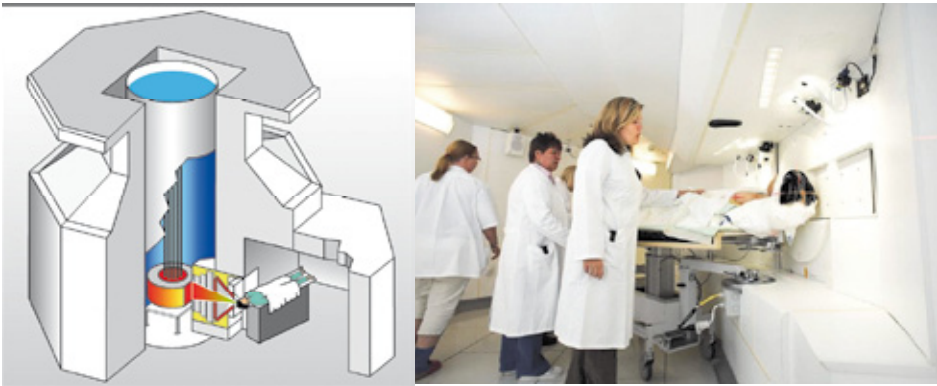
use and safety of nuclear energy, and the VTT Centre of Excellence in Nuclear Energy is in charge of its use. Support for education and research related to the original goal, i.e. the use of nuclear energy, remains an important application.

**Table 8.1.** The distribution of reactor operation days in 2009.

Purpose of use	%
BNCT activity	45
Isotope production and activation analysis	40
Training activity	10
Other irradiation tasks	5
<b>Total</b>	<b>100</b>

However, in terms of volume the most important activity in the near future will be Boron Neutron Capture Therapy (BNCT) and related research. This method is currently an important new option, also internationally, for treating certain malignant tumours. The most promising results in the treatment of head and neck cancers have been achieved in the treatment of tumours of the mouth and neck. The method will also continue to be used for treating brain tumour patients, and later on will include other cancers.

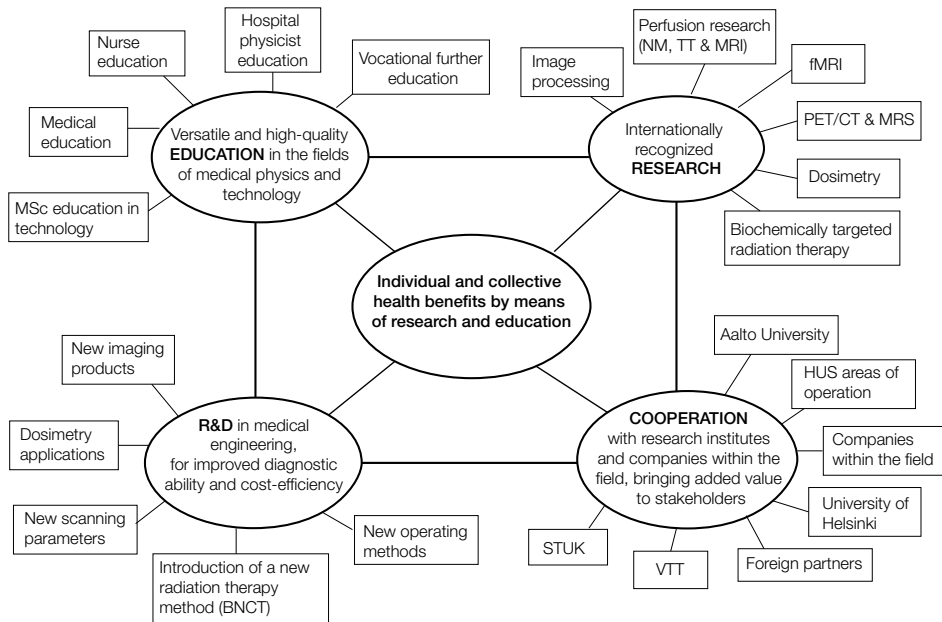
**Figure 8.1.** The BNCT treatment station operating in connection with the FIR 1 research reactor.



The treatment services are provided jointly by Boneca Oy - a company established for this particular purpose and owned by VTT, Clinical Research Institute HUCS Ltd and Sitra - and the Helsinki University Central Hospital of the Hospital District of Helsinki and Uusimaa (HUS) and VTT. A BNCT treatment station for radiation therapy has been built for the reactor, and in the late 1990s new premises were

constructed for this purpose in the reactor building. Overall, a wide range of organisations participate in the development of BNCT treatment activity, and in this connection a very extensive, multi-disciplinary field of competencies can be combined in the manner displayed in figure 8.2.

**Figure 8.2.** Connection of the development of BNCT treatment activity to a wide-ranging field of cooperation covering for example, the needs of education, research and product development.



The treatment activity is already an established practice and covered by a general quality assurance system for radiotherapy, although on an annual level the volumes still remain small. To date, more than 250 BNCT treatments have been administered, and more than 200 patients treated. The treated tumours have been primarily tumours that have recurred after previous treatments, advanced brain tumours that have recurred after surgery and conventional treatment, and head and neck cancer tumours. In addition to the treatment results achieved, the research papers published so far have studied dosage of boron carrier substance (boron phenylalanine) and relevant factors; other factors related to treatment techniques; and the efficacy and safety of the treatment method. Clinical studies are conducted in collaboration with the Department of Oncology at Helsinki University Central Hospital (HUCH). HUS has made a commitment to order at least 50 treatments a year from Boneca according to need. On the basis of the positive treatment results achieved in head and neck cancers, Boneca's strategic plans target a multiple

increase in the annual volume of treatments over the present level within the next few years.

In spite of the successful treatment results achieved over the past few years, published in renowned international medical journals, it must be noted that the number of treated patients has been relatively low. No extensive conclusions can therefore be drawn from them at this stage on the future clinical significance of the treatment. More trials and larger patient numbers are needed before more extensive and versatile introduction of the treatment method can be considered. A longer monitoring period will also be necessary for studying, for example, the duration of the treatment effect, and potential late-occurring adverse effects. Public research funding will therefore still be needed, at least for the next few years, for further development and diversification of this new treatment method alongside treatment activity operating on a commercial basis.

The vision held by Boneca Oy and others conducting research on boron neutron radiation therapy is that the volume of treatments will increase in the future and that Finland could become a future centre of research within this field.

In other words, future use of the FiR 1 research reactor for cancer treatment will increase substantially. Boneca's long-term strategic plan provides for replacement of the reactor in the long run by an accelerator-based treatment irradiation station placed at the hospital, although this is not expected to occur before 2023 at the earliest.

Alongside cancer treatments, a substantial proportion of reactor operation days are used for the production of short-lived isotopes, mainly for industrial tracer research and for medicinal purposes. Neutron activation analysis is currently employed mainly for electronics and chemistry industry process analyses. The demand for neutron radiation testing of electronics devices has been growing in recent years.

## **8.2.2 Education and Research in Medicine and Medical Physics**

In 1993 Finland initiated a review of dosimetry issues related to BNCT treatments, covering accumulation of knowledge in such fields as neutron dosimetry, dose planning, and radiobiology. All necessary basic surveys related to these topical areas had been completed by 1996, and research plans aiming at treatment activity were also presented publicly.

Since 1995 several young researchers who have been involved in extensive international projects have been working within the field of medical physics. The productivity of such activity is evidenced by the nine doctoral theses, nine graduate theses and one diploma thesis completed between 1995 and 2010 that fall within the field of medical physics. Two doctoral theses in the area of medical physics related to BNCT activity are currently in preparation. Most of the BNCT-related dosimetry



measurements have been performed as part of extensive international research cooperation, both in Europe and the U.S.

Thanks to BNCT operations the FiR 1 research reactor has evolved not only into a functional treatment station, but also into a significant education and research unit, conducting a notable amount of basic research within the field. For example, further development of neutron dosimetry towards individual dose planning is an important sub-area on which two University of Helsinki students are preparing their doctoral theses. In addition, the research reactor is authorised for one-year practical training of a hospital physicist.

Besides meeting the needs for basic training and offering a place for practical training of hospital physicists, the research reactor acts as an internationally recognised research unit relating to BNCT treatments which can combine wide-ranging theoretical and practical competencies in medical physics and neutron physics.

### 8.3 Research Reactor's Role in Ensuring Nuclear Energy Sector Competence and in Training Use

The FiR 1 reactor still plays a major role in support of the provision of higher education in the field of nuclear engineering. Students of Aalto University and Lappeenranta University of Technology (LUT) have traditionally used the reactor for conducting their practical work in reactor physics and reactor engineering. The practical work, although reduced in volume in recent years, still plays an important role in complementing the theoretical courses: familiarising future Masters of Science in Technology with the operation and control of nuclear reactors in an authentic environment. Aalto and LUT students use a total of 8-10 reactor days a year for their practical work. Thanks to the new Aalto Nuclear Safety programme there are no signs of the need declining.

With the closing down of other research reactors in the neighbouring areas, utilisation of the reactor for the needs of foreign education institutes and course organisers has increased over the past few years. The Master's programme in nuclear energy engineering of the KTH Royal Institute of Technology, Stockholm exploited the FiR 1 reactor at least until 2008. There are plans for similar arrangements with the universities of Tartu and Tallinn, as they are in the process of launching nuclear engineering education in Estonia in autumn 2011.

The supplementary training courses of Uppsala University for employees of Swedish nuclear power plants have begun to employ the FiR 1 research reactor on a regular basis. Practical teaching on the reactor has also been organised during courses arranged by companies operating within the nuclear engineering field.

Discussions have taken place on the use of the reactor on the national training course in nuclear safety (YK Course), but owing to the extent of the course the

most reasonable solution would be to provide the reactor work period as a separate course and restrict it to selected YK Course participants. At the moment the YK Course programme includes familiarisation with the FiR 1 reactor in the form of a lecture and an introductory visit.

A visit to the research reactor was organised in 2010 during the national course on nuclear waste management which had been arranged as a “pilot project”. On the basis of course feedback a similar visit to the research reactor will also be made part of the actual course. Since 2003, introductory visits to the research reactor have also formed a regular part of the course programme of Posiva’s staff training in nuclear waste management.

Expansion of the use of the research reactor as a teaching environment supporting training related to nuclear energy engineering is justified. Discussion should be held in the future on how the research reactor could additionally be employed for the training needs of authorities and actors, and possibly for other purposes. The FiR 1 reactor could offer a valuable complement, particularly to training of the personnel of the new nuclear power plant units.

The Baltic Research Reactor Network (BRRN) offers an opportunity to expand teaching usage. Another opportunity is to take advantage of the European Nuclear Education Network (ENEN), of which Aalto University and LUT are members. In issues concerning the use of the FiR 1 reactor for education and training purposes it would be recommended that VTT expand its cooperation with Aalto University. More flexibility regarding practical student work in the reactor would arise from training reactor operators from among Aalto University staff.

The envisioned strong expansion in use of the FiR 1 reactor for BNCT treatment may at some point pose a certain level of threat to the expansion of training activities. Whereas the current reactor time allocated for training purposes is eight hours a week, the long-term future visions reduce this to four hours. One solution to this could be the provision of summer courses, on the assumption that treatment use of the reactor will halt during the summer months.

**Table 8.2.** The numbers of students (LUT, Helsinki University of Technology TKK and KTH Royal Institute of Technology) and those in professional continuing education (Uppsala University, ÅF) in 2009 and 2010.

Year	2009	2010
LUT	8	21
TKK/Aalto University	52	45
KTH	0	0
Uppsala University	61	67
ÅF	16	0
<b>Total</b>	<b>137</b>	<b>133</b>

## 8.4 Current Status of Funding, Estimated Development and Diversification Needs

Along with the basic VTT funding, the sources of funding in the development phase of converting the research reactor for BNCT treatment activity included Tekes, Sitra, the power companies and the EU. The BNCT treatment operation using the VTT research reactor has already been relying on external revenues from the treatment activity for about a decade. The volume of treatment activity, however, has been growing relatively slowly, making this activity unprofitable for VTT in recent years. Even in more general terms, it has not been possible to make sufficient investments in the medical and technical development of this new treatment method in Finland.

On the basis of recent positive treatment results, the volume of BNCT treatment activity is expected to rise significantly within the next few years in accordance with the Boneca Oy strategy. Nevertheless, alongside the revenues from treatments implemented as purchased services the need for additional public research funding on the basis of normal application procedure will remain, at least for the time being. This is necessary to ensure that cancer tumour treatments based on BNCT technology can be developed further alongside the purchased services, and diversified to include treatment of other types of tumours.

Alongside BNCT activity it will also be necessary to develop the use of the research reactor for traditional forms of operation. It would be especially justifiable to expand its use as a teaching environment supporting training related to nuclear energy engineering, to include meeting the needs of power plant operators and other power plant operations.

In relative terms, many EU countries allocate far more public national funding than Finland for research activities related to research reactors, and the proportion of reactor maintenance costs attributable to commercial activity is substantially lower than in the case of FiR 1. Reactors focusing on neutron physics or neutron technology research typically offer neutron beam time without a separate charge to research projects selected according to scientific criteria, either through national or international financing arrangements. Such facilities include Institut Laue-Langevin (ILL) in Grenoble, FRM II in Munich and Berlin Neutron Scattering Centre BER II in Berlin.

Reactors suited for education and training purposes are typically used and financed by universities or special national training centres. Education and training operations are not normally expected to cover the costs of reactor maintenance, but only the marginal operating costs. International teaching and training has been organised under the auspices of the Eastern European Research Reactor Initiative (EERRI). In recent years, its focus of operation has shifted from education to induction training of the personnel of new nuclear energy states and organisations, often organised by IAEA. After the FiR 1 reactor, the reactor suited for educational purposes that is geographically closest to Finland is the VR-1 reactor of the Czech Technical University in Prague that belongs to the EERRI network.

The fact that in Europe and further afield the isotope production markets are heavily subsidised by public funding<sup>7</sup> significantly limits the opportunities for expanding the use of the research reactor as a provider of isotope production services.

In 2010 the amount of external revenues for research reactor funding was approximately 300 thousand euros, of which BNCT activity covered 60%. At this stage the volume of BNCT activity is not yet sufficient, and therefore some 175 thousand euros of the general expenses related to the FiR 1 research environment remained unaccounted for in 2010.

## 8.5 Recommendations

On the basis of the information processed by the committee there is a need to continue research reactor activity, taking into account its significance, both in terms of nuclear energy sector research and training, and in more general terms with a view to further development of medical applications, particularly BNCT treatments and their diversification.

This calls for expanding and ensuring the funding base, and requires that the versatile uses of the research reactor are taken into account in the process.

The use and application of the research reactor for educational and training purposes related to traditional nuclear energy production must be revived. The financial framework of these operations has nevertheless changed in Finland compared to the initial situation in the early 1970s, and consequently sufficient appropriations should be allocated for universities in order to expand the share of education and training on the research reactor.

The cooperation among VTT, Aalto University and Lappeenranta University of Technology must be strengthened with regard to education and training. In future, Aalto University could be more clearly the main provider of education and training services taking advantage of the research reactor. The precondition for this is that the co-financing needed for the maintenance of research reactor infrastructure for training purposes is taken into account in the funding arrangements.

Diversification of the basic research funding targeted for scientific and technical foundations of BNCT treatments requires cooperation among stakeholders in charge of the different sub-areas of operation, in order to ensure that the additional funding needs of activities focusing on both the medical foundations and the medical physics and technology are covered. Although VTT's general objectives - alongside the development of various technologies - also include support of security and welfare in society and the development of new technologies for promoting human health and wellbeing, an agreement should be made among stakeholders in charge of the various sectors with regard to BNCT activity, covering the overall financing required by the FiR 1 research reactor.

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7 The Supply of Medical Radioisotopes, An Economic Study of the Molybdenum-99 Supply Chain, NEA No. 6967, OECD 2010.

# 9 Key Conclusions and Recommendations

This chapter summarises the key conclusions and recommendations of the Committee for Nuclear Energy Competence in Finland for ensuring nuclear energy sector competence in the long run. More detailed conclusions have been written at the end of each chapter above, and these too have been jointly approved by the committee.

## **General Remarks about the Need for and Standard of Competence**

Concurrent with the continued use of the existing power plant units, the new Finnish nuclear facility projects require a substantial group of competent professionals at their design, construction and operation stages. The plant options for the new units are potentially of a type yet to be built in our country. The final disposal repository planned by Posiva is the first of its kind in the world. All this sets requirements for the development of the competence base in companies and in society as a whole. Through the obligations to the European Union and international conventions, Finland is also committed to the maintenance of national competence related to use and supervision of nuclear energy.

The standard of Finnish nuclear safety is high, and the Radiation and Nuclear Safety Authority (STUK) is an internationally recognised nuclear safety authority. The Finnish nuclear power plants operate reliably, achieving high load factors. Ensuring a high standard of operation requires constant development of the facilities, of the organisations operating them, and of nuclear safety competence. An advanced safety culture includes constant enhancement of nuclear safety, an obligation also set by the Nuclear Energy Act.

*Nuclear energy is used in Finland to the extent determined by Government and Parliament decisions. A strong national competence base is the prerequisite for safe and reliable operation of the existing and planned nuclear facilities.*

## **Nuclear Energy Sector Legislation and Regulation**

By law, the users of nuclear energy are responsible for the safety of their operations. Finnish nuclear facilities operate primarily within the framework of national nuclear energy legislation. More detailed standards concerning nuclear safety are provided by YVL guides drawn up by the Radiation and Nuclear Safety Authority (STUK) in its capacity as the authority in charge of nuclear safety.

National regulations will also play a key role in the future, even though the International Atomic Energy Agency (IAEA) conventions, nuclear safety standards and other standards provide global foundations for the regulations. The recent issue

of the first general nuclear safety directives within the EU (Euratom) will not bring any reduction in the importance of national regulations.

*Finnish nuclear energy regulation must continue to be developed to meet the highest nuclear safety requirements. High-standard legislation and up-to-date nuclear safety supervision are an essential part of the national competence base.*

### **Personnel Needs**

The nuclear energy sector needs highly educated personnel. According to the committee's survey, 80% of the personnel out of some 3,300 working within the sector have a higher education degree, typically in sciences or technical sciences. With regard to length of experience, the distribution graph resembles a two-humped camel: the personnel consist of both new and very experienced employees, but the number of those with 10 to 20 years of experience is small.

The nuclear energy sector is expanding, and the consequent increase in the number of personnel by 2025 is estimated at 38%. At that time, the sector would need 4,500 employees. The generational change also defines the need for training within the sector. The need for experts is the highest in power companies and Posiva. In quantitative terms, the following areas of competence will need the most additional personnel: construction engineering, automation and control room, mechanics and mechanical engineering, electrical engineering, process engineering, and quality management and inspections.

*In addition to the recruitment needs caused by the growth of the nuclear energy sector, new experts must also be found and trained to replace the retiring personnel. In all, by 2025 the field will need some 2,400 new employees with competence in the special features of the sector.*

### **Education and Training**

Among the areas of competence, the largest growth concerns the fields of 'traditional technology'. These experts are not required to have specialised in nuclear energy studies, but to have acquired the necessary competence in the special features of the nuclear sector – such as nuclear safety – as part of their minor subject or continuous professional development. Further education, such as postgraduate courses in the nuclear sector or specialist vocational qualifications, is provided by continuing education centres operating in connection with universities and other higher education institutions, and by a number of polytechnics. There is need for growth, for example, in quality management and project operations. Specialized training is also needed for security specialists operating within the nuclear energy sector.

The key fields of competence within the nuclear energy sector will in any case continue to constitute an area of operation requiring a substantial amount of expert personnel. A considerable number of the current experts are about to reach the retirement age.

Actual doctoral education focusing on the nuclear energy sector is provided in Finland only by Aalto University, Lappeenranta University of Technology (LUT) and the Laboratory of Radiochemistry of the University of Helsinki. In addition, many of the other doctors entering the sector have been educated by the Physics Department at the University of Jyväskylä. The Kuopio unit of the University of Eastern Finland provides doctoral education focusing on radiation protection.

*More full-time professors in the field of nuclear energy and other university instructors with in-depth knowledge of the sector will be needed for providing specialisation and minor subject education. The preconditions for this are top-level research within the field and a significant amount of postgraduate students. Cooperation among universities is necessary, for example, for the arrangement of competent minor subject teaching. Similar cooperation is also needed in polytechnics. It would be sensible to exploit the experts of various actors within the field for teaching purposes.*

*International educational cooperation is essential, especially at the postgraduate stage of studies. This can be effectively implemented, for example, through the exchange of students and researchers among universities and research institutions. In the nuclear energy sector, however, there are requirements set according to national discretion, particularly those concerning nuclear safety, that cannot be fully covered by international education. Special efforts must therefore be made to ensure high-standard national education.*

*Wide-ranging development of further education and supplementary training is also needed. A new area of training that could be mentioned is security sector training related to use of nuclear energy.*

According to recent studies there is also room for improvement in fields with less direct links to the nuclear energy sector, such as radiation protection training within the health care sector.

*Supplementary training should be developed with a view to improving radiation protection competence, particularly within the health care sector.*

When examining the overall contributions to education and research, Finland can be considered a small nation. Wide-ranging and effective exploitation of the national nuclear energy expertise and competencies must therefore be ensured. In practice, in-depth competence in special fields of nuclear energy engineering can be achieved only by working for several years after graduation in duties requiring special competencies. In Finland, the required competencies can be obtained mainly in high-level research and development duties, for example at VTT or universities.

*From the societal viewpoint it is justifiable to invest in high-standard research and education in the nuclear energy sector. The benefits from this are distributed over the entire sector and across industry in general, both as results applicable to relevant operations and as new competent professionals.*

### **Nuclear Safety Competence of the Radiation and Nuclear Safety Authority (STUK)**

The costs of nuclear safety supervision practised by the Radiation and Nuclear Safety Authority (STUK) are collected from the companies under supervision, which for its part ensures that sufficient supervisory resources are maintained. This is important with a view to safe and smooth implementation of projects for nuclear facilities, for example. STUK is a globally recognised nuclear safety authority. Its expertise is in equally great demand both in international forums and bilaterally.

*The high-level competence of the Radiation and Nuclear Safety Authority (STUK) and the resources facilitating efficient supervision are a benefit for the entire nuclear energy sector in Finland. The resources for supervision of nuclear safety must also be secured for the future in an enduring manner.*

*It is also justified to exploit the competence of STUK more extensively, for example in the development of international standards and nuclear safety in Finland's neighbouring areas.*

### **Research in Finland**

National research activity and related competence is an essential basis for safe use of nuclear energy. The development of national capabilities and their sufficiently extensive exploitation calls for long-term planning, adequate knowledge of the field, and international cooperation. International cooperation enables expansion of competencies and experimental preparedness, and gives access to significant research results.

Over the past few decades, nuclear safety research has been implemented in the form of public research programmes lasting 3 to 5 years. In 2004, the Nuclear Energy Act was amended with regulations concerning the funding of research projects within the sector. The research funds included in the State Nuclear Waste Management Fund (VYR) are collected annually from the companies involved and distributed through the National Nuclear Power Plant Safety Research (SAFIR) programme and the Finnish Research Programme on Nuclear Waste Management (KYT). The objective is to ensure competence within the sector in such a manner that the authorities will have the expertise and other capabilities necessary for safety assessments at their disposal if required.

The overall funding has not yet risen in real terms to the level of the early 1990s, even though funding has been increased in recent years. In 2010 total allocations



for nuclear energy research in Finland amounted to 73.5 million euros. Companies accounted for 72% of the total, VTT for 8% and the State Nuclear Waste Management Fund (VYR) for 6%. The share of Tekes and EU research programmes did not rise above five per cent. Two thirds of the total funding was used for nuclear waste research, one fifth for reactor safety research, and less than one tenth for fusion energy research.

Among nuclear power companies, both Fortum and Teollisuuden Voima (TVO) have significant nuclear energy research activities. The focus areas include extending the in-service life of nuclear power plant units, modernisation of existing and construction of new units, and nuclear waste management. The research and development conducted by Posiva aims at final disposal of spent nuclear fuel. As a new actor, Fennovoima is developing its own research operations. The companies also participate in coordinated national research projects as part of their own research activities.

Wide-ranging university-level research on the use of nuclear energy is conducted especially at Aalto University and Lappeenranta University of Technology. The Laboratory of Radiochemistry of the University of Helsinki and the Accelerator Laboratory of the University of Jyväskylä are also significant research organisations within the sector. Among research institutions, VTT has research activity covering several fields of competence within nuclear engineering, ranging from fission and fusion as sources of energy to study of all phases of the life cycle of a nuclear facility, including nuclear waste management.

In Finland, research activity related to nuclear energy is unable to provide in-depth coverage of all sub-areas, for example in nuclear engineering: top-level competence can only be achieved in a limited number. However, at the moment Finland lacks a comprehensive national strategy for the targeting of research resources.

*The primary responsibility for the financing of nuclear energy research now and in the future is borne by the companies operating within the sector. The Government for its part must ensure sufficient contribution to the development of Finnish research competence and to securing a high level of competence. This is largely effected through research funding from the State Nuclear Waste Management Fund (VYR).*

*Universities and research institutions conduct high-quality basic research and applied research, which play a major role in the development of competence. VTT is engaged in research on a broad front and serves the entire nuclear energy sector in various ways. The funding of this kind of research, upon which the practical applications and safety research of the use of nuclear energy are founded, must be ensured. Nuclear energy must be considered as an equal of other energy sources when contributions are directed for research.*

*The future needs and focus areas of Finnish nuclear energy sector research must be accurately defined and a long-term strategy drawn up for further development of research activity. This calls for a separate joint project among research organisations and other stakeholders within the field.*

With regard to emergency preparedness, Finland has made provisions against the release of radioactive materials into the environment. An initiating event for such a situation could be, for example, a nuclear power plant accident abroad or in Finland, or other incident associated with the use of radiation. Competencies in mitigating the spread of radioactive substances and the impacts of these on humans and the environment are the prerequisites of preparedness for radiation situations and rescue operations. This topical area is strongly linked with the research on the use of nuclear energy. Organisations actively involved in research within this field include the Radiation and Nuclear Safety Authority (STUK) and its cooperation partners, such as the Finnish Meteorological Institute and VTT.

*High-level research related to preparedness for radiation situations and environmental radiation supervision are crucial functions and in line with the overall good of Finnish society. The future financing of such research must be secured.*

### **Participation in International Research Activities**

Finnish nuclear energy sector actors participate in international research activity on a relatively broad front. In a small country not all research can be conducted independently, nor would it be practicable. However, own research results and facilities are also needed for gaining access to international cooperation.

The projects of the OECD Nuclear Energy Agency (NEA) and the EU (Euratom) are by far the most significant within the field. The Nordic Nuclear Safety Research Programme (NKS) projects are small in size, but essential with a view to joint Nordic competence. Finland and Sweden have common interests relating particularly to boiling water reactors, in use in both countries, and observation of the northern conditions. In the IAEA cooperation, on the other hand, the focus is on participation in different working groups and committees and on the related exchange of information. Universities and research institutions also have public and non-public bilateral cooperation agreements.

The significance of the EU's technology and research platforms as a channel of international cooperation is growing rapidly, bringing with it the expectation of an increase in the volume of international cooperation within the nuclear energy sector.

*International cooperation in the nuclear energy sector is essential. Nuclear safety research, for example, requires experimental facilities of such magnitude that it would be unreasonable to expect any one country to build them on its own.*

*Finnish participation in international projects has been typically effected under the auspices of relevant national projects. This enables active participation, but requires higher contributions for actual work conducted instead of mere participation and monitoring fees. For example, the OECD/NEA projects have generally been found useful, and the investments made in them profitable. The future of this proven mode of operation must also be secured.*

### **Research Infrastructure**

Research capabilities and competence form the basis for the national research services needed for the use and modernisation of nuclear facilities and the construction of new facilities. The national experimental research related to nuclear energy will supplement the internationally accessible research data, and facilitate the making of own contributions to ensuring the operability and development of safety systems.

The current Finnish infrastructure facilitates high-level research, for example with regard to preparedness for serious nuclear accidents. Examples of Finnish research projects and facilities with international significance include the thermal-hydraulic experimental facilities of Lappeenranta University of Technology as part of the developing research field of nuclear power plant processes, and the VTT test apparatus simulating aircraft impact.

A new important project in preparation is the investment in the VTT Centre for Nuclear Safety, in which the State Nuclear Waste Management Fund (VYR) and the power companies Teollisuuden Voima, Fortum, and Fennovoima will also participate. The objective is to centralise VTT's nuclear engineering competence in the Centre for Nuclear Safety and build modern premises for study of radioactive samples.

*The maintenance and renewal of the research infrastructure within the organisations involved requires significant and long-term national investments.*

*The VTT Centre for Nuclear Safety, with its material research capabilities, would bring extensive long-term benefits for the Finnish nuclear energy sector, and is therefore a justified investment in many ways. It seems that a permanent funding base for the project can be found between the Government and relevant companies.*

The operations of the VTT research reactor have focused in recent years on medical use (radiotherapy) and isotope production. BNCT treatments in particular are promising, and also involve medical teaching and research activities. In December 2011, the Government granted an operating licence for the research reactor until the end of 2023.

*The operation of the VTT research reactor should be secured, also taking into consideration its significance for nuclear energy sector research and education.*

*The use for education and training purposes should be revived and cooperation in this respect enhanced among VTT, Aalto University and Lappeenranta University of Technology.*

*Ensuring the operation of the research reactor requires securing the funding base for reactor operations, taking into account diversification of the targets for use, especially with regard to medical use and education.*

### **Promotion of National Cooperation**

The cooperation among nuclear energy sector actors should be encouraged on a continuous basis in order to enhance national competence. This does not refer to intervening in the competitive operations of the companies on the energy market, nor otherwise in the autonomy of the actors involved. Instead it means improving the operating conditions common to them all. Valuable contributions include the nuclear safety courses (YK Courses) that have been organised in a good cooperative spirit for some time, and the courses on nuclear waste management currently being initiated, as well as the Doctoral Programme for Nuclear Engineering and Radiochemistry beginning in 2012.

Development of research and training activity in the localities of nuclear power plants is fruitful with a view to cooperation. It is also important to be able to operate in one's own language in cooperation carried out within Finnish nuclear facilities and with the authorities. Up-to-date training in official practices within the sector is particularly needed in power companies.

*Universities, polytechnics and other training institutions, research institutes, companies and other stakeholders within the field should strive for wide-ranging cooperation in order to enhance the competence and knowledge base within the nuclear energy sector. For example, joint research and training projects and exchange of experts, as well as career advancement, are useful ways of developing the sector as a whole.*

*In the development of nuclear energy sector research and education it is important to observe both national and regional needs and synergies.*

*Competence related to official supervision is needed and must be continuously developed in collaboration with other stakeholders within the field.*

### **Exploiting the Competencies of the Finnish Entrepreneurial Sector**

Finland in many respects possesses world-class technical and information competence that can also be exploited commercially. Such competence is related, for example, to nuclear engineering, nuclear waste management, project management and consulting, and independent third-party evaluations.

Finnish business life is preparing for the forthcoming nuclear facility projects not only at the level of individual companies but also by actively developing mutual cooperation. FinNuclear and the branch groups of the Federation of Finnish Technology Industries are a clear indication of this. Fennovoima and Teollisuuden Voima, who are in charge of the new nuclear power plant projects, are also striving to involve Finnish industries and services as extensively as possible.

Since Finland lacks domestic nuclear power plant suppliers, the participation of Finnish companies in these projects would be mostly subcontracting and provision of services. In addition to the power companies, services are also needed by the main contractors and subcontractors implementing the projects, as well as the supervisory authorities. The projects require a substantial amount of official supervision at all levels of administration, and it is in the best interest of all parties involved that this activity runs smoothly and reliably.

*Development of competencies within the nuclear energy sector leads to results that can also be exploited on an international scale. The suppliers of equipment and services can take advantage of their own competencies in both domestic and international projects. Cooperation and networking among Finnish actors contributes to better opportunities for involvement in the projects.*

*To ensure smooth implementation of domestic nuclear facility projects, it is important to ensure that sufficient resources are allocated for official functions related to the projects, including at the level of regional and local authorities.*

## Appendix 1

### The Composition of the Committee for Nuclear Energy Competence in Finland

Some members of the Competence Committee at the press conference on 26 March 2012, from the left: Kaisa Koskinen, STUK, Marja-Leena Järvinen, STUK, Eija Karita Puska, VTT, Heikki Purhonen, LUT, Mikko Paunio, Ministry of Social Affairs and Health, Juhani Hyvärinen, Fennovoima, Riku Huttunen, Energy Market Authority (Chairman of the Committee), Petteri Kauppinen, Ministry of Education and Culture, Jaana Avolahti, Ministry of Employment and the Economy, Jarmo Ala-Heikkilä, Aalto University, Sami Hautakangas, Fortum, Jorma Aurela, Ministry of Employment and the Economy, Marjatta Palmu, Posiva, Miliza Malmelin, Ministry of the Environment, and Liisa Heikinheimo, TVO. The Competence Committee also had representatives from universities of Oulu, Jyväskylä and Helsinki and the FinNuclear Association.



#### Chair

Industrial Counsellor Riku Huttunen (Director General, Energy Market Authority, from 1 August 2011), Ministry of Employment and the Economy.

### **Members and deputy members:**

Petteri Kauppinen, Counsellor of Education, Ministry of Education and Culture  
Deputy member: Markku Suvanen, Senior Adviser, Ministry of Education and Culture  
Mikko Paunio, Ministerial Counsellor, Ministry of Social Affairs and Health  
Deputy member: Anneli Törrönen, Ministerial Adviser, Ministry of Social Affairs and Health  
Miliza Malmelin, Senior Adviser, Ministry of the Environment  
Deputy member: Magnus Nyström, Senior Specialist, Ministry of the Environment  
Timo Vanttola, Technology Manager, VTT Technical Research Centre of Finland  
Deputy member: D. Sc. (Tech.) Eija Karita Puska, Principal Scientist, VTT Technical Research Centre of Finland  
Kaisa Koskinen, Development Manager, Radiation and Nuclear Safety Authority (STUK)  
Deputy member: Marja-Leena Järvinen, Deputy Director, Radiation and Nuclear Safety Authority (STUK)  
Rainer Salomaa, Professor, Aalto University  
Deputy member: D. Sc. (Tech.) Jarmo Ala-Heikkilä, Senior Research Associate, Aalto University  
Riitta Kyrki-Rajamäki, Professor, Lappeenranta University of Technology (LUT)  
Deputy member: Heikki Purhonen, Senior Research Scientist, Lappeenranta University of Technology (LUT)  
Jukka Lehto, Professor, University of Helsinki  
Deputy member: Risto Harjula, University Lecturer, University of Helsinki  
Juha Äystö, Professor, University of Jyväskylä  
Deputy member: Jussi Timonen, Professor, University of Jyväskylä  
Mikko Halttunen, Project Manager, University of Oulu  
Deputy member: Martti Hyry, Director, University of Oulu  
Leena Jylhä, Director, FinNuclear Association/Prizztech Oy  
Deputy member: Katja Silvanto, Project Manager, FinNuclear Association/Prizztech Oy

### **Permanent experts:**

Juhani Hyvärinen, Chief Nuclear Officer, Fennovoima Ltd  
Deputy member: Nina Koivula, Human Resources Director, Fennovoima Ltd  
Sami Hautakangas, Head of Nuclear R&D and Waste Management, Fortum  
Deputy member: Olli Kymäläinen, Project Manager, Fortum  
Marjatta Palmu, Senior Adviser, Posiva Ltd  
Deputy member: Elisa Vahteristo, Personnel Manager, Posiva Ltd  
Liisa Heikinheimo, R&D Manager, Teollisuuden Voima Oyj  
Deputy member: Jaana Isotalo, Group Manager, Teollisuuden Voima Oyj

## **Secretaries:**

Jorma Aurela, Chief Engineer, Ministry of Employment and the Economy  
Eriika Melkas, Senior Inspector, Ministry of Employment and the Economy  
Jaana Avolahti, Counsellor, Ministry of Employment and the Economy  
Mauri Riihonen, Counsellor, Ministry of Employment and the Economy

## **Divisions of the Committee for Nuclear Energy Competence in Finland**

**Division 1**, Conducting the committee's survey and organising the data obtained

Jorma Aurela, Chief Engineer, MEE (head of division)  
Tellervo Brandt, Change Agent, Fortum  
Jaana Isotalo, Group Manager, TVO  
Janne Juntunen, Research Consultant, Innolink Research Oy  
Kaisa Koskinen, Development Manager, STUK  
Marjatta Palmu, Senior Adviser, Posiva Ltd  
Elisa Vahteristo, Personnel Manager, Posiva Ltd

The division convened four times.

## **Division 2, Education**

Jarmo Ala-Heikkilä, Senior Research Associate, Aalto University (head of division)  
Jorma Aurela, Chief Engineer, MEE  
Anssi Auvinen, Professor, University of Tampere  
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Marja-Leena Järvinen, Deputy Director, STUK  
Petteri Kauppinen, Counsellor of Education, Ministry of Education and Culture  
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Leena Korpinen, Professor, Tampere University of Technology  
Jari Koskinen, Professor, Aalto University  
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Jukka Lehto, Professor, University of Helsinki  
Kauko Leiviskä, Professor, University of Oulu  
Jussi Leveinen, Professor, Aalto University



Marjatta Palmu, Senior Adviser, Posiva Ltd  
Mikko Paunio, Ministerial Counsellor, Ministry of Social Affairs and Health  
Mauri Riihonen, Chief Counsellor, MEE  
Rainer Salomaa, Professor, Aalto University  
Heli Talja, Technology Manager, VTT  
Jussi Timonen, Professor, University of Jyväskylä  
Anita Vastamäki, Head of Unit, Aalto University Professional Development (Aalto PRO)  
Juha Äystö, Professor, University of Jyväskylä

The division convened four times.

### **Division 3, Industry**

Juhani Hyvärinen, Chief Nuclear Officer, Fennovoima (head of division)  
Leena Jylhä, Director, FinNuclear  
Olli Kymäläinen, Project Manager, Fortum  
Martti Kätkä, Director, Federation of Finnish Technology Industries  
Keijo Latvala, Head of Department, TVO  
Martti Vilpas, Assistant Director, STUK

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### **Division 4, Infrastructure**

Heikki Purhonen, Senior Research Scientist, LUT (head of division)  
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Sami Hautakangas, Head of Nuclear R&D and Waste Management, Fortum  
Liisa Heikinheimo, R&D Manager, TVO  
Rauno Julin, Professor, University of Jyväskylä  
Marja-Leena Järvinen, Deputy Director, STUK  
Riitta Kyrki-Rajamäki, Professor, LUT  
Eija Karita Puska, Principal Scientist, Team Leader, VTT  
Risto Sairanen, Section Head, STUK  
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The division convened four times.

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Marjatta Palmu, Senior Adviser, Posiva Ltd  
Arja Saarenheimo, Principal Scientist, Team Leader, VTT  
Tuomo Sevon, Senior Scientist, VTT  
Kaisa Simola, Principal Scientist, Team Leader, VTT  
Riitta Zilliacus, Senior Scientist, VTT

#### **Division 5, Research**

Eija Karita Puska, Principal Scientist, Team Leader, VTT  
Jaana Avolahti, Counsellor, MEE  
Sisko Salomaa, Professor, STUK  
Marja-Leena Järvinen, Deputy Director, STUK  
Kaisa Koskinen, Operation Development Manager, STUK  
Sami Hautakangas, Head of Nuclear R&D and Waste Management, Fortum  
Liisa Heikinheimo, R&D Manager, TVO  
Juhani Hyvärinen, Chief Nuclear Officer, Fennovoima  
Marjatta Palmu, Senior Adviser, Posiva Ltd  
Rainer Salomaa, Professor, Aalto  
Jarmo Ala-Heikkilä, Senior Research Associate, Aalto  
Riitta Kyrki-Rajamäki, Professor, LUT  
Jukka Lehto, Professor, University of Helsinki  
Juha Äystö, Professor, University of Jyväskylä  
Kari Rasilainen, Principal Scientist, VTT  
Seppo Karttunen, Principal Scientist, VTT  
Timo Vanttola, Technology Manager, VTT  
Seppo Vuori, Customer Manager, VTT  
Pentti Kauppinen, Technology Manager, VTT  
Eila Lehmus, Technology Manager, VTT  
Heli Talja, Technology Manager, VTT  
Jari Hämäläinen, Technology Manager, VTT

The contacts required for writing chapter 4 were mainly conducted by e-mail, and in preparation of chapter 6 the division convened four times.

### **Division 6, Research reactor**

Jaana Avolahti, Counsellor, MEE (head of division)

Raija Asola, Ministerial Counsellor, Ministry of Social Affairs and Health

Olli Vilkkamo, Head of Unit, STUK

Jarmo Ala-Heikkilä, Senior Research Associate, Aalto University

Iiro Auterinen, Principal Scientist, FiR 1 Reactor Manager, VTT

Seppo Vuori, Responsible Manager of the Research Reactor, VTT

Pirjo Kutinlahti, Counsellor, MEE

The division convened four times.

Talvivaara Sothamo Ltd is planning to start uranium extraction in this facility in 2012–2013. The goal for uranium production is 350–500 tonnes of yellow cake. It still needs an environmental permit and the start up permit from STUK. Picture is taken in early 2012.



# Appendix 2

## Survey

### MINISTRY OF EMPLOYMENT AND THE ECONOMY – SURVEY ON NUCLEAR ENERGY SECTOR COMPETENCE

#### REGISTER INFORMATION (RECORDED AUTOMATICALLY)

E-mail address \_\_\_\_\_

0. Target group					
1.	<input type="checkbox"/>	Group 1	3.	<input type="checkbox"/>	Group 3
2.	<input type="checkbox"/>	Group 2	4.	<input type="checkbox"/>	Group 4

#### BACKGROUND INFORMATION

1. Name and address of your company/organisation \_\_\_\_\_

2. Name of the respondent \_\_\_\_\_

3. Your telephone number \_\_\_\_\_

#### PERSONNEL RESOURCES

1. How many persons with competence in the special features of the nuclear energy sector are presently employed by your organisation (employment relationship with the organisation)? Give the number of these persons according to how many years of experience each of them has in the nuclear energy sector (count each person only once).				
<b>Nuclear energy experts (higher university/polytechnic degree suitable for the industry)</b>	0–5 years in the nuclear sector	6–10 years in the nuclear sector	11–20 years in the nuclear sector	more than 20 years in the nuclear sector
Research, development and planning related to nuclear waste management				
Security (incl. business security and fire safety)				
Safeguards				
Radiation protection				
Radiochemistry				
Water chemistry				
Nuclear and particle physics				
Operators (nuclear power plant shift supervisors, simulator instructors, etc.)				
Electrical engineering				
Automation and control room				
Mechanics/mechanical engineering				
Construction engineering				
Human factors				
Reactor physics and dynamics				
Nuclear fuel				
Thermal hydraulics				
Process engineering				
Severe accidents				
Material engineering (nuclear facility materials, failures, component manufacturing, inspection and lifetime management)				
Probabilistic Risk Analysis (PRA)				
Quality management and inspections				
Project management				
Other duties requiring nuclear sector competence				
A: Please specify				

B: How many of the persons above are -doctors: _____ -licentiates: _____				
<b>Nuclear energy experts (lower university/polytechnic degree suitable for the industry or equivalent)</b>	0–5 years in the nuclear sector	6–10 years in the nuclear sector	11–20 years in the nuclear sector	more than 20 years in the nuclear sector
Research, development and planning related to nuclear waste management				
Security (incl. business security and fire safety)				
Safeguards				
Radiation protection				
Radiochemistry				
Water chemistry				
Nuclear and particle physics				
Operators (nuclear power plant shift supervisors, simulator instructors, etc.)				
Electrical engineering				
Automation and control room				
Mechanics/mechanical engineering				
Construction engineering				
Human factors				
Reactor physics and dynamics				
Nuclear fuel				
Thermal hydraulics				
Process engineering				
Severe accidents				
Material engineering (nuclear facility materials, failures, component manufacturing, inspection and lifetime management)				
Probabilistic Risk Analysis (PRA)				
Quality management and inspections				
Project management				
Other duties requiring nuclear sector competence				
A: Please specify				
<b>Blue-collar employees in the nuclear energy sector (e.g. secondary-level vocational qualification)</b>	0–5 years in the nuclear sector	6–10 years in the nuclear sector	11–20 years in the nuclear sector	more than 20 years in the nuclear sector
Electrical engineering				
Automation technology				
Mechanics/mechanical engineering				
Construction engineering				
Chemistry/process engineering				
Security (incl. business security and fire safety)				
Radiation protection				
Other blue-collar duties				
A: Please specify				

2. How many nuclear energy experts would your organisation need in the future, including existing employees? Enter the number of persons under the appropriate year.			
<b>Special nuclear energy experts (higher university/polytechnic degree)</b>	2015	2020	2025
Research, development and planning related to nuclear waste management			
Security (incl. business security and fire safety)			
Safeguards			
Radiation protection			
Radiochemistry			
Water chemistry			
Nuclear and particle physics			
Operators (nuclear power plant shift supervisors, simulator instructors, etc.)			
Electrical engineering			

Automation and control room			
Mechanics/mechanical engineering			
Construction engineering			
Human factors			
Reactor physics and dynamics			
Nuclear fuel			
Thermal hydraulics			
Process engineering			
Severe accidents			
Material engineering (nuclear facility materials, failures, component manufacturing, inspection and lifecycle management)			
Probabilistic Risk Analysis (PRA)			
Quality management and inspections			
Project management			
Other duties requiring nuclear sector competence			
A: Please specify			
_____			
B: How many of the persons above are			
-doctors: _____			
-licentiates: _____			
<b>Nuclear energy experts (lower university/polytechnic degree suitable for the industry or equivalent)</b>	2015	2020	2025
Research, development and planning related to nuclear waste management			
Security (incl. business security and fire safety)			
Safeguards			
Radiation protection			
Radiochemistry			
Water chemistry			
Nuclear and particle physics			
Operators (nuclear power plant shift supervisors, simulator instructors, etc.)			
Electrical engineering			
Automation and control room			
Mechanics/mechanical engineering			
Construction engineering			
Human factors			
Reactor physics and dynamics			
Nuclear fuel			
Thermal hydraulics			
Process engineering			
Severe accidents			
Material engineering (nuclear facility materials, failures, component manufacturing, inspection and lifetime management)			
Probabilistic Risk Analysis (PRA)			
Quality management and inspections			
Project management			
Other duties requiring nuclear sector competence			
A: Please specify			
_____			
<b>Blue-collar employees in the nuclear energy sector (e.g. secondary-level vocational qualifications)</b>	2015	2020	2025
Electrical engineering			
Automation technology			
Mechanics/mechanical engineering			
Construction engineering			
Chemistry/process engineering			
Security (incl. business security and fire safety)			
Radiation protection			
Other blue-collar duties			
A: Please specify			
_____			

3. What other nuclear energy experts might your organisation need in the future and how many?

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RESEARCH INFRASTRUCTURE AND RESEARCH PRIORITIES

4. Which software does your organisation have available for nuclear energy research? Indicate the manner in which the software is linked to the nuclear energy sector using the following classification: **a) nuclear-energy-specific; b) strong link to the nuclear energy sector; c) used in the nuclear energy sector**

SOFTWARE	BENEFIT			NUMBER OF USERS	GROUNDS FOR USE			LINK TO THE NUCLEAR ENERGY SECTOR		
	insignificant	significant	considerable		licence	cooperation agreement	other	a.	b.	c.
a. <input type="checkbox"/> APROS	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. <input type="checkbox"/> TRACE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. <input type="checkbox"/> RELAP	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. <input type="checkbox"/> TRAB3-D/HEXTRAN	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. <input type="checkbox"/> FLUENT	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. <input type="checkbox"/> CFX	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. <input type="checkbox"/> NEPTUNE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. <input type="checkbox"/> MELCOR	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i. <input type="checkbox"/> MAAP	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
j. <input type="checkbox"/> SERPENT	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
k. <input type="checkbox"/> CASMO	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
l. <input type="checkbox"/> HELIOS	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
m. <input type="checkbox"/> ABACUS	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
n. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
o. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
p. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
q. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
r. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. Which databases does your organisation have available for nuclear energy research? Indicate the manner in which the software is linked to the nuclear energy sector using the same classification as in the question above.

SOFTWARE	BENEFIT			NUMBER OF USERS	GROUNDS FOR USE				LINK TO THE NUCLEAR ENERGY SECTOR		
	insignificant	significant	considerable		licence	cooperation agreement	own	other	a.	b.	c.
a. <input type="checkbox"/> OECD/NEA COMPSIS	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. <input type="checkbox"/> OECD/NEA FIRE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. <input type="checkbox"/> OECD/NEA ICDE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. <input type="checkbox"/> OECD/NEA SCAP	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. <input type="checkbox"/> OECD/NEA OPDE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. <input type="checkbox"/> OECD/NEA ISOE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. <input type="checkbox"/> OECD/NEA TDB	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
j. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
k. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
l. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
m. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
n. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
o. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
p. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
q. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
r. <input type="checkbox"/> Other, please specify	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6. What experimental facilities does your organisation use/have available for nuclear-energy-sector research?

---



---

7. How and to what extent has each of the facilities been used for such research?

\_\_\_\_\_

\_\_\_\_\_

8. The results achieved?

\_\_\_\_\_

\_\_\_\_\_

9. Further plans related to these facilities?

\_\_\_\_\_

\_\_\_\_\_

10. Does your organisation produce software related to the nuclear energy sector? If so, please specify.

\_\_\_\_\_

\_\_\_\_\_

**RESEARCH FUNDING**

The purpose of questions 11–14 is to collect up-to-date information on the amount of money used for nuclear research in Finland in 2010. In other words, we are updating the information acquired through earlier similar surveys (in 2007, 2002 and 1999).

The goal is simply to obtain an answer to the question: what amount of money was spent on nuclear research in Finland in 2010?

Replies to the nearest 10–100 thousand Euros (where applicable) will be sufficient.

Further instructions for TVO, Fortum, Fennovoima and Posiva

Funding from the State Nuclear Waste Management Fund (VYR) should be excluded from the sums reported. Instead, any research commissioned by your organisation from other parties should be included in the total volume.

Further instructions for research institutions

Here, we are not inquiring about the total volume of research conducted by your organisation. The question is one of how much funding from public sources your organisation is using for nuclear research (= budget funding, funding from foundations, TEKES funding, EU funding, and VYR funding). We can obtain the amount of VYR funding from funding decisions, but please indicate whether the said funding is included in the sums you report to ensure that they are not duplicated.

Any research commissioned by power companies or STUK should not be reported here, since they are included in the sums they report separately. Nor is it intended that any research commissioned by foreign companies, for their internal purposes only, is reported here.

11. What was the amount of money your organisation used for financing nuclear research in 2010? (sums in thousands of euros)

\_\_\_\_\_

12. How is funding provided by you divided among the following groups? (in percentages) Please report the total amount in accurate figures so that the sum total is 100%.

Internal research _____%	Funding for international programmes _____%
Funding for national programmes (other than VYR) _____%	Other, please specify _____%
Commissioned research _____%	

13. How is the funding reported above divided among the following sectors of research? (in percentages) Please report the total amount in accurate figures so that the sum total is 100%.

Nuclear power plant safety: the existing facilities _____%	Environment etc. _____%
Nuclear power plant safety + fuel cycle: GenIV _____%	Fusion _____%
Nuclear waste _____%	Other, please specify _____%



14. How much money does your organisation receive from the EU for nuclear research? (sums in thousands of euros)  
Please note: TACIS or other such funding is NOT included here. Improvement projects of nuclear facilities in neighbouring areas and Safeguards issues are also excluded.

\_\_\_\_\_

\_\_\_\_\_

15. Which international research infrastructure does your organisation use for cooperation in nuclear research?

\_\_\_\_\_

\_\_\_\_\_

16. Is the research infrastructure of your organisation available for cooperation in international nuclear research?

\_\_\_\_\_

\_\_\_\_\_

17. Cooperation organisations?

\_\_\_\_\_

\_\_\_\_\_

18. Extent of cooperation in 2010?

A: Own work contribution, in person  
months: \_\_\_\_\_

B: Estimate of cooperation partner's work contribution, in person  
months: \_\_\_\_\_

19. Which domestic or international research infrastructure would your organisation need to join/what is lacking?

\_\_\_\_\_

\_\_\_\_\_

**INTERNATIONAL RESEARCH**

20. Participation of the organisation in international nuclear research.

A: Research projects

		Name	Sector	Overall budget	Finnish organisation	Budget 2011 of the Finnish organisation	Contact person	Website, if any
OECD/NEA	<input type="checkbox"/> Nuclear waste management	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Nuclear safety	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Radiation protection	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Other	_____	_____	_____	_____	_____	_____	_____
EU (Euratom)	<input type="checkbox"/> Nuclear waste management	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Nuclear safety	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Radiation protection	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Other	_____	_____	_____	_____	_____	_____	_____
EU (Others)	<input type="checkbox"/> Nuclear waste management	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Nuclear safety	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Radiation protection	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Other	_____	_____	_____	_____	_____	_____	_____
NKS	<input type="checkbox"/> Nuclear waste management	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Nuclear safety	_____	_____	_____	_____	_____	_____	_____
	<input type="checkbox"/> Radiation	_____	_____	_____	_____	_____	_____	_____
		_____	_____	_____	_____	_____	_____	_____

	protection <input type="checkbox"/> Other							
IAEA	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Radiation protection <input type="checkbox"/> Other	_____	_____	_____	_____	_____	_____	_____
Other international projects	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Radiation protection <input type="checkbox"/> Other	_____	_____	_____	_____	_____	_____	_____

**B. Technology and research consortiums (e.g. SNE-TP, IGD-TP, MELODI)**

Name	Sector	Number of members/membership	website address
a. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
b. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
c. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
d. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
e. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
f. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
g. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
h. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
i. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
j. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
k. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____
l. _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other	_____	_____

**C. Bilateral agreements (so-called framework agreements, not single projects)**

Parties	Sector
a. _____ & _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other
a. _____ & _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety <input type="checkbox"/> Other
a. _____ & _____	<input type="checkbox"/> Nuclear waste management <input type="checkbox"/> Radiation protection <input type="checkbox"/> Nuclear safety



EDUCATION PROVISION

Questions 21–24 are intended solely for the University of Helsinki, Lappeenranta University of Technology, Aalto University and Jyväskylä University.

21. Are you implementing or planning education programmes within fields that are significant for the nuclear energy sector? (Fields listed under section "Personnel Resources")		
1.a	Higher university/polytechnic degree (Master's degree, MSc Tech, MSc or equivalent)	<input type="checkbox"/> Implementing <input type="checkbox"/> Not implementing
1.b	Lower university/polytechnic degree (Bachelor's degree, BSc or equivalent)	<input type="checkbox"/> Implementing <input type="checkbox"/> Not implementing
2.	Scientific post-graduate degree (licentiate's or doctor's degree or equivalent / LicSc, DSc, PhD)	<input type="checkbox"/> Implementing <input type="checkbox"/> Not implementing
3.	Supplementary education	<input type="checkbox"/> Implementing <input type="checkbox"/> Not implementing

if you have answered "not implementing" for all three questions above, ignore questions 22–24.

<p>22. Provision of basic and further education programmes significant for the nuclear energy sector at the end of 2010.</p> <p>A. Which training programmes or separate courses significant for the nuclear energy sector are you offering?</p> <hr/> <p>B. What degree does the training lead to, or what degree is the course part of?</p> <hr/> <p>C. What is the student volume in these training programmes (intake and graduates per year) or courses (number of participants per year)?</p> <hr/> <p>D. What are the instructor resources available for these programmes and courses (number of instructors and division of tasks, e.g. professors, lecturers, assistants)?</p> <hr/> <p>E. What are the key advanced courses in the training programme (headlines and extent)?</p> <hr/> <p>F. Hyperlink to electronic training programme?</p> <hr/>
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<p>23. Planned extensions of basic and further education programmes significant for the nuclear energy sector.</p> <p>A. Which training programmes or new courses significant for the nuclear energy sector are you planning to offer in the future?</p> <hr/> <p>B. What degree does the training lead to, or what degree is the course part of?</p> <hr/> <p>C. What is the planned volume (training programme: intake and graduates per year; course: number of participants per year)?</p> <hr/> <p>D. What are the key courses in the new training programme (headlines and extent)?</p> <hr/>
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<p>E. What is the intended implementation schedule?</p> <hr/>
<p>F. What are the preconditions for implementation of the plans?</p> <hr/>

<p><b>24. Provision of supplementary education courses significant for the nuclear energy sector.</b></p>
<p>A. What kind of supplementary education significant for the nuclear energy sector are you offering or planning to offer?</p> <hr/>
<p>B. Which basic degree constitutes the starting level?</p> <hr/>
<p>C. What is the student volume (students per year)?</p> <hr/>
<p>D. What are the key courses (headlines, duration in weeks and extent in credit points)?</p> <hr/>
<p>E. What is the intended implementation schedule?</p> <hr/>
<p>F. What are the preconditions for implementation of the planned courses?</p> <hr/>

<p><b>25. Personnel development methods</b></p>
<p>A. What kind of development methods does your organisation use to acquire nuclear sector competence for the personnel and to what extent (person-days per year)? (E.g. on-the-job learning, various trainee programmes, work induction, mentoring, internal training, outside courses, etc.)</p> <hr/>
<p>B. How much nuclear sector training are you implementing internally? (E.g. number of training days/person/year)</p> <hr/>
<p>C. What kind of nuclear sector training are you implementing internally? (Themes of training, extent in training days)</p> <hr/>
<p>D. How much nuclear sector training do you acquire externally? (E.g. number of training days/person/year)</p> <hr/>
<p>E. What kind of nuclear sector training are you seeking externally? (Provider of training, themes of training, extent in training days)</p> <hr/>
<p>F. What kind of additional needs do you perceive in the provision of training for nuclear sector personnel?</p> <hr/>

Question 26 is intended for all except the University of Helsinki , Lappeenranta University of Technology, Aalto University and Jyväskylä University.

26. What kind of nuclear sector training are you offering to persons outside your own organisation? (Themes of training, extent in training days)

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27. Finally, please give feedback on the subject in your own words.

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**THANK YOU FOR RESPONDING TO THE SURVEY!**

## Appendix 3

### Descriptions of Educational Institutions

In addition to the actual survey, universities and polytechnics providing education and training within the field of technology were sent a request to write a description of no more than two pages about their operations, focusing on nuclear energy sector education and research. The following headlines were given:

- Description of the university/polytechnic
- Degree programme education
- Research activities
- Supplementary education
- Future prospects of the university/polytechnic (continuity and new initiatives)

This appendix presents the replies received from the educational institutions. The replies have been placed in alphabetical order, first the universities (8 replies, a total of 16 universities in Finland) and then the polytechnics (4 responses, a total of 25 polytechnics in Finland):

- Aalto University
- Lappeenranta University of Technology (LUT)
- Tampere University of Technology
- University of Eastern Finland
- University of Helsinki
- University of Jyväskylä
- University of Oulu
- Åbo Akademi University
- Central Ostrobothnia University of Applied Sciences (polytechnic)
- Kajaani University of Applied Sciences (polytechnic)
- Oulu University of Applied Sciences (polytechnic)
- Satakunta University of Applied Sciences (polytechnic)

In addition, the training provision within the security sector was reviewed separately. The following key educational institutions submitted their replies:

- Aalto PRO
- Laurea
- Police College of Finland
- Tampere University of Applied Sciences
- Tampere University of Technology
- Turku University of Applied Sciences

# The Provision of Education within the Nuclear Energy Sector in Universities

## Aalto University

### 1. Description of the University

Aalto University was created through the merger of three separate Finnish universities in 2010. At the beginning of 2011 it was formed into six separate higher education institutions: the School of Engineering (Aalto-ENG); the School of Chemical Technology (Aalto-CHEM); the School of Science (Aalto-SCI); the School of Electrical Engineering (Aalto-ELEC); the School of Economics; and the School of Arts, Design and Architecture. In 2010, Aalto University had 19,516 (13,725) graduate and postgraduate students and a staff of 4,685 (3,187), of whom 338 (234) were professors. The number of Master's degrees passed was 2,312 (1,887) and that of Doctoral degrees 184 (153). The figure in brackets represents the technical schools. Further information is available at: <http://www.aalto.fi/>

### 2. Degree Programme Education

The technical schools of Aalto University do not have special training programmes in the field of nuclear energy, but there are several degrees that are related to nuclear technology. The most important of these are:

- Degree programme in automation and systems technology (automation, information technology and systems)
- Degree programme in electronics and electrical engineering (electrical systems)
- Degree programme in energy and HVAC technology (energy technology)
- Degree programme in geoinformatics (geoinformatics)
- Degree programme in information networks (man and interaction, information-intensive business)
- Degree programme in mechanical engineering (materials technology in mechanical engineering, technical mechanics)
- Degree programme in material science and engineering (applied material science, processing of materials)
- Degree programme in engineering physics and mathematics (engineering physics, energy sciences, mechanics, systems and operation research)
- Degree programme in computer science and engineering (computer science)
- Degree programme in industrial engineering and management (work psychology and management)
- Degree programmes in structural and environmental engineering (structural engineering, construction materials and structural physics, geoengineering, foundation and rock engineering, engineering geology, and applied geophysics).



The fields of study mentioned in the brackets are the key subjects of specialisation, with several professors in charge of implementing each. Part of a matrix structure, the professors can belong to different schools of the University (e.g. in energy sciences both SCI and ENG).

The degree structure includes Bachelor of Science in Technology, Master of Science in Technology, Licentiate in Technology and Doctor of Science in Technology. The studies consist of modules, and optional courses in nuclear engineering can be included in the degree programmes of most of these.

### 3. Research Activities

Aalto University has versatile nuclear-energy-related special competence dispersed into several research units. The number of postgraduate students and specialists within the field is counted in dozens.

The fission and fusion research groups of the Department of Applied Physics are in charge of traditional reactor and radiation physics education, with a total of almost thirty researchers and postgraduate students. The research practised by these groups is mutually highly synergistic and heavily computational. In addition to using the department's own computational resources the groups exploit the relevant resources of the IT Centre for Science Ltd (CSC). The fission group has conventional nuclear technical measuring devices at its disposal, which are also used for practical student work. Furthermore the Triga research reactor, under VTT management and located at the Otaniemi campus, is used for laboratory courses in nuclear engineering (see chapter 8). The fission group participates in numerous EU nuclear engineering training projects, the results of which are exploited through the European Nuclear Education Network (ENEN).

An important role in Aalto fission group research in nuclear engineering is played by the NETNUC project, which is part of the Academy of Finland's SusEn Programme (2008-11). In this project, Aalto investigates the world of phenomena associated with new types of reactors in collaboration with VTT and under the coordination of Lappeenranta University of Technology (LUT). The objective of NETNUC is to develop increasingly safe and cost-efficient reactors, the environmental impacts of which would be minimised and which would have fuel resources available for decades of use. With regard to experimental activity, the group's strategic goal is to become Finland's representative in some of the major European fission technology research projects (for example the Jules Horowitz test reactor). The fission group is involved in the SAFIR2014 and KYT2014 research programmes. The experimental activities of the fusion group already focus on Euratom's two international tokamak test facilities, AsdexUG and JET, with the ITER test reactor constituting the latest challenge.

Aalto University's Department of Civil and Environmental Engineering conducts research in engineering geology, rock engineering and geoengineering from the

perspective of final disposal of nuclear waste. The research group develops the School of Engineering's research competence related to geological final disposal sites of nuclear waste with regard to geological, hydrogeological, hydrogeochemical and rock mechanical characterisation of bedrock. The focus of research is on modelling of the long-term safety of geological final disposal and on development of related methods, assessment of the properties of natural materials as engineered release barriers (such as bentonite buffer or filling), and design and optimal construction of underground facilities for final disposal. The research also takes account of the requirements for geological final disposal posed by nuclear waste produced by transmutation. The material sciences and materials research groups of mechanical engineering also participate in nuclear waste research. Aalto University researchers engaged in nuclear waste research are also involved, for example, in KYT2014 and the PETRUS2 training project, and participate in the geological disposal platform IGD-TP.

The research group for material engineering in the Department of Engineering Design and Production possesses wide-ranging and profound experimental and theoretical competence concerning materials, welding and NDT research on nuclear power plants and nuclear waste final disposal canisters. The group has comprehensive experimental facilities of its own, and its activities are supported by efficient national and international cooperation.

Aalto University is currently conducting several activities related to programmable automation, safety-critical programming, reliability and requirements management under the auspices of the SAFIR2014 programme and through Tekes projects and commissioned research. The Department of Industrial Engineering and Management conducts significant nuclear engineering research within the field of "man, organisation and society" in collaboration with the BIT Institute and VTT. Other Aalto University activities in the field of nuclear engineering that need to be mentioned include fluid dynamics, risk analysis, energy efficiency, technical mechanics and plant engineering, all having significant research groups.

Aalto University has coordinated cooperation with LUT and networks closely with VTT, power companies and STUK, a proof of which are, for example, the many national research programmes in nuclear engineering and several theses made in these organisations under the guidance of experts within the field. The importance of Aalto University's nuclear engineering research can be further increased by enhancing internal networking within the university. The Doctoral Programme for Nuclear Engineering and Radiochemistry (YTERA) to be initiated in 2012 will act as a cooperation organ for all parties involved.

#### 4. Supplementary Education

Aalto University Professional Development (Aalto PRO, <http://aaltopro.aalto.fi>) acts as the supplementary education and training unit of Aalto University. The unit has recognised the challenges of the nuclear sector.

## 5. Future Prospects of the University

The management of Aalto University has acknowledged the importance of the nuclear energy sector and launched an overall survey of the strategic focus areas within the field. Acute steps taken by the University include fulfilment of a professor-level tenure track position at the Department of Applied Physics. A similar application process is about to be initiated at the Department of Industrial Engineering and Management. Aalto-ENG has significantly enhanced its research activity on nuclear waste management, and the need for material research in nuclear engineering is evident.

With regard to post-graduate education, the Doctoral Programme for Nuclear Engineering and Radiochemistry (YTERA) was initiated at the beginning of 2012 as a joint project of LUT, the Laboratory of Radiochemistry of the University of Helsinki and VTT.

## **Lappeenranta University of Technology (LUT)**

### 1. Description of the University

From as early as 1969 Lappeenranta University of Technology (LUT) has been combining two fields of science that complement each other – technology and business studies. The university's areas of strength include energy efficiency and the energy market, strategic management of business and technology, and scientific computing and modelling of industrial processes. LUT has a total of 5,000 graduate and postgraduate students, and 930 staff members, 90 of whom are professors. In 2010 the number of Master's degrees was 872, including 687 M.Sc. (Tech.) degrees, and of doctoral degrees 42, of which 34 were in the field of technology. Further information is available at: <http://www.lut.fi/>

### 2. Degree Programme Education

LUT Energy of Lappeenranta University of Technology (LUT) is the largest academic research and education organisation within the energy sector in Finland. The department consists of the profit units and degree programmes in energy technology, electrical engineering and environmental engineering. A total of 170 experts are acting in research and teaching positions, under 16 professors and 40 doctoral instructors/researchers. Approximately 130 students pass the Master of Science in Technology degree and 12 the Doctor of Technology degree at the unit each year.

The special feature of LUT is the national role the university plays in nuclear engineering training. Students in study programmes tangential to nuclear technology who are seeking nuclear-specific education can also choose a minor subject from among the largest offering in Finland of special courses in nuclear

technology, ranging from reactor physics to accident management (10). Tangential study programmes that also produce experts for the nuclear sector are mechanical engineering, chemical engineering, industrial management, technical physics, and mathematics. Internationally speaking, LUT's nuclear sector education operates primarily through the contacts provided by the EU's European Nuclear Education Network (ENEN).

### 3. Research Activities

LUT Energy coordinates two national graduate schools for research scientists: the Graduate School in Electrical Energy Engineering and the Finnish Graduate School in Computational Fluid Dynamics. Cooperation with all domestic universities related to the sector and with VTT is close and continuous.

The main application areas of energy technology research include energy production and conversion processes, and energy-efficient equipment and processes in accordance with sustainable development principles. The research operations within these areas are built primarily upon robust basic competencies in thermal dynamics, fluid dynamics and heat transfer. There are 70 researchers working in the research groups of the profit unit, in such fields as nuclear engineering, renewable energy systems, modelling and simulation of energy processes, and heat transfer and flow machines. The profit unit is engaged in extensive cooperation with relevant companies and research institutions, both nationally and internationally.

A substantial part of Finnish nuclear energy engineering research is carried out at LUT. The primary research area has been experimental and computational research of nuclear safety. Several extensive test facilities have been constructed at the university research laboratory for simulation of light water reactor safety systems: PACTEL, PWR PACTEL, PPOOLEX. Unique test data has been produced using these test facilities, primarily for the purposes of software validation. This data is utilised every year by various organisations in several SAFIR2014 research programme projects. The SAFIR2014 projects constitute the foundations of the research activity at LUT. When required, LUT also has competence in rapid development and production of separate effect test facilities and this opportunity has been exploited by authorities, power plants and plant suppliers in their R&D projects and safety assessments.

Using its own test results, LUT has developed calculation codes for thermal-hydraulic and fluid dynamic safety analyses of transient and accident situations as part of several international projects, such as the ongoing EU projects and within OECD/NEA. These thermal-hydraulic and CFD codes (APROS, CATHARE, RELAP5, SMABRE, Fluent, TransAT, NEPTUNE CFD) have also been applied to the analysis of own testing. Over the years the organisation has also participated in plant safety analyses. The latest measuring systems are utilised with the aim of producing accurate validation data required for 3D CFD computing. The NETNUC project studies phenomena related to new types of nuclear reactors in a consortium coordinated

by LUT, with Aalto University and VTT as partners, under the Sustainable Energy (SusEn) research programme of the Academy of Finland. LUT focuses particularly on modelling of gas-cooled Pebble Bed Modular Reactors (PBMR), also taking advantage of the institute's competence in firing plant modelling. Reactor physical modelling has been carried out using VTT's Serpent software. LUT is a member of the Sustainable Nuclear Energy Technology Platform SNE-TP of the EU.

LUT Energy's Laboratory of Fluid Dynamics has long-term experience in process calculation, and in fluid dynamic engineering and modelling (CFD) of turbines. The turbine sizes range from small bio energy units through wind turbines to nuclear power plant applications. The process efficiency and reliability of these has been successfully increased due to improved materials and developments in flow computing.

Some nuclear sector research is also carried out at LUT Metal Technology and CEID (The Centre of Computational Engineering and Integrated Design), which specialises in numerical modelling of industrial processes, one of the focus areas of LUT research. A particular field of application is welding technology. In its own project, the Mechatronics Unit is developing a welding robot for the primary wall of the ITER fusion test reactor, taking advantage of its expertise in remote operating and virtual engineering.

LUT Chemistry's Centre for Separation Technology (CST) develops modern separation methods applicable, for example, to mining industry, and the laboratory of the Department of Chemical Technology has also conducted small-scale investigation related to separation of uranium.

#### 4. Supplementary Education

LUT coordinates the national training course in nuclear safety (YK Course) providing training for those working in the nuclear energy sector. The course is implemented in collaboration with nuclear power companies, STUK, VTT, Aalto University and the Ministry of Employment and the Economy. LUT has also been involved in the planning of the reform of nuclear power plant operator training, and participates in arrangement of courses for them within its own fields of expertise.

LUT Centre for Training and Development manages supplementary training activities in a centralised manner. The training provision within the field of welding technology is especially extensive. (<http://developmentcentre.lut.fi/>)

#### 5. Future Prospects of the University

LUT intends to continue investing in nuclear energy technology teaching and research best suited for the strategy areas of the University. In 2012, an international Master's Programme and the Doctoral Programme for Nuclear Engineering and Radiochemistry (YTERA) will be initiated as a joint project with Aalto University

and the University of Helsinki. Efforts are being taken to acquire resources for the establishment of a second professorship focusing on nuclear engineering. Investments have been made in research infrastructure by renovating a second research hall, while funding from the SAFIR2014 research programme and the Academy of Finland are used for the modernisation of research instrumentation.

## **Tampere University of Technology**

### **1. General**

Tampere University of Technology (TUT) focuses on scientific research in technology and architecture, and higher education within these fields based on this research. TUT is a significant national and international pioneer in the development of technology, and a sought-after cooperation partner among the scientific community and business life. In addition, TUT is an attractive research and study environment, where internationality is inherently linked to all activities. The scientific activities are founded on a combination of strong research of the natural sciences and technology and research related to industry and business. The number of staff is approximately 2,000. Over 80% are employed in teaching or research tasks, or duties assisting teaching or research. At the beginning of 2010 TUT became a university based on a foundation.

TUT's values are responsibility, courage, culture and wisdom. They emphasise the fact that TUT acknowledges its responsibility for the future of the environment and of humankind by boldly seeking new openings in research and education. Furthermore, TUT fosters culture through its strong commitment to the academic tradition and the promotion of equality and internationality. In all its operations TUT strives after wisdom, manifested in the persistent development of the University's operations for the benefit of Finnish society and all humankind. Competent Masters of Science in Technology and Architecture, as well as Doctors in Technology or Architecture and Doctors of Philosophy, graduate from TUT to work in key branches of industry. The largest fields of education are information technology and electrical, mechanical and automation engineering. There are some 10,000 students at TUT engaged in undergraduate studies and 1,600 on postgraduate studies.

### **2. Education**

TUT offers thirteen degree programmes leading to Bachelor's and Master's degrees in science, architecture and technology. The degree programmes are those of architecture, machine automation, bioengineering, mechanical engineering, materials engineering, civil engineering, signal processing and communications engineering, electrical engineering, science and engineering, information and knowledge management, information technology, industrial engineering and

management, and environmental and energy technology. Nuclear-energy-related education is provided particularly in the study programmes of machine automation, mechanical engineering, civil engineering, signal processing and communications engineering, electrical engineering, information technology, industrial engineering and management, and environmental and energy technology. In the study programme of environmental and energy technology, for example, the student may choose subject-related studies in energy and process technology. Overall, TUT offers an extensive amount of education providing students with first-rate competencies for acting in various duties at nuclear power plants. One central form of cooperation enhancing the nuclear energy technology competence of students takes the form of theses and dissertations made within the industry. Small projects of this kind are regularly implemented in various study programmes.

It is also possible at TUT to obtain a postgraduate degree with the focus on nuclear power plants, from the automation engineering, electrical engineering, power plant engineering, safety engineering or mechanical engineering perspective, for example. Postgraduate studies are constructed on the basis of an individual study plan, so that the focus of the degree can be tailored to individual requirements.

EduTech, the supplementary education organisation of Tampere University of Technology, organises supplementary training for industry and other parties in need of such training. TUT is also currently conducting a commissioned training programme related to nuclear power plants. The professors of the Tampere University of Technology are actively involved in the instruction.

### 3. Research Activities

Close to 40% of Tampere University of Technology's funding consists of external funding, such as revenue from The Finnish Funding Agency for Technology and Innovation (Tekes), industry, the Academy of Finland and EU projects. Several research projects related to nuclear energy are also conducted on a regular basis. However, these projects are usually confidential, and information cannot be obtained without the permission of the funding partner. Taken overall, Tampere University of Technology's research activity and competence related to nuclear energy is extremely wide-ranging and versatile. Its competencies are also reasonably well exploited. The focus at TUT is on other matters than actual reactor physics. As a result of its systematic and continuous research and education activity, Tampere University of Technology has generated robust competencies relating to nuclear power plants, and interest in exploiting these in close collaboration with the Finnish energy industry will remain high well into the future.

## University of Eastern Finland

### 1. Description of the University

The universities of Joensuu and Kuopio were merged to become the University of Eastern Finland at the beginning of 2010. The University of Eastern Finland is one of the largest science universities in Finland. The new university has some 14,000 students and a staff of almost 3,000, with campuses in Joensuu, Kuopio and Savonlinna. The multi-disciplinary university provides education in more than 100 subjects of specialisation. There are four faculties: the Philosophical Faculty, the Faculty of Science and Forestry, the Faculty of Health Sciences and the Faculty of Social Sciences and Business Studies. The university's areas of expertise in research include:

- 1 Forests and the environment
- 2 Health and wellbeing
- 3 New technologies and materials

These areas of expertise and multi-disciplinary cooperation on the interface areas of the four faculties provide excellent conditions for research related to nuclear energy and the associated environmental and health risks.

### 2. Degree Programme Education

The degree programme in environmental science offers two areas of specialisation: environmental health and environmental biology. The basic studies of all students include basic knowledge of radiation protection. Students can specialise in radiation protection by selecting suitable courses. The course offering includes several advanced courses related to radiation (e.g. radiation biology, radiation ecology, radiation toxicology and dosimetry) with a focus on both ionising and non-ionising radiation. These courses have been intended primarily for those studying in the environmental health study programme, although in principle students of environmental biology can also specialise in radiation issues (interest in impacts of radiation on natural biota is increasing) with the help of these courses if they so wish.

Within the degree programme of physics, the study programme in medical physics provides capabilities for acting in expert positions related to radiation protection and medicinal use of radiation (e.g. in hospitals).

The doctoral programme also produces experts specialising in radiation issues. In recent years doctoral graduates have specialised mainly in non-ionising radiation, but earlier (post-Chernobyl) dissertations were related to ionising radiation. Doctoral theses on ionising-radiation-related subjects are currently being prepared by four postgraduate students in the environmental science study programme. Education for these students is organised by the Doctoral Programme in Environmental



Health, SYTYKE (with radiation as one of its theme areas) and the Finnish Doctoral Programme in Environmental Science and Technology (EnSTe). In most of the doctoral degrees in medical physics the central role has been played by imaging, diagnostics and treatment based on ionising radiation.

### 3. Research Activities

The University of Kuopio (now the Kuopio campus of the University of Eastern Finland) has conducted research on health and environmental impacts of radiation since the 1980s. However, after the projects initiated by the Chernobyl accident were completed, most of this research activity has focused on non-ionising radiation. Ionising radiation is currently researched in two projects, one studying the biological impacts of ionising radiation and the other the transport of radionuclides in the biosphere. Three doctoral theses are in preparation under these projects. Two of the dissertation works develop a new research method for joint cartilage based on X-ray radiation.

### 4. Supplementary Education

The University of Eastern Finland offers a wide range of supplementary training related to environmental risks. The themes of the training events vary, some of them having also included topics associated with radiation and nuclear energy (the latest being “The Risks of Uranium Production and Nuclear Power” in October 2010). In addition, the combination of applied physics and biosciences produces a training package that corresponds in scope with the requirements laid down for the position of responsible manager in the field of general medical use of radiation. The University of Eastern Finland, in collaboration with the Radiological Society of Finland, is responsible for providing the radiation training required for the responsible manager qualification for all students specialising as radiologists in Finland.

### 5. Future Prospects of the University

Study programmes in environmental sciences and physics will continue to include the opportunity to specialise in duties related to radiation protection. Teaching cooperation among these study programmes will be increased to provide enhanced opportunities for such specialisation. If necessary, the training volume within this field can be increased. With regard to supplementary training, plans are being made for a training package providing qualification for environmental risk assessment.

## University of Helsinki

### 1. Description of the University

With almost 37,000 students and 4,800 instructors and research scientists, the University of Helsinki is the largest higher education institution in Finland. Nuclear research at the University of Helsinki is conducted at the Laboratory of Radiochemistry of the University of Helsinki and the Department of Physics.

The Laboratory of Radiochemistry is one of the nine units of the Department of Physics at the University of Helsinki. The laboratory is the only general unit of radiochemistry operating in Finnish higher education institutions, and therefore holds a special status as an educator of radiochemistry experts for the needs of Finnish society. The laboratory is also a large and significant university-level laboratory of radiochemistry on an international scale. There are 30 persons currently working at the laboratory, of whom one professor, two university lecturers, two laboratory engineers, a secretary and a research technician operate with university funding (25% of the overall funding), and 25 researchers, 14 of whom are enrolled in doctoral programmes, who work with supplementary funding (75%). Research within the field of nuclear energy is conducted by six senior researchers, four other researchers and ten students engaged in doctoral studies.

The Department of Physics is a multi-disciplinary research and educational institute of high international level. It is one of the largest departments of the University of Helsinki. The focus areas of research are (1) material physics, including nanostructures, fusion and fission materials, semiconductors, insulating materials and biomaterials; (2) atmospheric sciences, including climate change, the carbon cycle, and interactions between ecosystems and the atmosphere; (3) elementary particle physics, including basic constituents of matter and development of the universe; and (4) geophysics and astronomy, including hydrosphere, solid earth, space between the Sun and the Earth, and planets. Computational research is a strong part of experimental and theoretical research. The researchers are involved in large international infrastructures, such as the European Organisation for Nuclear Research (CERN), ESRF (synchrotron radiation centre), ESO (observatory) and ITER (fusion reactor). The department has SMEAR research stations, which are part of the national infrastructure, two Academy of Finland and two Nordic Centres of Excellence in Research, two Academy of Finland Academy Professors and two FiDiPro (Finland Distinguished Professor Programme) project professors. The Department is highly international: there are 50 foreign researchers working at the Department and an equal number of Finnish researchers working abroad (researcher visits of more than two weeks). Research cooperation is practised with numerous international universities and research institutions, 170 of which are located in Europe, 60 in North America, 7 in Latin America, 20 in Asia, 4 in Australia and 2 in Africa (figures include cooperation over a period of five years). Nuclear energy sector research

is conducted by five senior researchers, two other researchers and four students engaged in doctoral studies.

## 2. Degree Programme Education

The Laboratory of Radiochemistry of the University of Helsinki educates both Masters and Doctors within the field of radiochemistry, an average of four of the former and one of the latter. The Master's programme education given by the Laboratory of Radiochemistry (120 credit points) is internationally unique in its comprehensiveness, offering a total of thirteen courses in radiochemistry, most of which include laboratory work in addition to lectures. The compulsory courses primarily teach the basics of radioactive decay and radiation, radiation protection, detection and measurement of radiation, and chemistry and analysis of radionuclides. There are several optional courses in various aspects of radiochemistry, including the following suited to the nuclear energy sector: chemistry of the nuclear fuel cycle; environmental radioactivity; atmospheric radioactivity; and natural radioactive decay series and their use in environmental sciences. In addition to a professor and two university lecturers, the teaching staff at the Laboratory of Radiochemistry of the University of Helsinki includes one laboratory engineer, three senior researchers and four docents from outside the unit. All students in the doctoral programme participate in the mentoring of laboratory work. In addition to the dissertation, doctoral studies include 60 credits of course study.

The Department of Physics educates some 50 Masters and some 20 Doctors per year in the field of physics. On average one Master's and one Doctoral student conducts research on a topic related to the area of nuclear energy. The Master's degree at the Department includes a course in radiation protection and laboratory work related to nuclear physics as compulsory courses. The education within the field of material physics and particle physics includes several courses on nuclear physics and ion beam physics.

## 3. Research Activities

The primary research areas of the Laboratory of Radiochemistry are:

- Migration and retention of radionuclides dissolving from spent nuclear fuel in ground and bedrock. This area of research, initiated in the early 1980s, studies migration of long-lived radionuclides (particularly anionic) in bedrock and ground; diffusion of radionuclides in bedrock; porous structure of rock; formation of colloids and their impact on migration of radionuclides; sorption of actinides on clay mineral surfaces; the effect of redox reactions on the behaviour of uranium; and the impact of radiolysis products on leaching of uranium fuel.

- Development of ion exchangers and sorbents for separation of radionuclides from nuclear waste effluents and other industrial liquid wastes. Over three decades the Laboratory of Radiochemistry of the University of Helsinki has developed a range of inorganic ion exchangers for selective separation of radionuclides from nuclear waste effluents. Fortum produces three ion exchangers developed at the Laboratory of Radiochemistry on an industrial scale. Over the years the exchangers have been used at several nuclear facilities all over the world.
- Environmental radioactivity research. From as early as the beginning of the 1960s the Laboratory of Radiochemistry of the University of Helsinki has studied the migration of radionuclides stemming from nuclear weapons testing and the Chernobyl accident in the environment and food chains. Over the past ten years the research has also covered the study of natural radionuclides. The most important current research within the field targets radioactivity problems caused by the waste produced by Finnish mining operations.
- Development of radiopharmaceuticals for the purposes of medical research, clinical diagnostics and, in particular, pharmaceutical development.

The research funding for the Laboratory of Radiochemistry of the University of Helsinki stems from many sources, the most important of which are the Academy of Finland, the EU, Tekes, MEE (KYT), Posiva and Fortum. The Laboratory of Radiochemistry has appropriate premises for radioactivity research and teaching: several laboratories suited for working with low-level materials, and three for intermediate-level work. Unlike most European and U.S. universities, the Laboratory of Radiochemistry of the University of Helsinki is capable of processing practically all radionuclides, including transuranium elements, as well as other radionuclides emitting alpha radiation, albeit in most cases at a very low radioactivity level. The Laboratory has extensive instrumentation for measuring stable elements and the radiation emitted by such radionuclides. On the other hand, equipment needed for chemical research is in short supply, and the need for such instrumentation is covered by the equipment owned by the Department of Chemistry and other laboratories and international research partners.

At the Department of Physics, the most important research areas related to the nuclear energy sector include research on radiation damage to materials and utilisation of nuclear physical techniques in materials analysis. Research of radiation damage, conducted both experimentally and computationally, covers radiation damage in all classes of materials, ranging from metals through to biomaterials. The focus areas of research are:

- 1 Research on the basic mechanisms of neutron radiation damage to reactor materials. The Department is involved in extensive international cooperation with the aim of understanding - with the help of multiscale modelling, and beginning with the quantum mechanical physical foundations - how and why the load-bearing structural materials used in reactors (such as steel) become

embrittled under radiation. By means of modelling it is possible to predict the formation of dislocations in materials. Comparison with experimental data enables an understanding of how embrittlement of materials progresses.

- 2 Researchers at the Department of Physics used radioactive ion beams produced by the Cern/ISOLDE facility for the analysis of diffusion properties of topical materials
- 3 Research of plasma-wall interactions in fusion reactors. The Department studies how particles seeping from fusion plasma transform the properties of first wall materials in fusion reactors. This is significant, on the one hand with a view to how long materials last in a reactor to still ensure its operation, and on the other to how much radioactive tritium adheres to materials.
- 4 Radiation tolerance of semiconductor detectors and glass materials. All types of reactors contain instrumentation necessary for their operation by which reactor performance can be monitored. Their functioning capacity weakens and finally ceases altogether under radiation. The Department of Physics investigates how the properties of materials weaken at an atomic level and how this affects the properties of detectors and the glass materials protecting them.

The research funding for nuclear-energy-related research practised by the Physics Department comes from several sources, the most important of which are the Academy of Finland, the EU and Tekes. The Department has versatile research facilities suited for analysis and computational research of reactor materials. Senior staff members of the Department are involved in several IAEA and OECD Nuclear Energy Agency (NEA) working groups.

#### 4. Supplementary Education

The Laboratory of Radiochemistry of the University of Helsinki does not arrange supplementary education. The Department of Physics, however, has a wide offering of supplementary education, although less frequently related to the nuclear energy sector.

#### 5. Future Prospects

Research related to final disposal of nuclear fuel, primarily involving the study of the migration and retention of radionuclides in ground and bedrock, will remain the largest area of research at the Laboratory of Radiochemistry of the University of Helsinki for at least the next decade. New initiatives will be launched in this research area within the next few years, for example in investigation of the behaviour of radiocarbon and the development of radionuclide analyses needed for the decommissioning of nuclear power plants. The annual number of Master's degrees is expected to rise to 5-6 and that of Doctors to 1-2 within the next few years.

The Department of Physics will reinforce its nuclear energy research capabilities, especially within the area of reactor steels. The Department has recently finalised the world's first atomic-level interaction model for stainless steel. The model will be developed further so as to include the most important precipitating agents for radiation-proof ferritic-martensitic steels, such as tungsten. Research will also be expanded in the direction of the modelling of oxide-nanoparticle-strengthened steels and dislocation interactions.

## **University of Jyväskylä, Department of Physics (JYFL)**

### **1. Basic Studies**

Degrees available at the University of Jyväskylä within the field of physics are those of Bachelor of Science (lower university degree) and Master of Science (higher university degree), and the postgraduate degrees of Licentiate of Philosophy and Doctor of Philosophy. The studies required for the Bachelor of Science degree can be completed within three years, and constitute a basis for Master's studies which can be completed in two years.

The Bachelor's degree gives extensive basic knowledge of physics and capabilities for versatile application of experimental, mathematical and information technical methods in problem solving. The competencies learned through experimental and theoretical exercises include data acquisition, cooperation skills and written and oral presentation of results. A physicist with a Master's degree has in-depth command of the knowledge and methods of the field of specialisation of his or her choosing, and is capable of applying these creatively and independently to demanding basic research or applied physics duties in international operating environments.

Appropriate selection of courses enables the targeting of duties with a certain task description, such as that of researcher, designer or instructor in the industrial sector, research institutions or higher education institutions; marketing positions in the service of industry or trade; duties of hospital and radiation physicist in hospitals and in companies operating within the field; or communications tasks in the service of the media. Physics teachers are needed at comprehensive schools, upper secondary schools, vocational schools, colleges and polytechnics. In addition to actual teaching positions, those with teacher education also have job openings in public communications and the administrative sector.

In optional studies students concentrate on the areas of applied physics of their choosing, including nuclear- and accelerator-based physics, material physics, nanoscience, particle physics, cosmology, applied radiation and biophysics, industrial physics, electronics, and measuring, equipment and sensor technology. Often the studies include a training period in a foreign university or research institution. Minor subjects that best support physics studies include mathematics and computer sciences. Studies in other fields of expertise, such as chemistry, environmental

sciences, economics, and communications, can be quite freely included in the degree programme. Minor subjects particularly recommended for those studying to become physics teachers are mathematics and chemistry. The study programme in nanoscience includes chemistry and biology in addition to physics.

In the Master's programme in industrial physics the major subject is applied physics. The areas of specialisation in this programme, on the basis of separately agreed course selection, will be general processing industry and the nuclear energy sector. The compulsory major subjects are electronics, material physics, measuring technology and nuclear physics. Optional studies in the major subject can include the following courses: fluid mechanics I; technical thermodynamics; heat transfer processes; plasma physics; radiation safety; accelerator physics; applied nuclear/radiation physics; experimental methods in nuclear physics; interaction of radiation with matter; and accelerator-based materials research.

## 2. Postgraduate Studies

The Department of Physics at the University of Jyväskylä, (JYFL) admits postgraduate students to research groups twice a year. Research work related to the doctoral thesis is usually conducted in one of the research groups of the Department of Physics under the steering of the professor and docents of the department. The doctoral or licentiate thesis can also be completed outside the university, in industry or a research institution.

Admission to postgraduate studies in physics is granted by application. Applicants are required to hold a higher university degree. Students can apply for postgraduate studies twice a year by submitting an application form and attaching an extract from student records, a plan for postgraduate studies and any other factors the applicant wishes to present in his or her favour. The application periods are announced on the website of the Department of Physics.

The Department of Physics is involved in five national training programmes for researchers, those in: particle nuclear physics; nanoscience; material physics; mathematics; physics and chemistry teaching; and pulp and paper science and technology. Students can also apply for scholarships for research work related to postgraduate studies from various foundations.

## 3. Future Prospects of the University

More than half the 70 persons doing their doctoral theses at the Department of Physics at the University of Jyväskylä are engaged in research related to nuclear-, elementary-particle- and accelerator-based physics or to various problems related to final disposal of nuclear waste. Their work is steered by ten professors and well over a dozen permanent or fixed-term senior research scientists, and they have

well-equipped laboratory premises at their disposal with facilities suited for several fields of study.

The focus of education is primarily on basic research but includes courses aiming at practical applications, especially with regard to migration phenomena. From 2011, the Department of Physics at the University of Jyväskylä, (JYFL) will make additional investments in nuclear energy sector education by establishing a new study programme aiming at a basic degree suitable for the sector. This will increase the amount of nuclear-energy-specific sections from the present teaching offering. As a consequence, the number of postgraduate students, and thus the amount of research, is expected to rise. Additional resources will be needed to expand education and research within this field of study.

### **University of Oulu**

The following description concerns only the Faculty of Technology at the University of Oulu, and the reply has been compiled from those received from the various departments. The faculty consists of five departments with altogether slightly over 4,000 students, and some 700 staff members. Students at the faculty can study for Master of Science in Technology or Master of Arts in Architectural Design degrees or for postgraduate degrees. Even though the faculty has no education or research linked directly to nuclear energy engineering or reactor engineering, all departments of the faculty provide teaching that supports the nuclear energy sector. There are naturally also subjects at the Departments of Physics and Chemistry at the Faculty of Science that serve the educational needs of the nuclear energy sector. In the following, research and education are discussed by department, after which the plans for supplementary training are described in brief.

#### *Department of Architecture*

Research: The land use of a nuclear power plant project and its impacts on other land use planning in the surrounding areas (cf. the development prospects of the municipality of Simo, completed as a practical work in 2010).

Education: optional design course on industrial buildings (i.e. not nuclear power alone) directed at architectural students could be arranged.

#### *Department of Mechanical Engineering*

Research: The department has special competencies, for instance in maintenance technology, material engineering, structural design and mechanical engineering. All these are needed in the maintenance duties of nuclear power plants. There is no research with direct links to nuclear energy, but research also applicable to nuclear energy industry has been conducted within the fields mentioned above.

Education: The departments offers a study programme in mechanical engineering with varying focuses according to the area of specialisation. The wide range of the



study programme means that it is especially well suited for the needs of nuclear power plant design, construction and maintenance. Competence in material engineering makes it possible to address special material engineering issues related to nuclear power plants, particularly with regard to steel materials. Competence in structural design and engineering mechanics facilitates the handling of demanding design assignments and strength issues. Machine diagnostics plays a central role in the maintenance of nuclear power plants, and the department has suitable study entities for this purpose. Machine design and production technology are key areas of the study programme in mechanical engineering that are also needed in education related to nuclear energy.

#### *Department of Process and Environmental Engineering*

Research: No research has been conducted with direct links to nuclear energy, but research related to power plants and power plant automation is under way.

Education: Instruction at the department includes a wide variety of elements suited for nuclear energy education, at least concerning operations taking place outside the actual reactor room: power plant automation and automation engineering in general; a major part of heat transfer and diffusion technology; pumping; fluid dynamics; flow modelling and simulation, and so on.

#### *The Department of Electrical and Information Engineering*

Research: With regard to control room engineering needed in nuclear power plants, the department has tangential research and even some courses. The department has competencies in instrumentation, digital engineering and embedded systems. Research related to critical infrastructure has already been conducted for some time. The department was also previously involved in research on positron annihilation, and in this connection acquired experience in nuclear technology instrumentation (sensors, electronics and signal processing). The research project produced three doctoral theses and related publications. The department at that time (1970–90) had a Nuclear Engineering Institute, which had a laboratory environment for research purposes – some parts of it are still in use.

Education: In principle, the department could offer a course under the heading “Nuclear electronics” that would include the manifestations of alpha, beta, gamma and other such particles, and measuring of the energy and moment of appearance of these by means of pulse electronics. This constitutes a typical content of the course, and good basic knowledge of electronics is required for following the teaching. This kind of course could be needed for enhancing the researcher training within the field. One or more theory periods could also be attached to this course at the Department of Physics.

### *Department of Industrial Engineering and Management*

The department has research and education experience in many fields tangential to the nuclear energy sector: company policies, strategy, plant operation, plant safety, plant management and performance, plant systems and configuration management, human resource management, etc. With regard to project and quality management, the department is engaged in the research project “Large project governance”, where the construction project for a nuclear power plant constitutes one topic of research. The overall volume of the project is 2.5 million euros, but the department’s contribution is comparatively small, less than 100,000 euros. The project is implemented by a consortium consisting of Aalto University, Åbo Akademi University and the University of Oulu. In addition, one of the students is producing a thesis on the final disposal of nuclear fuel. Research on large project governance addresses problems that arise when organisations stemming from different institutional environments work together in projects. The courses in project management are connected directly to construction-phase problems, and there are several courses available on the subject at various levels (the foundations of project operations; project management; special work on project management; literary seminar on project management; and project business). In addition, quality and quality management play an important role, especially within the nuclear energy sector. Several related courses are available (the foundations of quality; quality management; special work on quality management; evaluation of quality assurance systems; and continuing course on quality). The Work Science Unit of the Department of Industrial Engineering and Management has versatile research and education also applicable to the nuclear energy sector, related to productivity, safety and health aspects of work and wellbeing at work. Safety management and management of the risks of damage is also a special area regarded as part of a good management entity. Another special area is the ergonomics of machine use and maintenance, as well as machine design, pressure vessel design and many other safety-related issues. Such themes are taught especially as part of the following study programmes: safety in process industry; machine safety and usability; usability and safety in product development; and chemical and physical environmental factors. One thesis has been completed at the unit on the safety management and work site planning needs of a foreign construction developer of the Olkiluoto nuclear power plant.

### *Supplementary Education*

The faculty is in the process of initiating professional-development (PD)-level supplementary training for the nuclear energy sector. The training will be implemented from the beginning of 2012 as two consecutive intakes of students (30–40 students in all). Decisions will be made during the project on whether such training will be provided as an area of specialisation on a permanent basis.

## Åbo Akademi University

### 1. Description of the University

Åbo Akademi University is Finland's Swedish-language university, meaning that the basic degree tuition is provided in Swedish. Åbo Akademi University consists of three divisions: the Division for Arts, Education and Theology, the Division for Social Sciences, and the Division for Natural Sciences and Technology. Physics is included in the last-mentioned through the Department of Natural Sciences.

Åbo Akademi University is a comparatively small university, with some 7,000 students. Approximately 500 Master's and Bachelor's degrees and some 80 Doctoral degrees are passed each year. Staff total slightly over 1,300, of whom almost 60% are teaching and research staff. Since there are more than 50 subjects in all, each subject programme is relatively small. A large share of those who obtain a Master's degree become teachers, since Åbo Akademi University is the only university in Finland operating in the Swedish language that is obligated to provide teacher education.

### 2. Degree Programme Education

As in other universities, education leads to the lower graduate degree of Bachelor and the higher degree of Master (MA degree). In addition, the Department of Physics offers postgraduate education for obtaining the Licentiate of Philosophy degree (Ph. Lic., quite rare today) or Doctor of Philosophy degree (Ph. D.). The Department of Physics has four areas of specialisation: organic electronics, quantum optics, nuclear physics, and Mössbauer spectroscopy.

The Department of Physics has been conducting nuclear physics research since 1976, when the "K-20 cyclotron", capable of accelerating protons to an energy of 20 MeV, was placed at the Åbo Akademi University. The apparatus was installed primarily for the production of medical isotopes, but several MA degrees at the time had nuclear physics as the topic, as did many Ph.Lic. and Ph.D. degrees. When a professorship in material physics was established at the turn of the 1990s, this educational field also started to attract students. Nuclear physics has nevertheless been a continuous target of student interest at all levels. A few Master's degrees are passed in the field each year, and a record number of five students are currently engaged on doctoral studies in nuclear physics.

### 3. Research Activities

Research activity in nuclear physics is mainly what would be called basic research. At the Åbo Akademi University this means study of microscopic nucleus structures, both experimentally and theoretically.

Experimental research in nuclear physics usually employs accelerators in which particles used for bombardment are given a sufficiently high energy to make them penetrate the target nucleus, thus generating a nuclear reaction. The gamma radiation from this product nucleus reveals the properties of its inner states. The Åbo Akademi University uses its own accelerator for low-energy reactions and the K-136 cyclotron of the Department of Physics at the University of Jyväskylä (JYFL) if higher energies are needed. The JYFL facility is also capable of accelerating heavier ions, right the way through to xenon. Furthermore, in special cases use is made of the accelerator at the University of Oslo.

The interpretation of results requires a theoretical background, i.e. theoretical models. Theoretical calculations cannot be performed within the Åbo Akademi University, but are carried out in collaboration with JYFL theoreticians. This provides for a versatile interpretation of the experimental measuring results.

#### 4. Continuing and Supplementary Education and Training

The main mission of the university shall be “to promote free research and... to provide higher education based on research, and...” (Universities Act, section 2). In popular language this translates into “to educate Masters and Doctors of Science and Philosophy for the use of society”. The Department of Physics at the Åbo Akademi University educates such persons in the four divisions mentioned above.

Nuclear energy has been a new field of study within nuclear physics since 2005. About half a dozen new courses have been developed for the purposes of this educational programme, illuminating issues related to nuclear energy in particular. The nuclear physics study package consists of a total of nine courses (<http://users.abo.fi/tlonnrot/nucl-teaching-future.htm>). As an example, approximately 60 credit points of courses related to nuclear energy can be incorporated in this way in the Master's degree. If the Bachelor's and graduate theses are also included (providing 8 and 40 credit points respectively), this constitutes a total of about 110 credit points, when the total volume of the Master's degree is 300 credits. If the Master's degree consists of other topics/fields, these courses can be included in the study material for the Ph.D. degree.

#### 5. Future Prospects of the University

When writing this description, the future of Åbo Akademi University, as well as the field of physics, seems stable. No (internal) threats have emerged over a time span of several years. Therefore it can be presumed that all forms of education will remain as they are at least for one educational period (an MA takes 5-7 years to complete) and probably much longer.

It is unlikely that the course selection within the field of nuclear energy will be much increased. However, efforts will be made to seek closer links to industry. There are already contact persons in TVO, Fortum and STUK who have committed themselves to acting as tutors within the field of technology, but further expansion of such activity is recommended.

## **The Provision of Education and Training within the Nuclear Energy Sector in Polytechnics**

### **Central Ostrobothnia University of Applied Sciences**

#### 1. Presentation of the Polytechnic

The purpose of Central Ostrobothnia University of Applied Sciences is to promote the development and wellbeing of its area of operation as a combined effect of working-life-oriented education, and research, development and innovation (RDI) activity. The University of Applied Sciences has campuses at Kokkola, Ylivieska and Pietarsaari. Engineer education is provided at both Kokkola and Ylivieska. Central Ostrobothnia University of Applied Sciences is profiled as an international polytechnic encouraging innovation activity and entrepreneurship. The focus areas of education and RDI at Central Ostrobothnia University of Applied Sciences are:

- ICT; decentralised and wireless systems
- development of industrial processes and production technologies, and
- multi-professional wellbeing and cultural services and service business.

The average number of students is approximately 3,000, almost half engaged in engineer studies. Some 500 students obtain a degree each year. Some 1,500 students are enrolled in the engineering study programme. There are 300 persons on the payroll of Central Ostrobothnia University of Applied Sciences, 150 of whom hold teaching positions. The overall revenues of the University of Applied Sciences are approximately 27 million euros, 7 million of which is competitive external funding. The balance sheet total is 13 million euros.

#### 2. Degree Programme Education

Students at Central Ostrobothnia University of Applied Sciences can study for a Bachelor's degree in 20 different study programmes, five of which are taught entirely in English (<http://www.cou.fi>). A Master's degree can be obtained in three separate training programmes, one of which is organised in English. The degree programmes in the field of technology are:

- Mechanical and production engineering
- Chemical engineering

- Information technology
- Media technology
- Electrical engineering
- Industrial engineering and management
- Chemistry and technology
- Industrial management
- Information technology
- and a degree programme in management of technological competence leading to a Master's degree.

The study programme in electrical engineering offers three areas of specialisation: energy technology, electric power technology, and communications technology. Energy technology, especially technology related to electricity and heat production, has been one of the focus areas ever since the education programme for electrical engineers was launched (1990).

### 3. Research, Development and Innovation Activity

Research, development and innovation activity is implemented in all educational fields at Central Ostrobothnia University of Applied Sciences under the auxiliary business name CENTRIA (<http://www.centria.fi>) used for the purposes of R&D operations. In 2010, the total number of ongoing projects was 90 (83 in 2009) A total of 44 applications for new projects were submitted to the financiers (49 in 2009). CENTRIA R&D, Central Ostrobothnia University of Applied Sciences, administers 57 projects and acts as one of the collaborators in 33 projects. The volume of R&D projects was 4.4 million euros in 2010 (3.5 million euros in 2009) and the revenues from fee-based services 2.1 million euros (2.0 million euros in 2009). The overall volume of project activities increased by 19% from the previous year. Training services accounted for 53% of the provision of fee-based services (25% in 2009).

The ProBoat research project was a subproject of the Tekes Boat Programme, implemented in collaboration with companies within the field and the Institute of Design of Lahti University of Applied Sciences. The purpose of the project was to investigate and develop opportunities for the application of alternative product concepts and environmentally-friendly materials and manufacturing processes within the boat sector. The project focus was on interior design of the boats and development of components.

The first project within the field of technology funded from the ICT SHOK programme, Cooperative Traffic ICT, was implemented in 2010. The R&D Wood project was extended until the end of 2011. The project budget for 2008–11 was approximately 1.2 million euros. The project enhances the development environment of the wood products industry, as well as the wood products enterprises in Central and Northern Ostrobothnia. In 2010 development pilots of 13 companies were brought to an end under the project. Activities included in the part of the project

focusing on the development environment concerned continuing enhancement of computational competence in thermal transfer of windows and doors; development of testing facilities for windows and doors; study into the basics of soundproofing; and investigation of industrial surface finishing of heat-treated wood. Furthermore a review was commissioned on application of wood-plastic composites within the door and window industry.

The research in energy technology focuses on exploitation of renewable domestic sources of energy in the production of electricity and heat. In the 1990s the focus areas of research were biogas reactors of farms and CHP technology. In the 2000s the research concentrated on wood gasification technology and CHP technology.

#### 4. Supplementary Education

Central Ostrobothnia University of Applied Sciences has for some time been one of the leading providers of open university training in Finland. The open electronic polytechnic AVERKO has been offering virtual teaching unlimited by time and place for almost 15 years (<http://www.averko.fi>). Last year approximately 1,500 students studied at AVERKO, collecting 3,500 credit points. The AVERKO offers more than 70 study programmes in various fields.

#### 5. Future Prospects

Cooperation with Fennovoima has been initiated. The proportion of nuclear technology education in the curriculum will increase. It should be pointed out, however, that in addition to actual nuclear engineering experts the nuclear energy industry will also need specialists in many other sectors.

### **Kajaani University of Applied Sciences**

Kajaani University of Applied Sciences operates as an enterprise owned by the City of Kajaani. In addition to Kajaani, degree education is also arranged in Kuusamo. The number of students is approximately 2,000, some 500 of whom are engaged in engineering studies. There are three study programmes: information technology, mechanical and production engineering and construction engineering. We also organise versatile supplementary and specialisation training for adult students.

Depending on the decisions made by Fennovoima, we will offer our students interested in the nuclear energy sector a training package of 15 credit points with similar contents within all three study programmes mentioned above. If they so wish, students may include these as part of their optional studies.

The contents of the training package will consist of study entities in quality management, project management, mechanics, mechanical engineering, industrial maintenance and user reliability technology that support nuclear energy expertise

in particular, and enhance basic-level competencies. In any of the study programmes, this provides the students with an opportunity to gain command of basic nuclear energy knowledge and opportunities to find employment in the industry supporting or operating within the sector. Good command of basic knowledge and skills is the basic condition by which those with a degree have proved their preparedness to enter the sector. They have also shown their ability to continue learning working life skills in demanding duties according to their area of special expertise, particularly as holders of basic knowledge and skills in automation and construction engineering.

The Centre for Measurement and Information Systems (CEMIS) is a joint research and training centre established in Kajaani by two universities (the University of Oulu and the University of Jyväskylä), two research institutions (the Centre for Metrology and Accreditation MIKES, and VTT) and Kajaani University of Applied Sciences. There are some 130 experts within the measuring and information system sector working in the research and training units participating in CEMIS activities. CEMIS is tasked with offering an inspiring training environment to students aiming for future professions, and an innovative and international working environment to development-oriented researchers and specialists. To companies and research institutions developing and applying measurement and information systems the Centre offers the best competence within the field, internationally acknowledged research operations, and new innovations.

CEMIS consists of the University of Oulu's measurement technology unit at the Kajaani University Consortium, the information systems competence area of Kajaani University of Applied Sciences, MIKES's Kajaani research group, VTT's Kajaani unit, and the measurement technology development activities of the Department of Sports Technology of the University of Jyväskylä at Vuokatti. The University of Oulu's units engaged in technology research currently operating in the Kajaani region (the Laboratory of Bio-sciences and Technologies, the Measurement and Sensor Laboratory, the Sotkamo unit of the Centre for Wireless Communication, and the Kajaani unit of computer sciences) have been collected into the research unit of measurement technology of the University of Oulu. The information technology (engineer education) and computer science (Bachelor of Business Administration education) teaching and R&D staff of Kajaani University of Applied Sciences have been collected into the information systems competence area. The research group on applied metrology of MIKES has been established at Kajaani for the purpose of developing industrial metrology and maintaining national measurement standards. In other words, we are also capable of offering companies and actors representing the nuclear energy sector versatile research-, development- and innovation-based cooperation within the fields of measurement technology and information systems using all resources available to us.

At the time this description is written, the key objective in the development of the content of education is the development of a new polytechnic degree programme in engineering, and the conducting of the application process. We currently offer



mining engineering as an area of specialisation as part of our training programme in mechanical and production engineering.

We are developing the content of training further to better support the needs of the mining sector, and combining the existing construction technology competence by redirecting it towards the perspectives of mining and rock construction, precision blasting and environmental technology competences, as well as environmental and recycling competencies during the life cycle of the mine. The special features of a closed and safe operating environment are also taken into account. For this purpose we will file an application, on our own or with a partner, in spring 2012 at the Ministry of Education and Culture for a polytechnic degree programme in engineering that will be totally new in Finnish conditions. We believe that competence supporting the mining sector will also serve the needs of the nuclear energy sector with a view to construction, maintenance and operation, and industrial automation.

### **Oulu University of Applied Sciences**

Oulu University of Applied Sciences is an attractive and important social actor and influential organisation in Northern Finland. Oulu University of Applied Sciences is one of the most significant multi-disciplinary polytechnics in Finland. The staff includes more than 800 experts within various fields, and the number of students is approximately 9,000. The University of Applied Sciences has 27 study programmes in Finnish and three in English leading to a polytechnic degree, and eight study programmes in Finnish and two in English leading to a polytechnic Master's degree. One of Finland's five higher vocational teacher education institutions operates at Oulu University of Applied Sciences.

The task of Oulu University of Applied Sciences is to act as a developer of the highest professional competence in the Oulu region and Northern Finland as a whole. Of the students, 90% come from Northern Finland, and half the study programmes are of a kind not implemented in any other polytechnic in Northern Finland. Oulu University of Applied Sciences develops the competitiveness of the region's wellbeing and trade and industry by means of research, development and innovation activity, with contributions amounting to over a hundred separate projects and 250 experts.

Oulu University of Applied Sciences is profiled as an institution with robust competence that relies on a multi-disciplinary approach, and as an active developer of innovation activities in the region. The University of Applied Sciences operates in an environment in which future challenges are addressed by emphasising market-orientation and international business and marketing competence, and by enhancing the operation of innovation clusters in accordance with the Oulu Innovation Alliance Agreement.

In line with its vision of being "a reformer creating wellbeing for the northern region", Oulu University of Applied Sciences implements development goals of its

area of operation as part of a high-standard regional innovation cluster within the following focus areas:

- Internet and information technology based innovations and services;
- sustainable production, living environment and energy solutions;
- new operating models for promoting health and wellbeing; and
- new cultural contents and experiences.

The large-scale industry of Northern Finland on one hand, and the sparsely populated rural areas on the other, need a sustainable and competitive living environment and energy solutions. Observation of the bearing capacity of the environment, especially in northern conditions, is particularly important in mining operations, infrastructure and renovation construction, and development of tourism. Sustainable living environment solutions improve the viability of the region, therefore also enhancing the prerequisites for entrepreneurial activity.

Future energy solutions are founded on increasing demands for enhanced energy efficiency and growth in the number of renewable energy solutions. Education focusing on energy technology at Oulu University of Applied Sciences does not concentrate on any special or individual technologies, but the aim is to provide the students with capabilities for implementing overall system design and in-service management, and with an understanding of how these are controlled as an entity and automated intelligently to serve the entire system.

## **Satakunta University of Applied Sciences**

### **1. Description of Satakunta University of Applied Sciences**

Satakunta University of Applied Sciences is a multi-disciplinary, internationally oriented higher education institution with 6,500 students and 500 experts. Training is provided in four different localities at Pori, Rauma, Huittinen and Kankaanpää. Our areas of operation are business and culture, social services and health care, and technology and navigation.

We offer lower and higher polytechnic degree education in well over twenty degree programmes. Degree studies can also be completed entirely in English. The Continuing Education Centre organises professional specialisation studies, open polytechnic studies and courses and seminars. Satakunta University of Applied Sciences has been awarded the following titles by the Ministry of Education:

- Centre of Excellence in Regional Development Impact, 2001-2002
- Centre of Excellence in Education in 2002-2003 with the study programme “International Business and Marketing Logistics”
- Centre of Excellence in Education in 2005-2006 with an innovative pedagogic solution Enterprise Accelerator.

## 2. Degree Education (Technology and Maritime Management)

- Automation technology, Master of Engineering (higher polytechnic degree)
- Automation technology, Bachelor of Engineering (polytechnic degree)
- Environmental Engineering, Bachelor of Engineering (polytechnic degree)
  - Nuclear Technology - module gives the student the basic understanding of nuclear reactions and the needed technology behind the energy production by fission. After this module the student understands the risks involved in nuclear power plants and understands the need for regulations for nuclear and radiation safety.
- Welfare technology, Master of Engineering (higher polytechnic degree)
- Chemical engineering, Bachelor of Engineering (polytechnic degree)
- Mechanical and production engineering, Bachelor of Engineering (polytechnic degree)
- Logistics, Bachelor of Engineering (polytechnic degree)
- Maritime management, Bachelor of Maritime Engineering (Engineer, polytechnic degree) or Bachelor of Maritime Management (Sea Captain, polytechnic degree)
- Maritime management, Master of Maritime Management (Sea Captain, higher polytechnic degree)
- Construction, Bachelor of Engineering (polytechnic degree)
- Electrical engineering, Bachelor of Engineering (polytechnic degree)
- Information technology, Bachelor of Engineering (polytechnic degree)
- Industrial engineering and management, Bachelor of Engineering (polytechnic degree).

## 3. Research, Development and Innovation Activity (RDI)

The RDI activity takes advantage of the strengths and versatile expertise provided by a multi-disciplinary organisation. The RDI activity manifests itself in local, national and international cooperation, projects and initiatives implemented by experts, researchers, instructors and students. The cooperation partners of Satakunta University of Applied Sciences can range from local SMEs to major global corporations.

The R&D programme serves the development needs of business life in the Satakunta region, linking Satakunta University of Applied Sciences R&D with other research, development and innovation activities and international networks. The R&D programme combines the various disciplines within Satakunta University of Applied Sciences in a manner that creates something new. The programme creates preconditions for new initiatives and implementation of higher-risk projects. The focus areas of RDI in 2010–2013:

Future energies and the environment:

- Energy systems
- Clean energy production solutions
- Energy-efficient and intelligent energy networks
- Urban landscape and sustainable development
- The environment and accessibility
- Participation in user-oriented research

Intelligence solutions in industry and services:

- Cost-efficiency and productivity
- Machine vision and learning machines
- Production processes and chains
- Quality of service and customer satisfaction
- Intelligent processing of information
- Human welfare.

#### 4. Supplementary Education

The supplementary education and training provided by Satakunta University of Applied Sciences is intended for people and companies willing to develop themselves and succeed. To ensure that everyone participating in training will enhance their professional skills and gain confidence in operating and advancing on the labour market, we focus on the learning of each student with equal enthusiasm. We respond to any company challenges with a similarly individual approach. We organise both short- and long-term training according to the needs of each customer. Since the people and companies we serve are busy, our operations are flexible but well focused.

We offer studies in the fields of business and culture, social services and health care, and technology and maritime management. Satakunta University of Applied Sciences provides degree-oriented higher education in the Satakunta region, and supplementary training and education are also clearly on the map. The education is provided on the campuses of Pori, Rauma, Huittinen and Kankaanpää, but also online. Online learning makes it easier to draft schedules and provides an efficient method for self-study. This environment is also well suited for group work. Satakunta University of Applied Sciences has also offered special studies in nuclear energy technology.

#### 5. Future Prospects of Satakunta University of Applied Sciences

Satakunta is an energy province, and Satakunta University of Applied Sciences invests continuously in energy-related and environmental competence in the fields of both education and research. Satakunta University of Applied Sciences has made strategic partnership agreements with significant partners, which include cooperation in teaching as well as in research and development projects, and

facilitate exploitation of the key competencies of both partners. In the near future, the University of Applied Sciences will initiate discussions with the aim of entering into strategic partnership with TVO.

Satakunta University of Applied Sciences has representation in the regional Olkiluoto working group. In addition, Satakunta University of Applied Sciences works together with Posiva, Rauma Chamber of Commerce and TVO in a small group preparing a “nuclear energy module”. The plan is to prepare a development plan for nuclear technology education to be implemented both in engineer education for youth and in training provided as supplementary adult education. Research cooperation within the nuclear energy sector is already being conducted continuously in the field of EMC testing.

## **Provision of Training in the Security Sector**

### **Aalto PRO**

Aalto University Professional Development – Aalto PRO has been training security management since 1990. The Dipoli Training Centre of the Helsinki University of Technology that used to organise such training is one of the units merged into Aalto PRO. Aalto PRO is the new education and training unit of Aalto University, the purpose of which is to educate new and experienced experts to become pioneers within their own fields.

Aalto PRO focuses in its security education primarily on lengthy training programmes in security management and information security, but also organises shorter seminars with special themes and training packages targeted at various professional groups requiring knowledge on security issues. The participants represent security management and information security management from both private and public sectors, and also include, for example, representatives of general management tasked with security management duties but lacking actual competence in the field of security management.

As university-level supplementary education, the security education and training provided by Aalto PRO is closely linked to basic education at Aalto University and other universities, and to working life practices. The content of tuition consists of theoretical knowledge and research combining several disciplines; application of working life-oriented knowledge and experience; understanding of the challenges of working life; supporting the growth of an individual’s own expertise; and accounting for individual needs and starting points of the participants. The starting point for the continued professional education programmes under implementation is a comprehensive approach to the security aspects belonging to the operations of the organisation:

- The education programme for security management (40 credit points) is a programme targeted at management responsible for the security functions

within an organisation. The purpose of the programme is to enhance the risk management capacity of the participants and to develop the reliability of operation of their organisation in a comprehensive manner.

- The education programme in information security (30 credit points) is an entity studying information security from the viewpoint of security architecture in a wide-ranging manner. The programme provides the participants with versatile and up-to-date tools for comprehensive development of information security.
- Professional Master of Security (105 credit points) is a security sector qualification programme. The studies give an opportunity to deepen professional competence and to supplement this with new information important with a view to work duties, and to develop capabilities needed within the developing security sector.
- ACCI-Learn - Learning about accidents and incidents and their investigation (8 credit points) is a programme directed at those involved in the investigation of accidents and incidents or those managing such investigations. The goal is to enhance the ability of the participants to increase their competence in investigation activities and their understanding of such operations in their own organisations.

## **Laurea**

Laurea is a university of applied sciences that produces new competencies in the field of service innovations and emphasises working life orientation in its operations. The operational model of Laurea Learning by Developing (LbD) combines training, regional development and R&D activities. Laurea's strategic development is steered particularly by European and national innovation policies and by future competence needs.

Laurea has approximately 7,500 students and a staff of 550. Laurea offers 16 Bachelor's degree programmes, of which 7 are delivered in English. Laurea has seven units in Uusimaa region.

### **Degree Programme in Security Management**

**Degree: Bachelor of Business Administration in Business Economics (BBA)**

Extent and duration of studies: 210 credit points, 3.5 years

Maintenance and development of a safe living and operating environment will in future be based more and more on cooperation. Increasingly complex and extensive operational chains and logistical networks also place new demands on security. Security specialist studies can be pursued in the security management training programme at Leppävaara.

Security competence is displayed in the everyday operations of an organisation as competence in planning, implementation and assessment of security-related affairs

and command of skills related to security management. Graduates of the degree programme in security management have core competences in risk management, business operations, personal safety, information security, security management, and the security of operations, facilities and the environment. During their studies, the students also learn to predict the financial aspects of various security risks and to determine the financial effects of security measures. Because the maintenance and development of a safe living and operating environment requires more and more cooperation skills and multi-professional networks, the studies also develop communications and multi-cultural skills. Masters of Business Administration in the security sector work in different security sector duties such as security specialist, security planner, risk management director, chief of security, fire inspector or instructor in the field of security. During studies it is also possible to launch and develop own business activities.

The degree programme in security management is also implemented as adult education.

The degree programme has been completed by 307 students (6/2011).

## Security management

### Bachelor's degree: Bachelor of Business Administration (BBA)

Duration of studies: 210 credit points, 3.5 years

The Degree Programme in Security Management produces competencies improving security, safety, innovative security solutions and new services. Utilising diverse development methods are central areas throughout the degree. The aim is to provide students with high integrity and the ability to develop innovative security solutions and new services for both the private and public sector.

Graduates of the Degree Programme in Security Management have core competences in risk management, business operations, personal safety, information security, security management, and the security of operations, facilities and environment. Security management experts have good general business competence: they can predict the financial aspects of various security risks and determine the financial effects of security measures. Questions related to personal and community security are crucial. Increasingly complex operational chains and logistical networks place new demands on security. Experts in security must be able to anticipate risks and work to minimise the damages through cooperation.

### Degree Programme in Security Competence

### Degree: Master of Business Administration (MBA)

Extent and duration of studies: 90 credit points, 1.5–3 years

Laurea is the only educational institution in Finland that offers training leading to a Master's degree in security management. The studies focus on security and

risk management in both national and international environments. The programme trains security experts for demanding management and expert positions in various organisations.

The degree programme serves the security competence needs of both the private and public sector. The purpose of the programme is to provide students with in-depth competence in security and security management, and to give them the theoretical knowledge based on the latest research data for operating in demanding development and management duties requiring security competence. The graduates of the programme become developers to enhance the competitiveness of companies and the effectiveness of organisations on both domestic and international markets. Through the degree programme, the students strengthen their knowledge, skills and competence on security and security management, and understand the working life, regional, international and social importance related to such issues. Graduates of the degree programme have the capabilities and the methodical abilities for life-long learning related to security competence and to continuous development of their professional skills. The students are capable of meeting the new global challenges of security development and management. Furthermore, the students have the communications and language skills required for security development and management duties. The higher polytechnic degree obtained, Master of Business Administration, gives the same qualification for public offices and duties as the higher university degree.

The degree programme has been completed by 22 students (6/2011).

#### Study Programme in Security Auditing

In December 2011 Laurea initiated a training programme in security auditing (30 credit points). The training prepares students for acquiring the qualification of chief security auditor in accordance with the requirements of the national criteria for security auditing, KATAKRI. The training will be implemented at the request of the Ministry of the Interior as part of the Internal Security Programme ratified by the Government. Training is self-financed.

#### **Police College of Finland (Polytechnic)**

The Police College of Finland provides professional training leading to the following degrees:

1. Diploma in Police Studies
2. Finnish Police Sergeant's Examination
3. Bachelor and Master in Police Command (polytechnic degree within the Police Administration sector)



In addition to degree programmes, the Police College of Finland also offers vocational continuing and supplementary training. The college is also tasked with giving training related to quality management and other security-sector training.

By consent of the Police College of Finland, students other than those in the service of the Police Administration can also be admitted to the training programmes. The College also has the right to deny entry to persons who do not fulfil the requirements imposed on the target group for education, or who have not completed the required preliminary exercises within the deadline.

The Police College of Finland also organises fee-based training, for trainees other than those in the service of the Police Administration. Fee-based training includes the basic course for security steward instructors, and instruction in training in the use of force for guard trainers. The application documents are sent to the Police College's Student Selection Unit.

- The basic course for security steward instructors is directed at persons wishing to apply for security steward instructors certification from the National Police Board.
- The refresher course for security steward instructors is directed at those certified security steward instructors wishing to apply for renewal of the security steward instructors certification from the National Police Board.
- Training for guard trainers related to training in the use of force is directed at trainers performing this function at educational institutions providing guard training and at companies engaged in the guarding services business.
- The key purpose of refresher training for guard trainers related to training in the use of force is to maintain their training capabilities regarding training in the special use of force and refresher training in the use of forcible means equipment.
- The key objective of firearms instructor training is to provide the trainees with the capabilities for acting as instructors of special use of force training for the section concerning firearms, instructors of refresher training in the use of forcible means equipment, and examiners in the test measuring firearm handling and firing skills.
- The key objective of refresher training for firearms instructors is to maintain the trainees' above-mentioned capabilities.

## **Tampere University of Applied Sciences**

Tampere University of Applied Sciences offers education to approximately 10,000 students in seven educational fields. The education focuses on technology, business, welfare services, tourism and culture. The School of Vocational Teacher Education, which provides the pedagogical qualification required of teachers and special needs teachers in vocational institutions, is also part of Tampere University of Applied Sciences. In addition to degree studies, Tampere University of Applied Sciences

offers diverse possibilities for maintenance of competence in various supplementary education programmes. The tasks of the University of Applied Sciences also include applied research and development activities and working-life-oriented service operations.

### **Security MBA Programme in Business Administration and Security Management(120 credit points)**

The studies are directed at private and public sector experts in administration, information technology and security, and at persons specialising in international business or administration. The programme includes the modules:

- 1 Security management, 7 credit points
- 2 Information security, 7 credit points
- 3 Future challenges facing the security sector in business and international cooperation, 7 credit points
- 4 Business legislation and operating environment, 7 credit points
- 5 Strategic leadership, problem solving and development, 7 credit points
- 6 European security practices, Brussels, 8 credit points
- 7 Diploma work seminar
- 8 Risk management, 7 credit points

### **Tampere University of Technology**

At Tampere University of Technology, security studies can be taken as a major or minor subject, or as individual courses as part of the Master of Science in Technology degree. The University also offers postgraduate education with security as a field of specialisation leading to postgraduate degrees (Doctor, Licentiate). Research and teaching related to security is implemented with more than 30 years of experience.

### **Turku University of Applied Sciences**

Turku University of Applied Sciences is a multi-branch educational community of 9,500 students and 800 experts. The University of Applied Sciences offers education that supports working life and entrepreneurship, research and development services (R&D) and holistic development of organisations. At Turku University of Applied Sciences students can study for a Bachelor's or Master's degree in seven different educational fields, update their knowledge and skills at the Open University of Applied Sciences, or acquire new energy for their work from continuing education. As part of continuing education Turku University of Applied Sciences arranges education providing the vocational qualification of Chief of Security.

Chief of Security, 30 credit points

The training is intended for persons responsible for security affairs in companies, those in expert or management duties in the field of security, and persons marketing or providing consultation on security sector services. Applicants are required to have a polytechnic, university or former college-level degree or other corresponding education and work experience. The training programme consists of the following entities:

- Holistic security management
- Basics of business security and risk management
- Facility security
- Personal safety
- Crime security
- Basics of information security
- Production and operational security
- Security in foreign operations
- Environmental safety
- Security planning
- Communications
- The training also includes a personal development task for trainees.

Security issues have emerged with increasing significance alongside quality and environmental affairs from the point of view of profitability and continuity of business activities. The training provides trainees with capabilities for systematic and coherent risk and security management work and its integration into the company management system.

## Appendix 4

### Current Personnel within the Nuclear Energy Sector

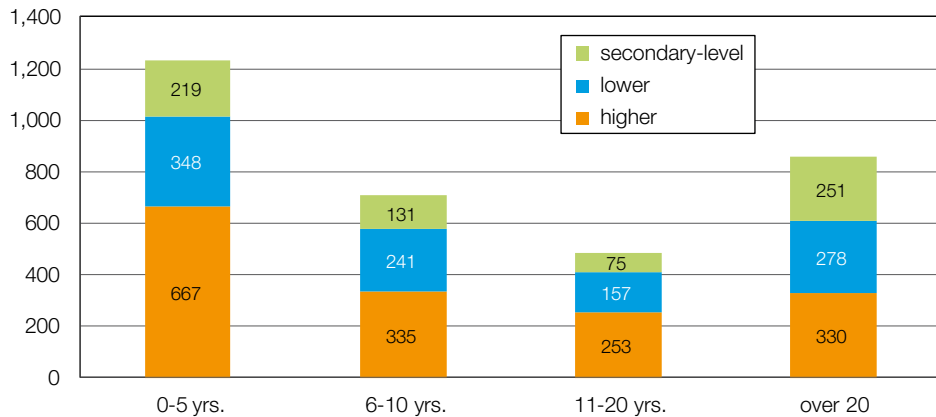
#### Personnel in Numbers by Degree Qualification

**Table 1.** Total personnel within the sector.

Degree	Number
Higher university/polytechnic degree (Master)	1,585
Licentiate, postgraduate degree	55
Doctorate, postgraduate degree	232
Lower university/polytechnic degree (Bachelor)	1,024
Secondary-level vocational qualification	676

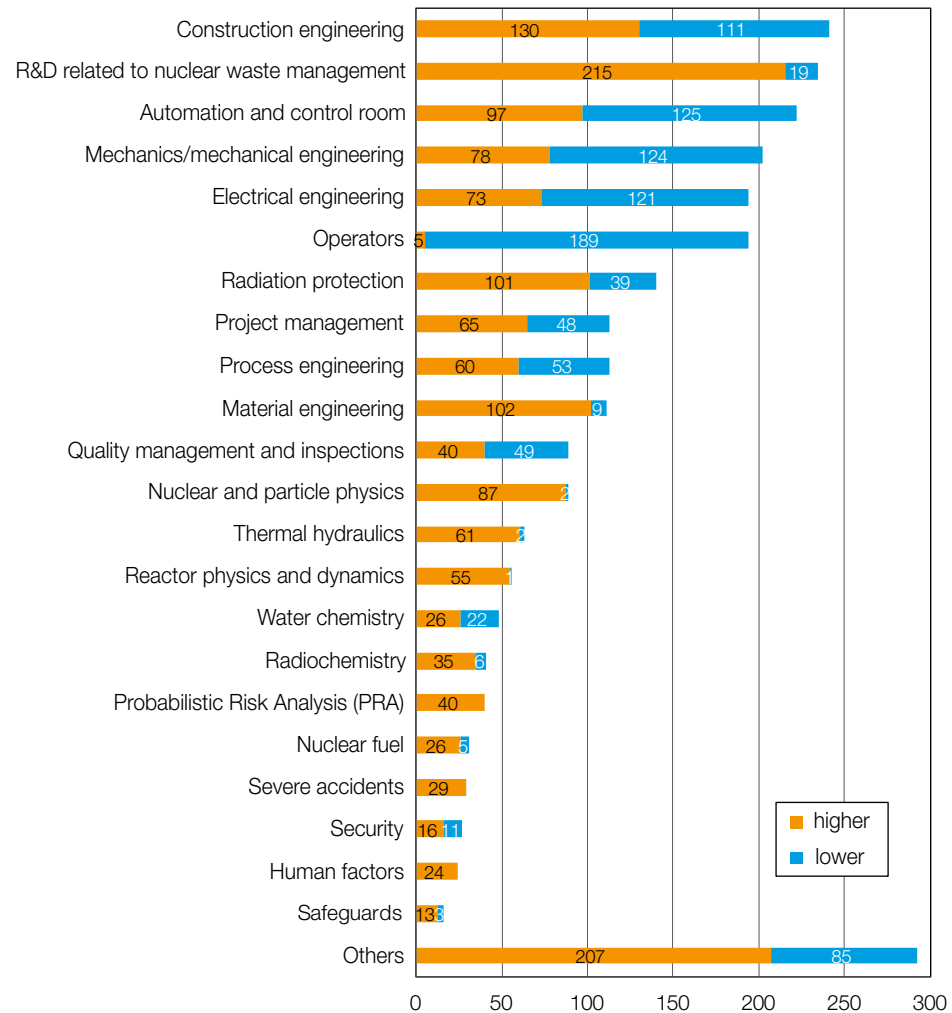
#### 1.1 Current Nuclear Energy Sector Personnel by Years of Experience and Age

**Figure 1.** The current personnel.



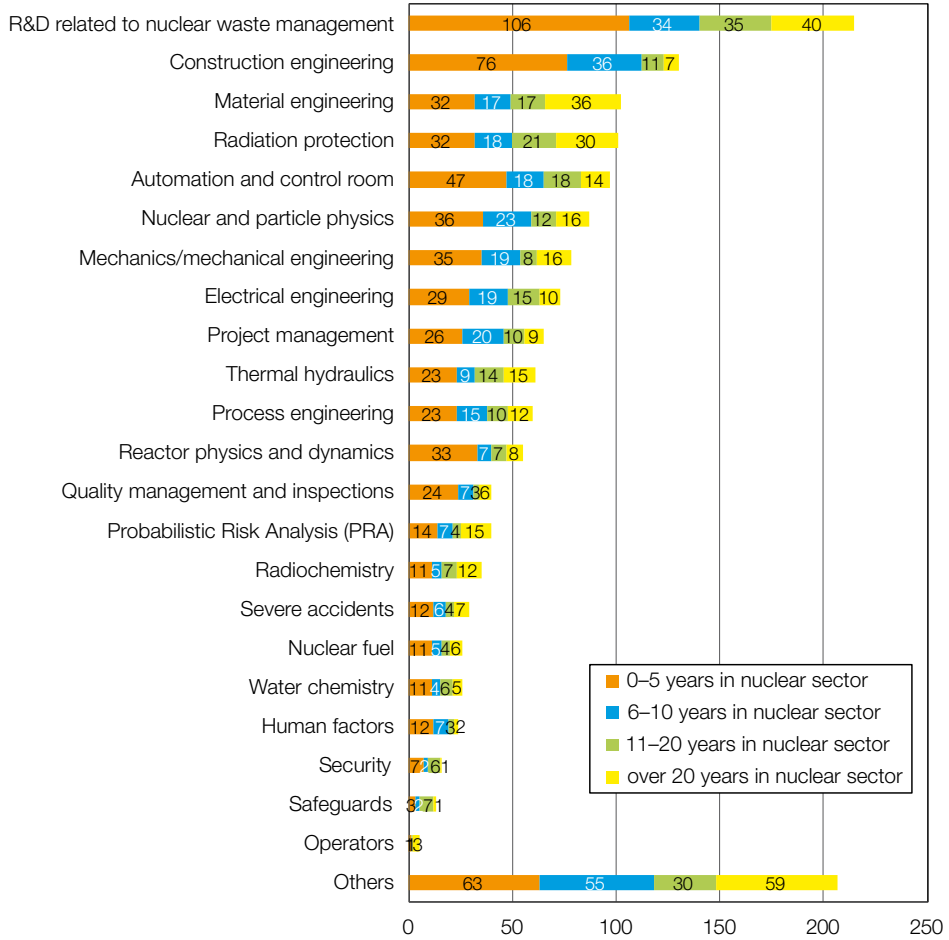
## 1.2 Total current Personnel by Area of Competence

Figure 2. Total current personnel by area of competence.



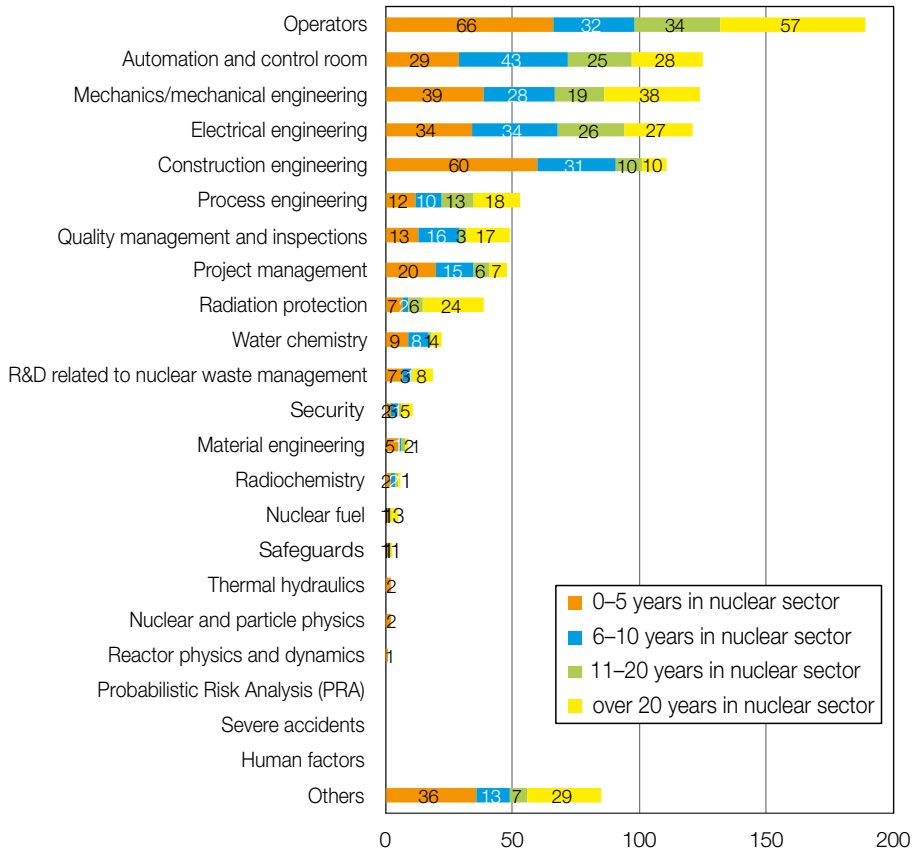
### 1.3 Personnel with Higher University or Polytechnic Degree

**Figure 3.** Personnel with a higher university or polytechnic degree by area of competence and years of experience.



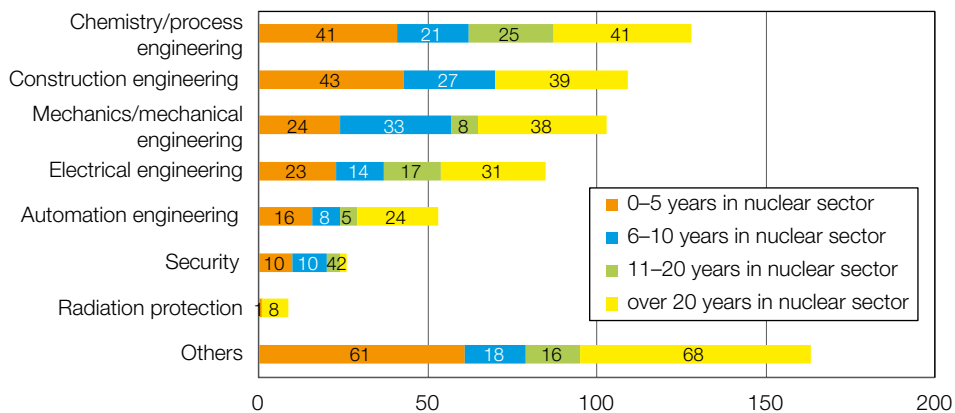
## 1.4 Personnel with Lower University or Polytechnic Degree

**Figure 4.** Personnel with a lower university or polytechnic degree by area of competence and years of experience.



## 1.5 Secondary-level Vocational Qualification

**Figure 5.** Personnel with secondary-level vocational qualification by years of experience.



## 2 Future needs

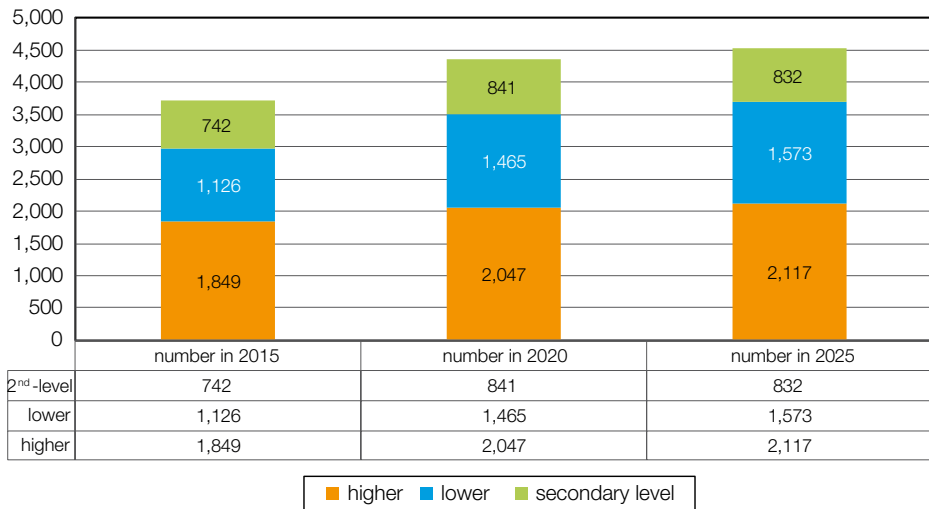
### 2.1 Entire Personnel within the Sector

**Table 2.** Overall need for personnel within the nuclear energy sector.

Degree	Number in 2015	Number in 2020	Number in 2025
Higher university/polytechnic degree (Master)	1,849	2,047	2,117
Licentiate, postgraduate degree	46		
Doctorate, postgraduate degree	253		
Lower university/polytechnic degree (Bachelor)	1,126	1,465	1,573
Secondary-level vocational qualification	742	841	832

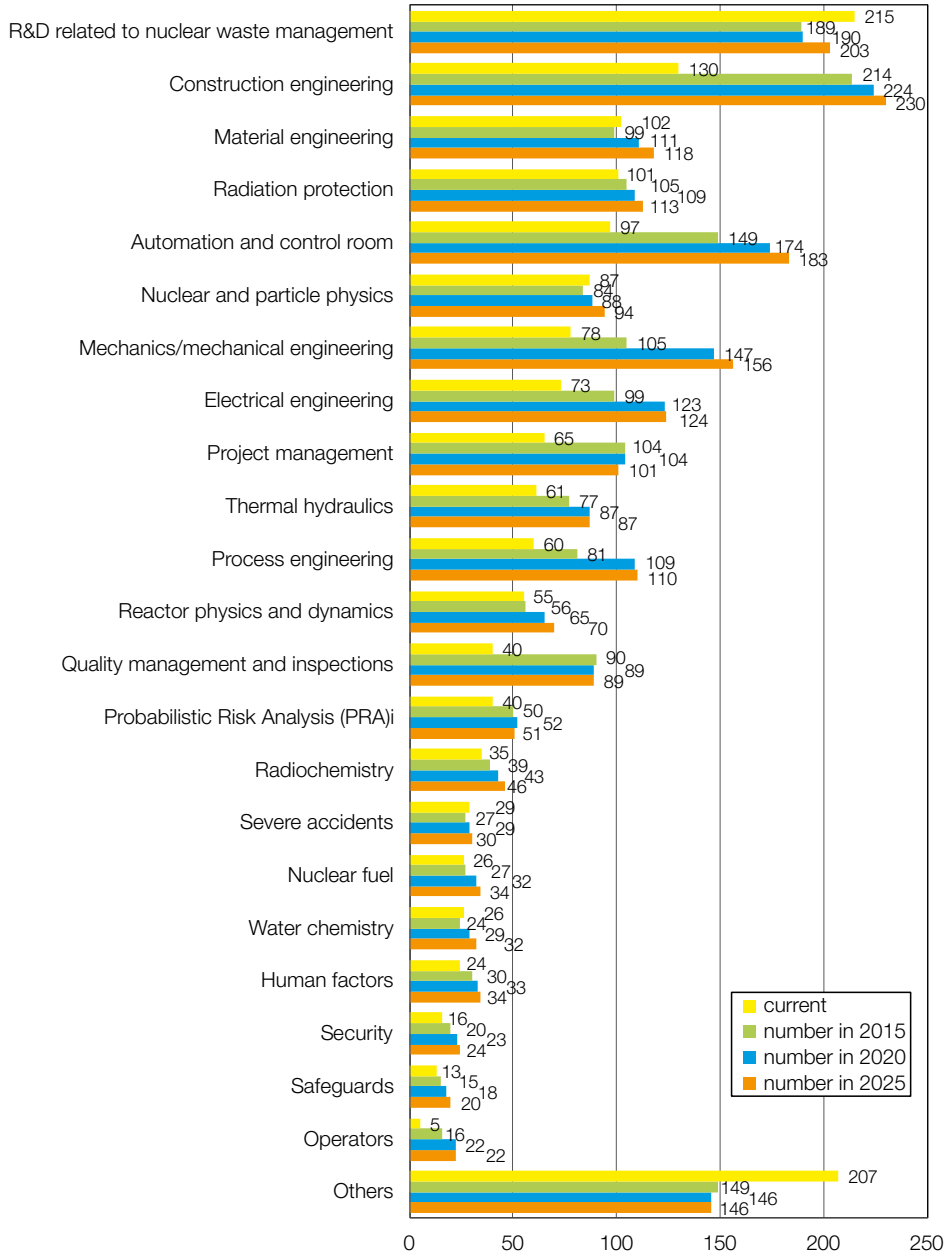


**Figure 6. Future need for personnel.**

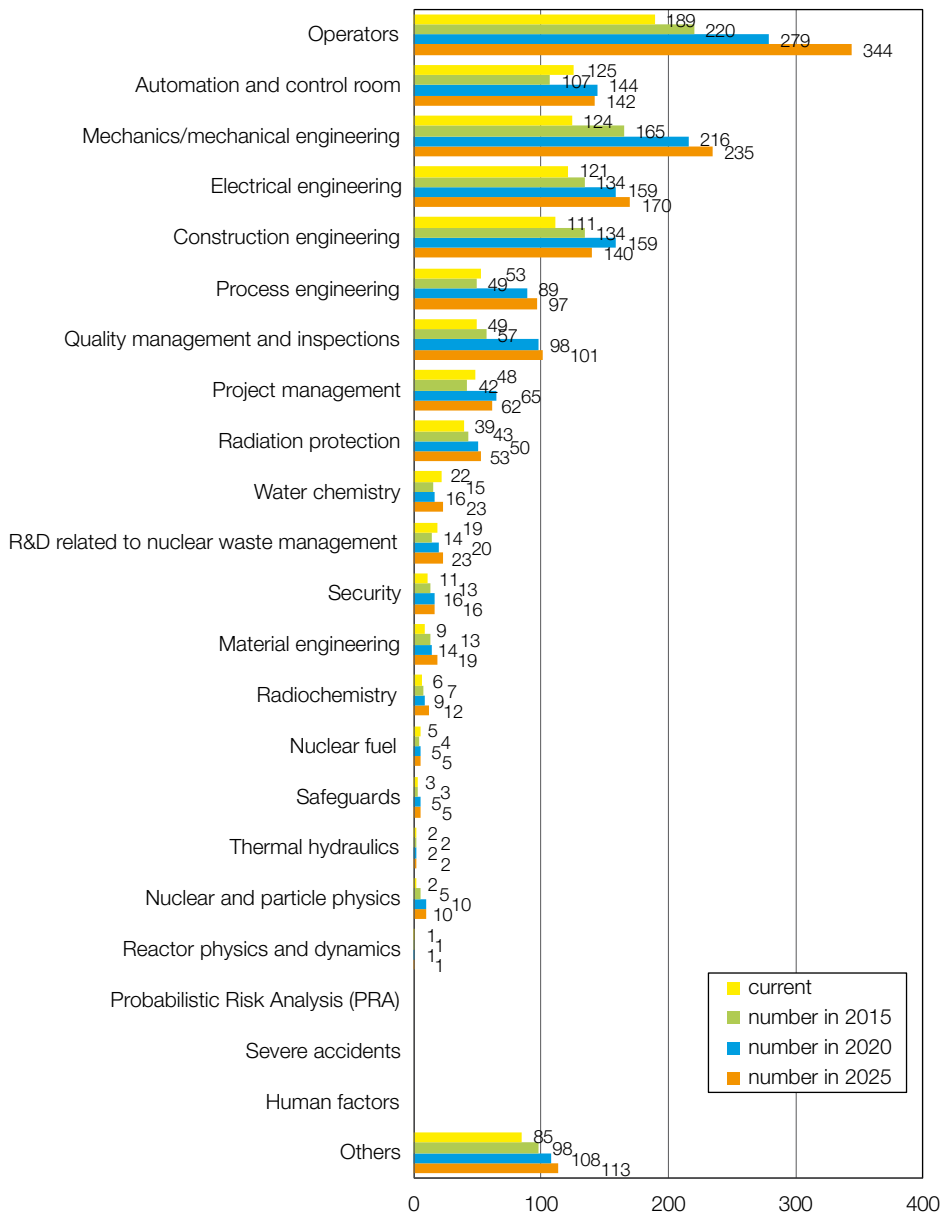


## 2.2 Need for Personnel by Area of Competence and Level of Education

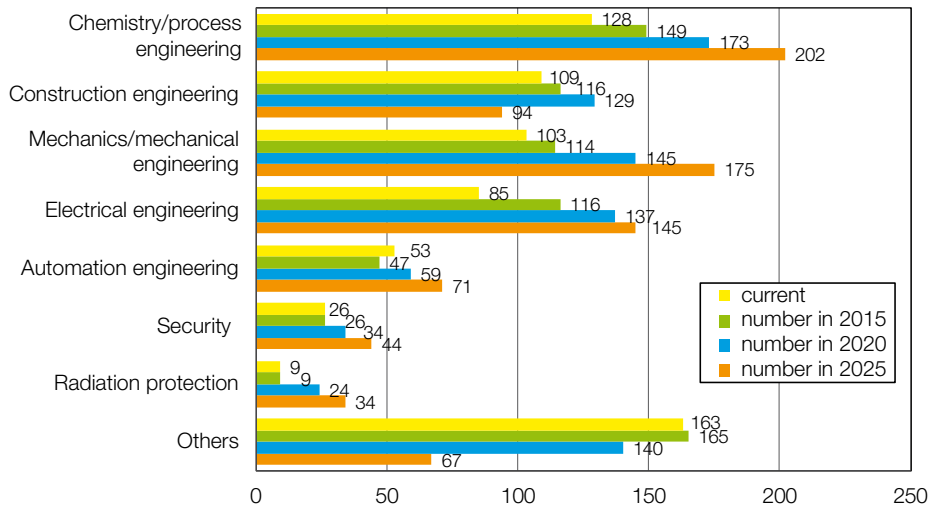
Figure 7. Future need for personnel, those with a higher university or poly-technic degree.



**Figure 8.** Future need for personnel, those with a lower university or poly-technic degree.



**Figure 9.** Future need for personnel, those with secondary-level vocational qualification.



## Appendix 5

### 1 Power Companies within the Nuclear Energy Sector

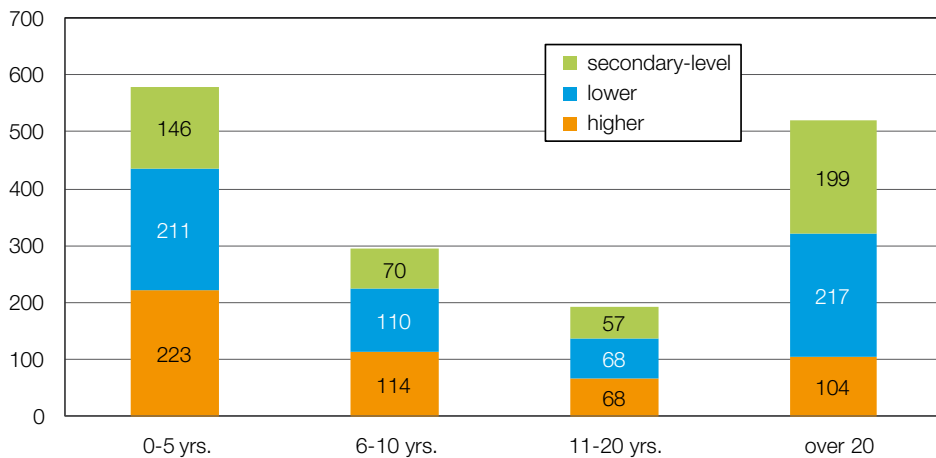
#### Power Company Personnel in Numbers by Degree Qualification

**Table 1.** Power companies

Degree	Number
Higher university/polytechnic degree (Master)	509
Licentiate, postgraduate degree	10
Doctorate, postgraduate degree	33
Lower university/polytechnic degree (Bachelor)	606
Secondary-level vocational qualification	472

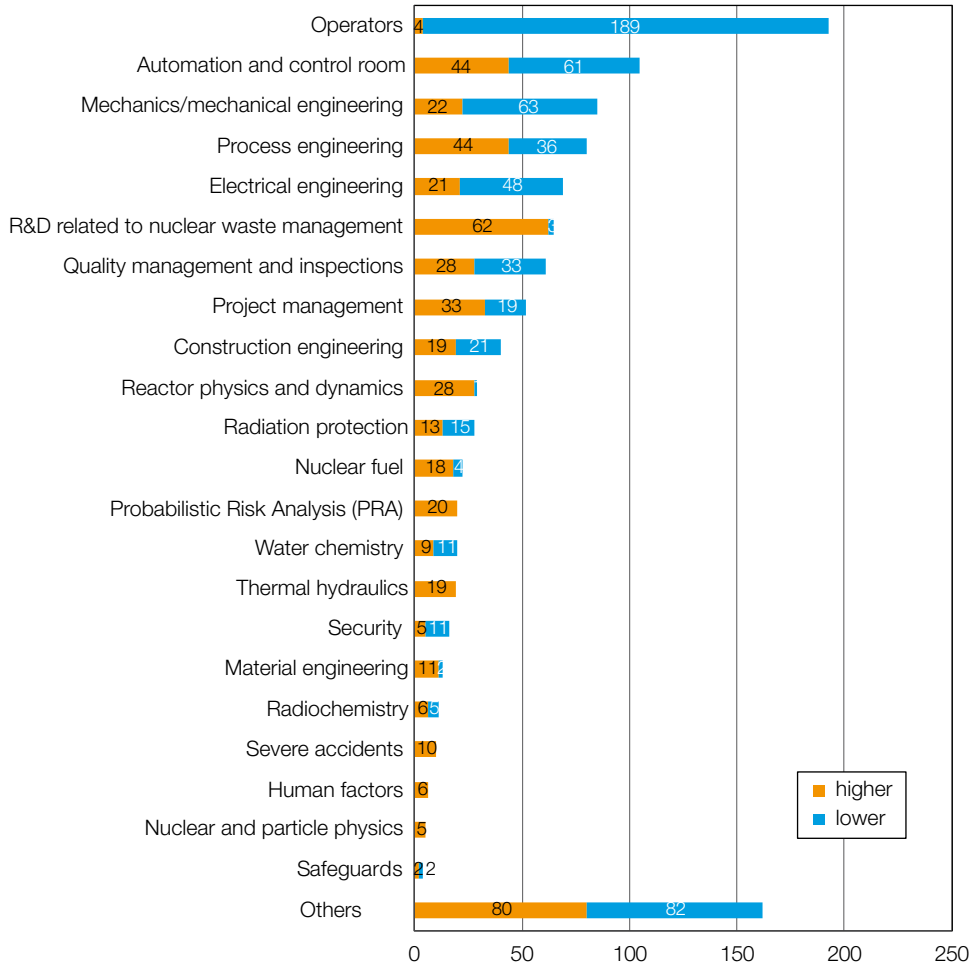
#### 1.1 Power Company Personnel by Years of Experience and Age

**Figure 1.** Current personnel.



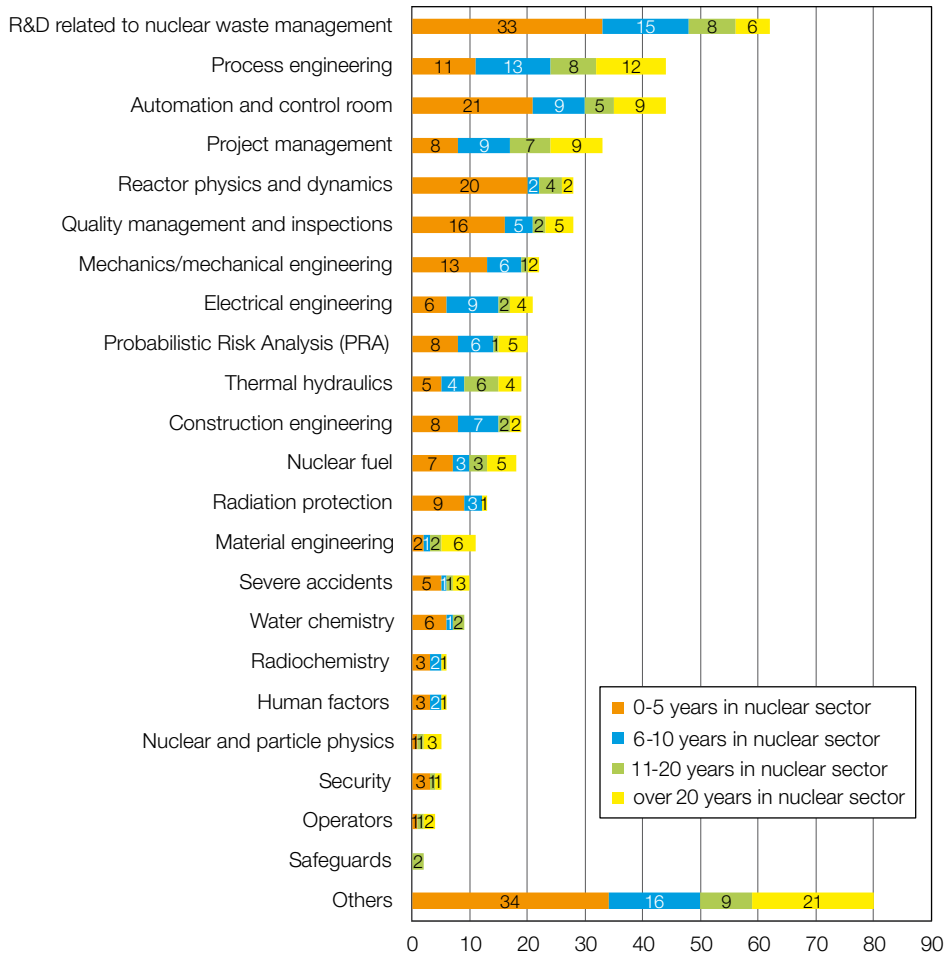
## 1.2 Current Power Company Personnel by Area of Competence

Figure 2. Power Company Personnel by Area of Competence.



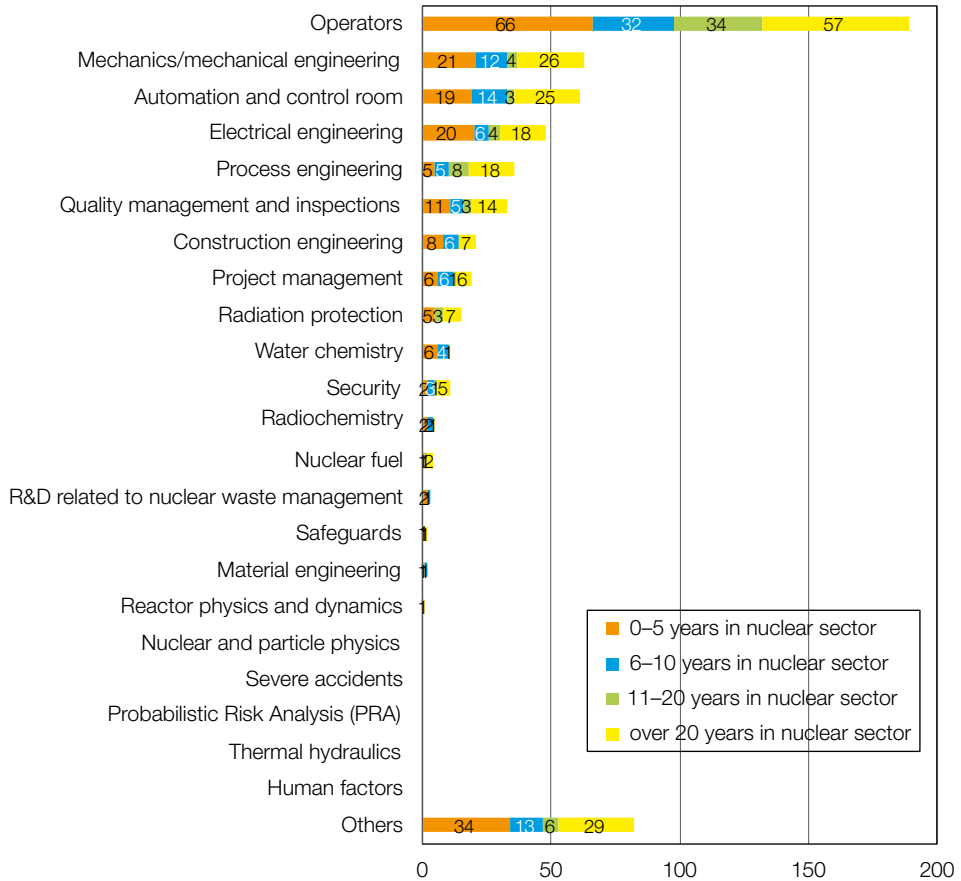
### 1.3 Personnel with Higher University or Polytechnic Degree

**Figure 3.** Personnel with a higher university or polytechnic degree by area of competence and years of experience.



## 1.4 Personnel with Lower University or Polytechnic Degree

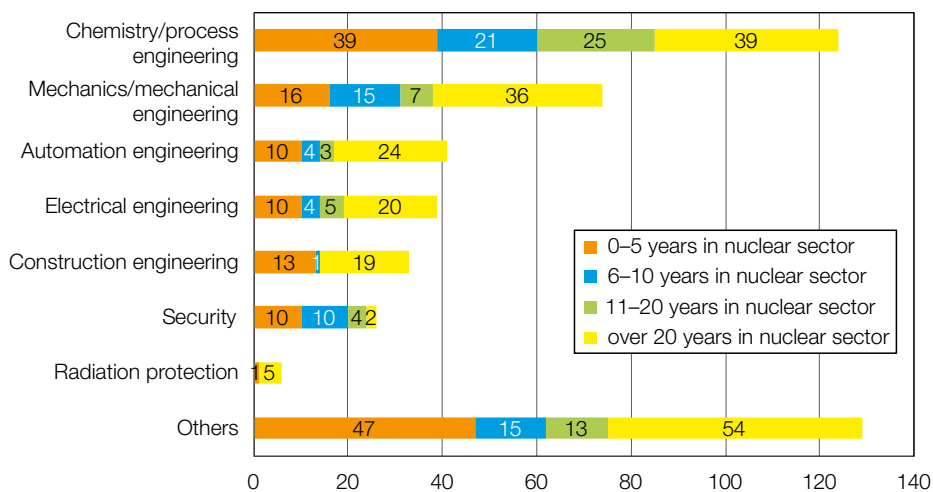
**Figure 4.** Personnel with a lower university or polytechnic degree by area of competence and years of experience.





## 1.5 Secondary-level Vocational Qualification

**Figure 5.** Personnel with secondary-level vocational qualification by years of experience.



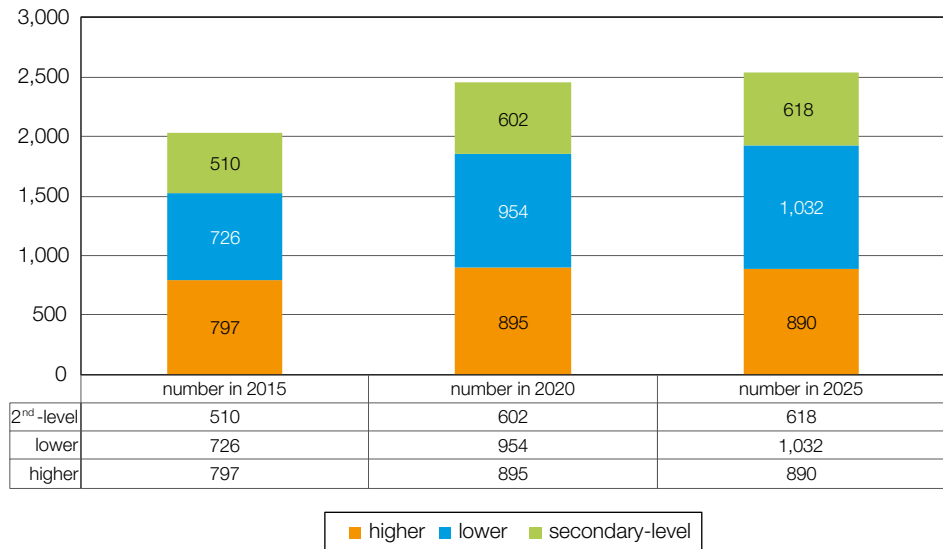
## 2 Future needs

### 2.1 Power Company Personnel

**Table 2.** Overall need for personnel

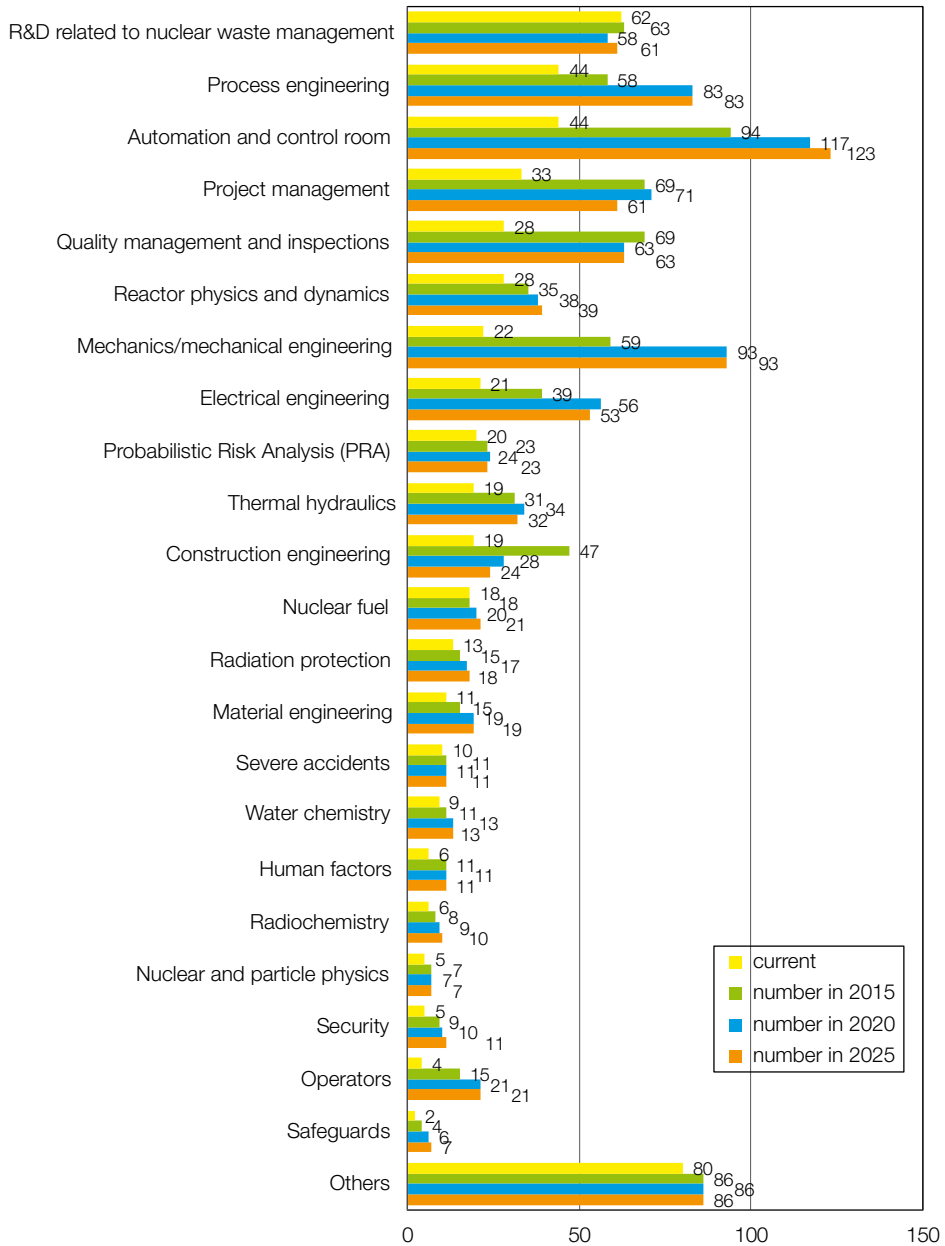
Degree	Number in 2015	Number in 2020	Number in 2025
Higher university/polytechnic degree (Master)	797	895	890
Licentiate, postgraduate degree	11		
Doctorate, postgraduate degree	37		
Lower university/polytechnic degree (Bachelor)	726	954	1032
Secondary-level vocational qualification	510	602	618

**Figure 6. Future need for personnel.**

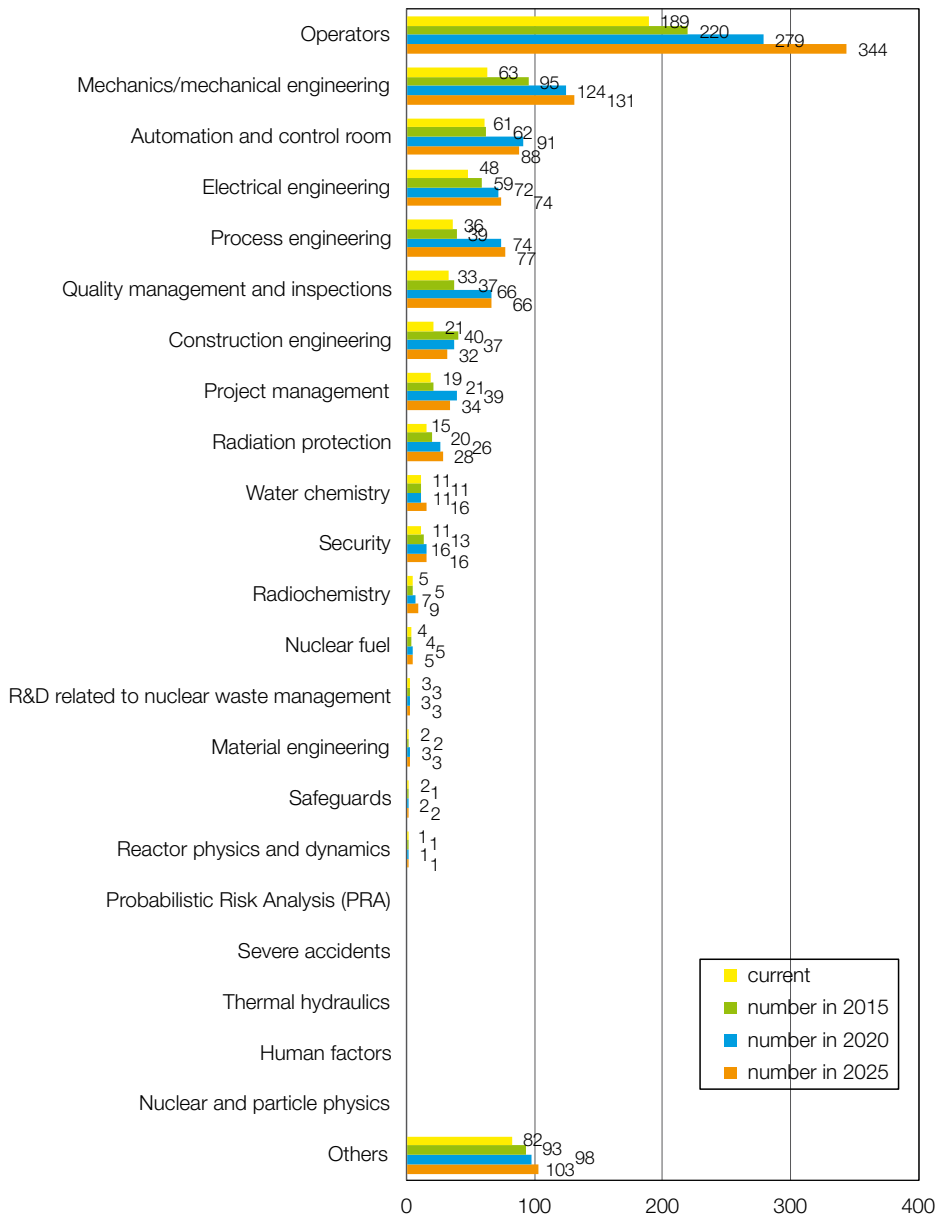


## 2.2 Need for Personnel by Area of Competence and Level of Education

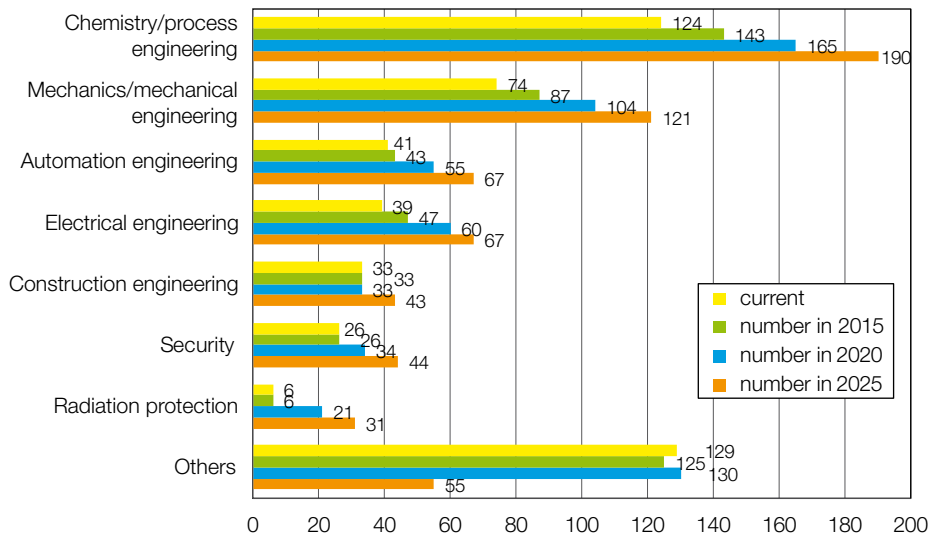
Figure 7. Future need for personnel, those with a higher university or poly-technic degree.



**Figure 8.** Future need for personnel, those with a lower university or poly-technic degree.



**Figure 9.** Future need for personnel, those with secondary-level vocational qualification.



## Appendix 6

### 1 Authorities within the Nuclear Energy Sector

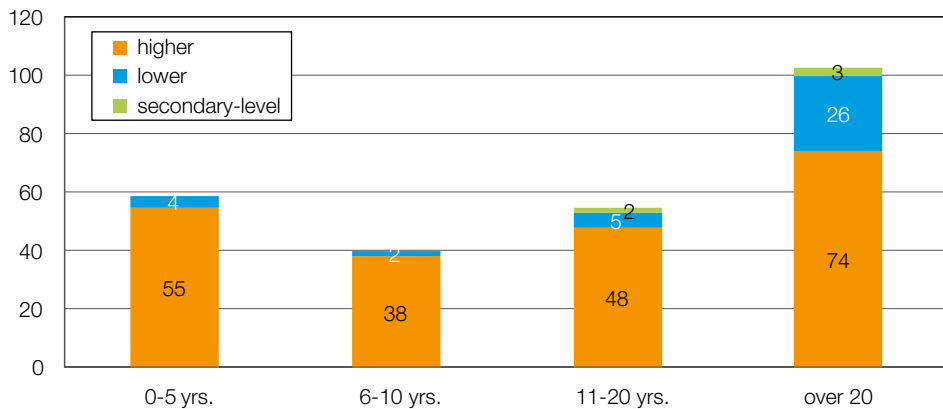
#### Personnel in Numbers by Degree Qualification

**Table 1. Authorities**

Degree	Number
Higher university/polytechnic degree (Master)	215
Licentiate, postgraduate degree	8
Doctorate, postgraduate degree	38
Lower university/polytechnic degree (Bachelor)	37
Secondary-level vocational qualification	5

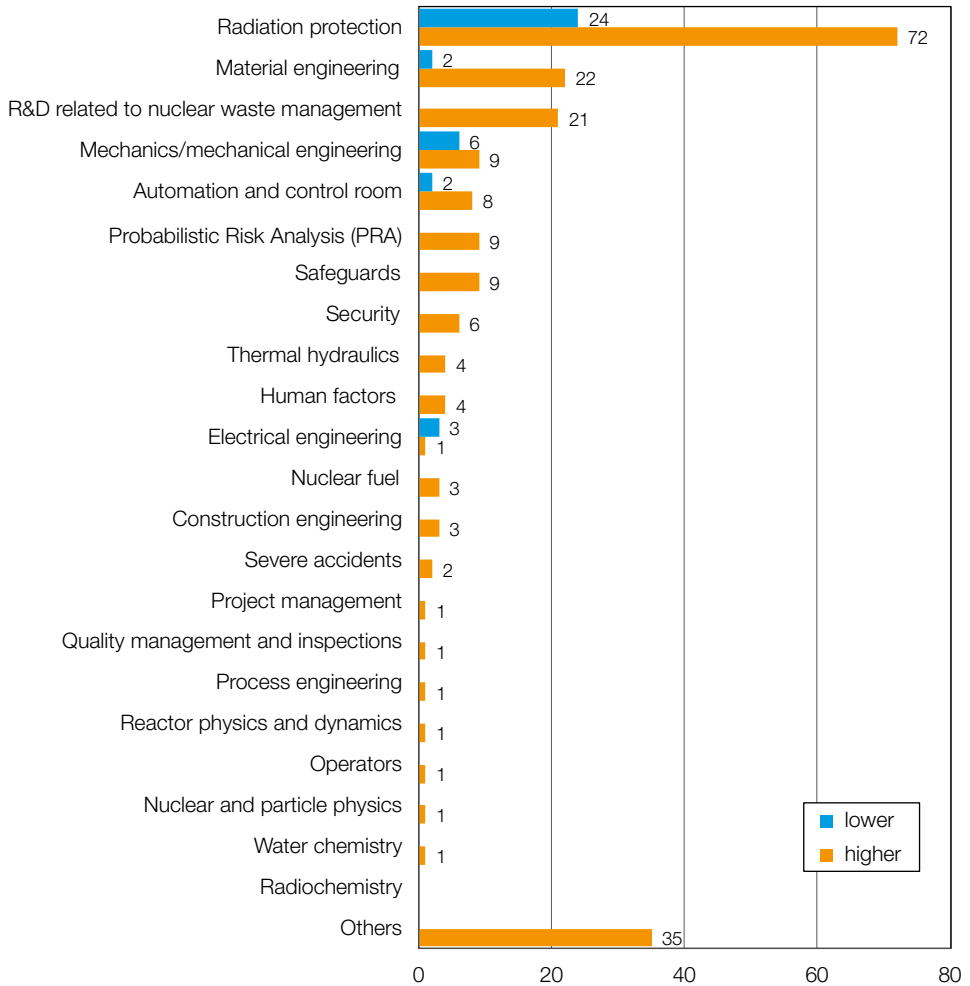
#### 1.1 Authorities by Years of Experience and Age

**Figure 1. Current personnel.**



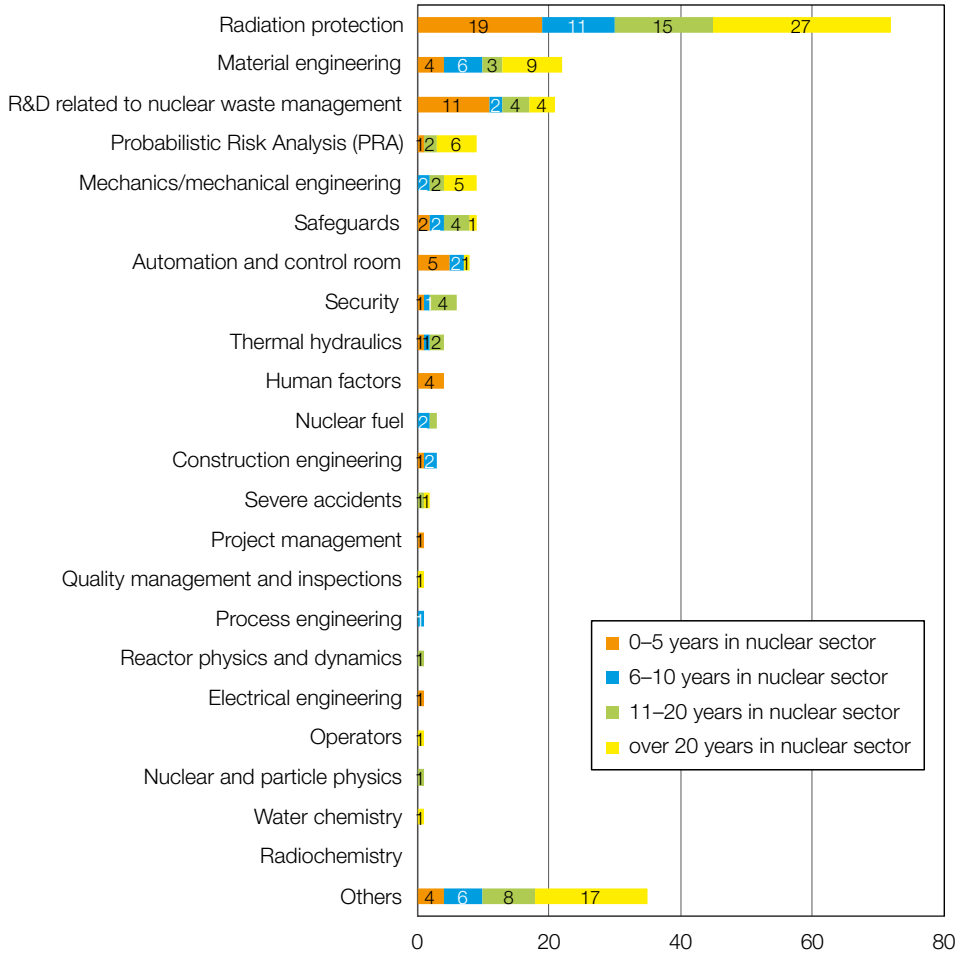
## 1.2 Current Personnel of Authorities by Area of Competence

Figure 2. Current personnel of authorities by area of competence.



### 1.3 Personnel with Higher University or Polytechnic Degree

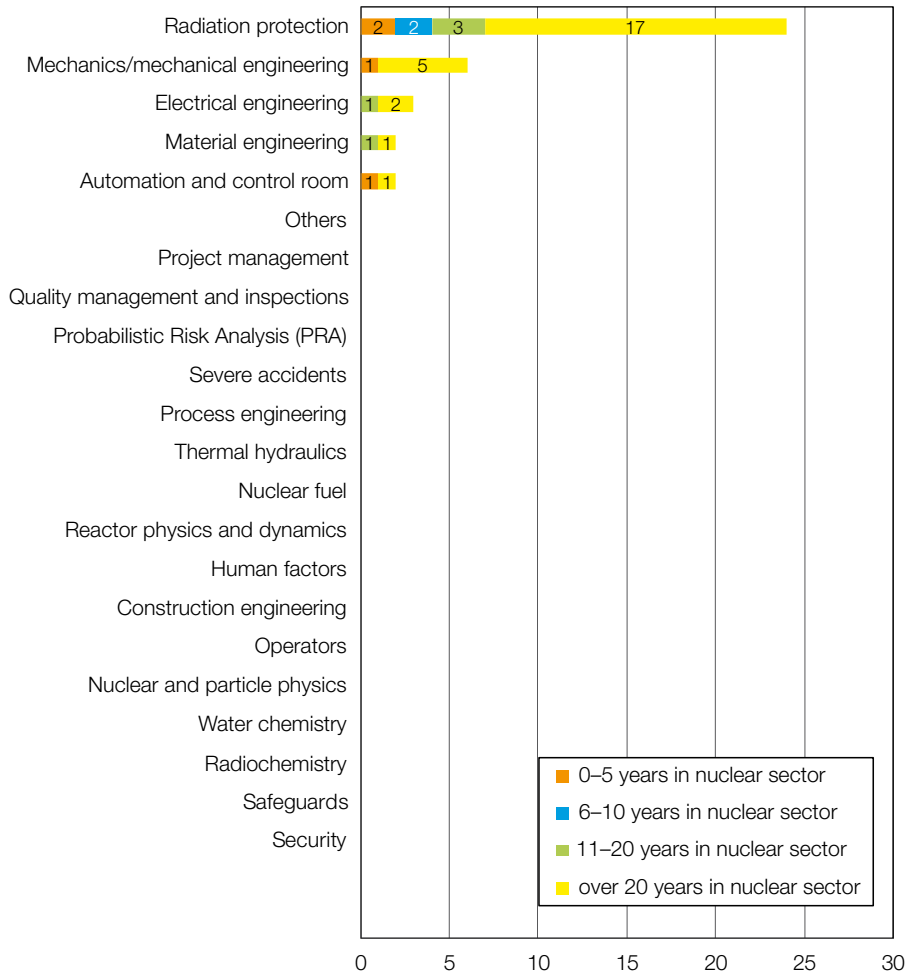
**Figure 3.** Personnel with a higher university or polytechnic degree by area of competence and years of experience.





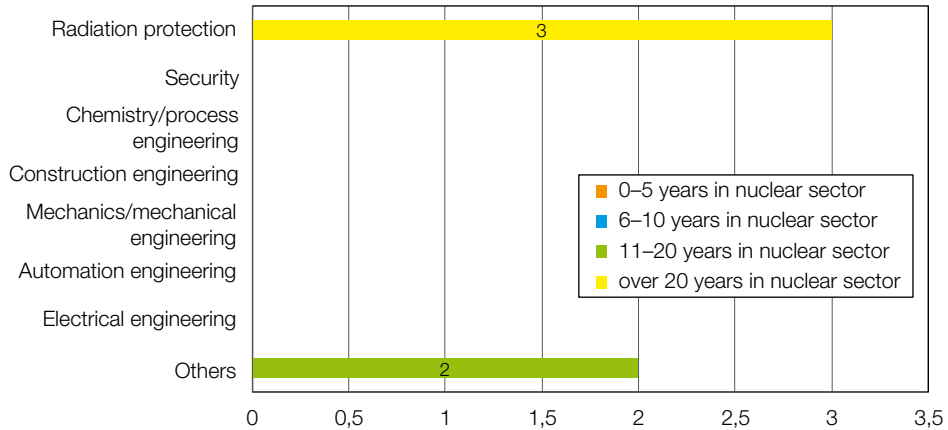
### 1.4 Personnel with Lower University or Polytechnic Degree

**Figure 4.** Those with a lower university or polytechnic degree by area of competence and years of experience.



## 1.5 Secondary-level Vocational Qualification

**Figure 5.** Those with secondary-level vocational qualification by years of experience



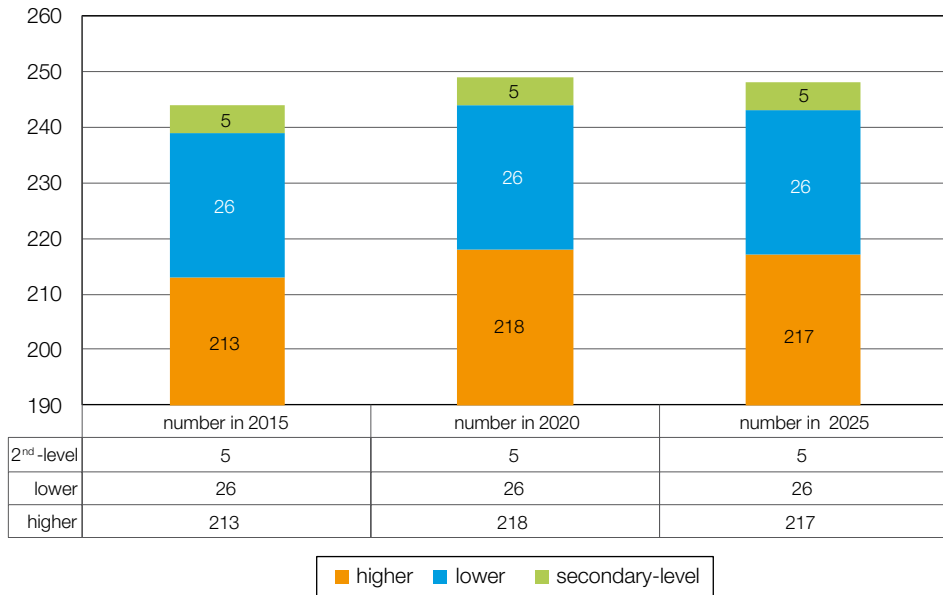
## 2 Future needs

### 2.1 Personnel Needs of Authorities

**Table 2.** Overall need for personnel.

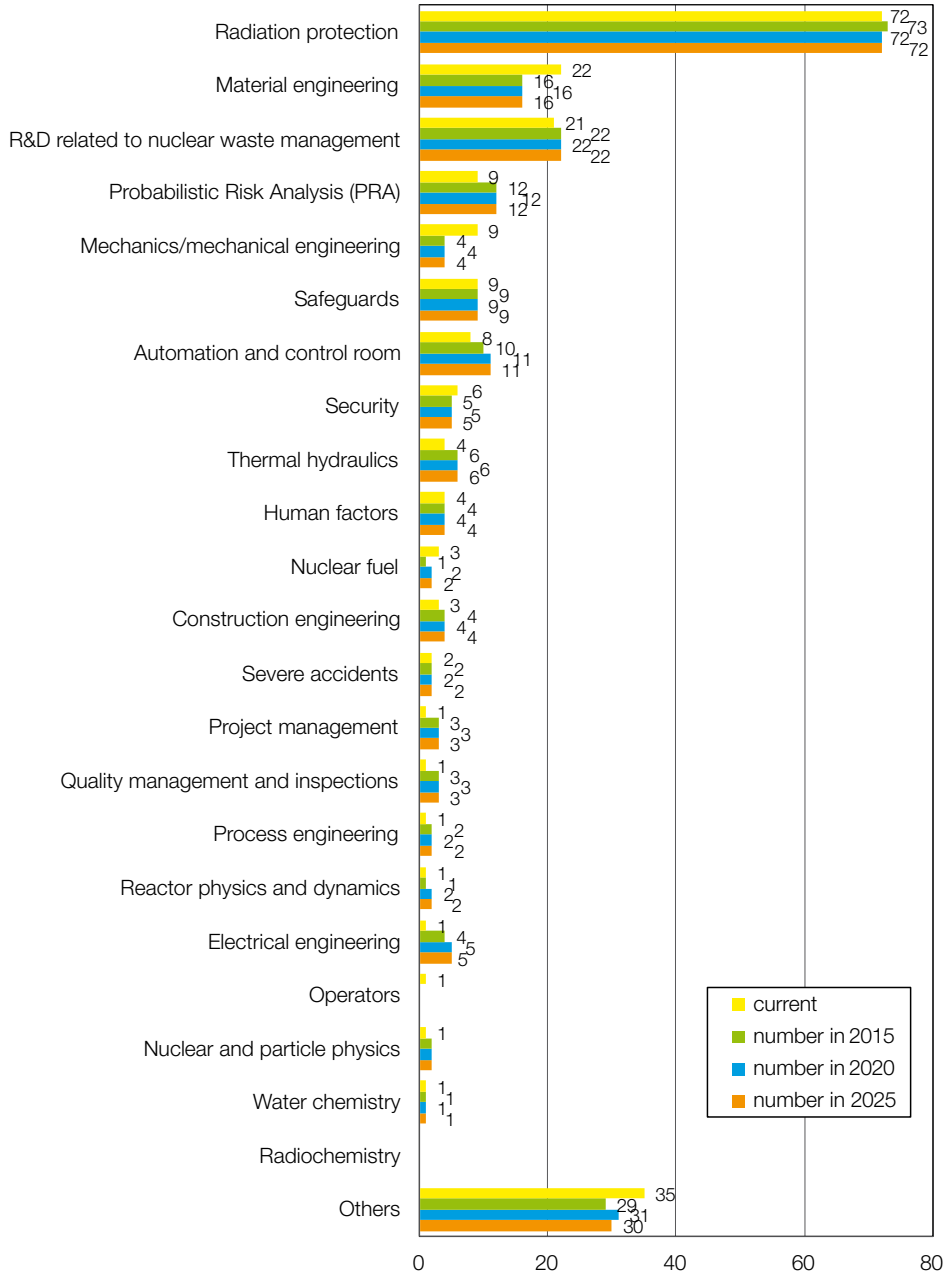
Degree	Number in 2015	Number in 2020	Number in 2025
Higher university/polytechnic degree (Master)	213	218	217
Licentiate, postgraduate degree	10		
Doctorate, postgraduate degree	30		
Lower university/polytechnic degree (Bachelor)	26	26	26
Secondary-level vocational qualification	5	5	5

**Figure 6. Future need for personnel.**

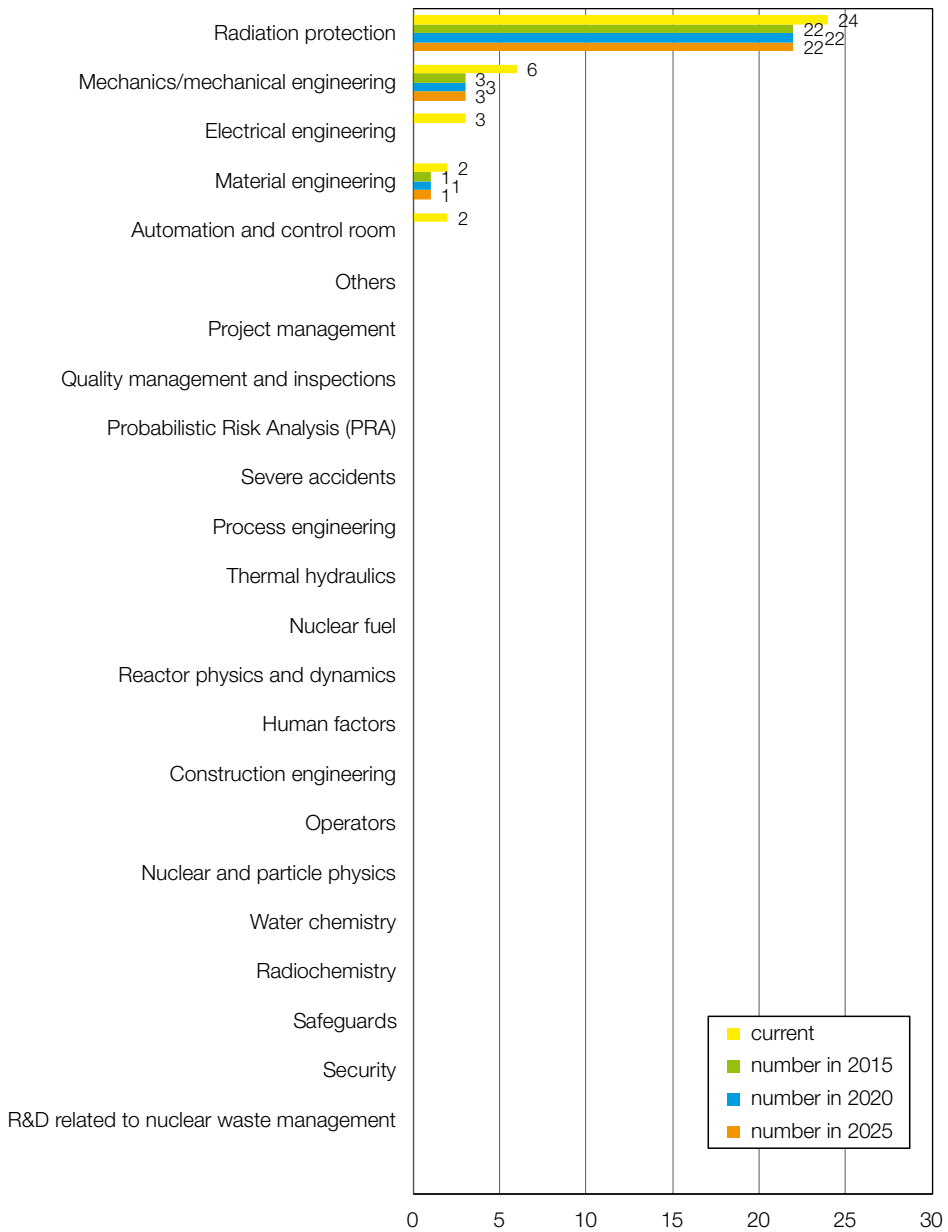


## 2.2 Need for Personnel by Area of Competence and Level of Education

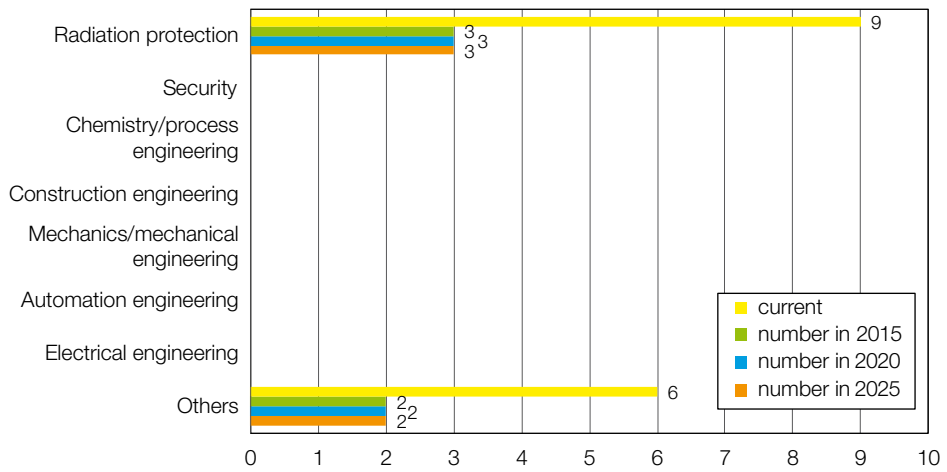
Figure 7. Future need for personnel, those with a higher university or poly-technic degree.



**Figure 8.** Future need for personnel, those with a lower university or poly-technic degree.



**Figure 9.** Future need for personnel, those with secondary-level vocational qualification.



## Appendix 7

### 3 Current Personnel within the Nuclear Energy Sector, Universities and Research Institutions

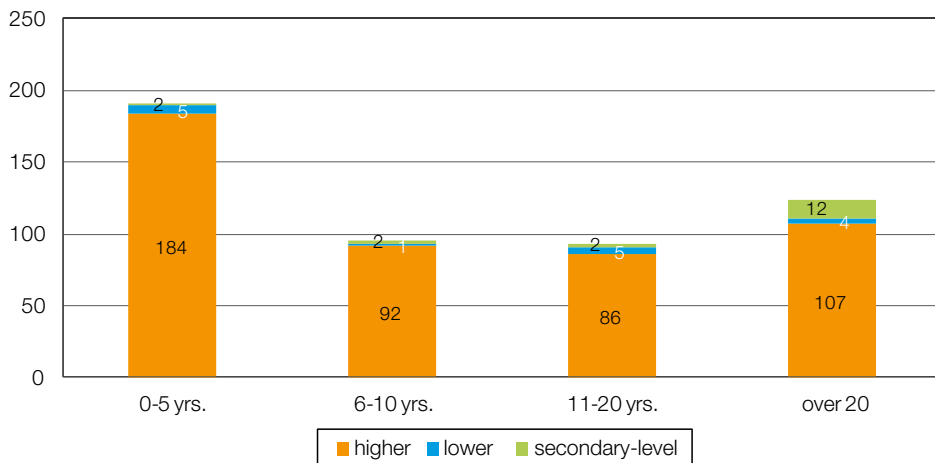
#### Personnel in Numbers by Degree Qualification

**Table 1.** Universities and research institutions

Degree	Number
Higher university/polytechnic degree (Master)	469
Licentiate, postgraduate degree	20
Doctorate, postgraduate degree	132
Lower university/polytechnic degree (Bachelor)	15
Secondary-level vocational qualification	18

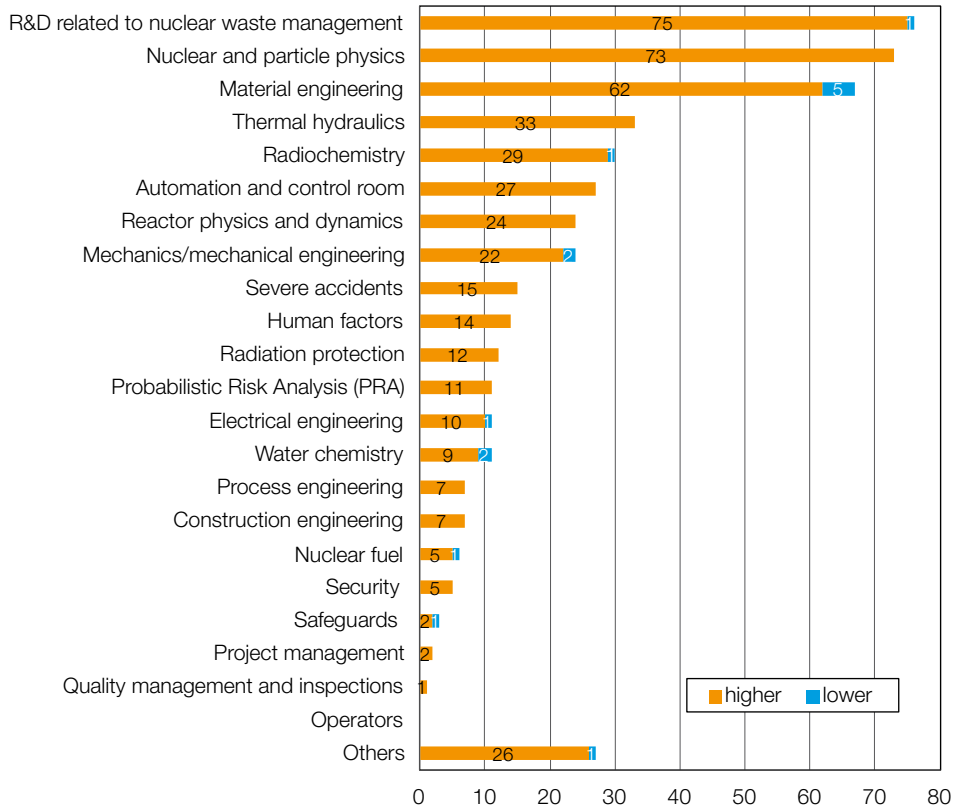
#### 1.1 Personnel of Universities and Research Institutions by Years of Experience and Age

**Figure 1.** Current personnel.



## 1.2 Current Personnel of Universities and Research Institutions by Area of Competence

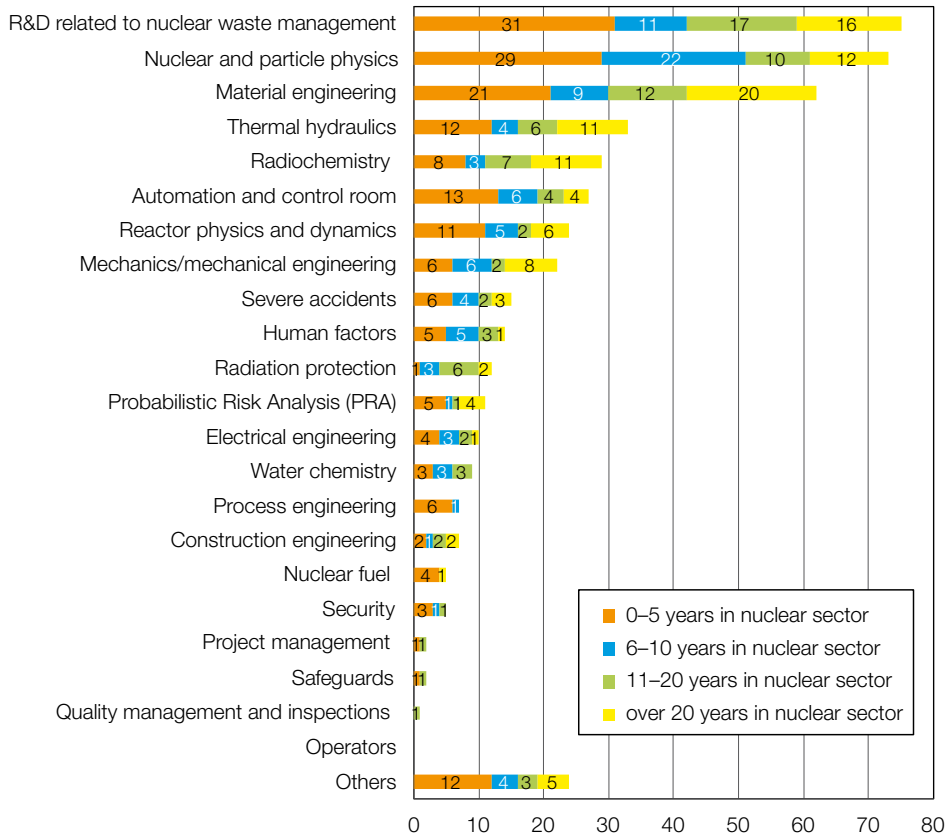
**Figure 2.** Current personnel of universities and research institutions by area of competence.





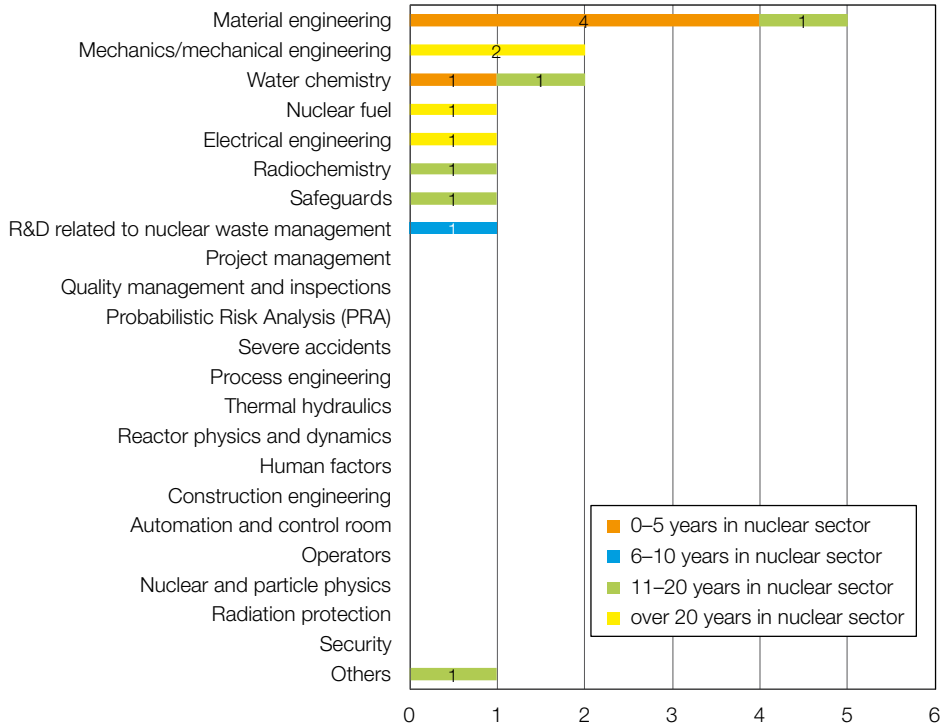
### 1.3 Personnel with Higher University or Polytechnic Degree

**Figure 3.** Personnel with a higher university or polytechnic degree by area of competence and years of experience.



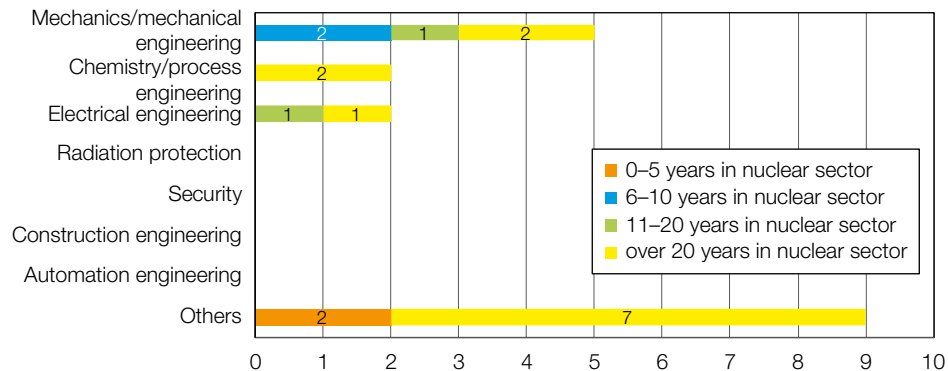
## 1.4 Personnel with Lower University or Polytechnic Degree

**Figure 4.** Personnel with a lower university or polytechnic degree by area of competence and years of experience.



## 1.5 Secondary-level Vocational Qualification

**Figure 5.** Personnel with secondary-level vocational qualification by years of experience



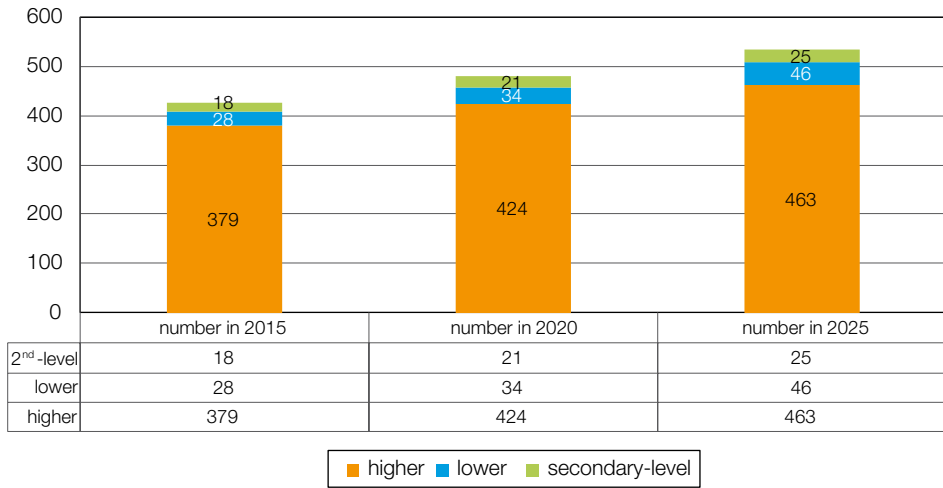
## 2 Future needs

### 2.1 Personnel of Universities and Research Institutions

**Table 2.** Overall need for personnel.

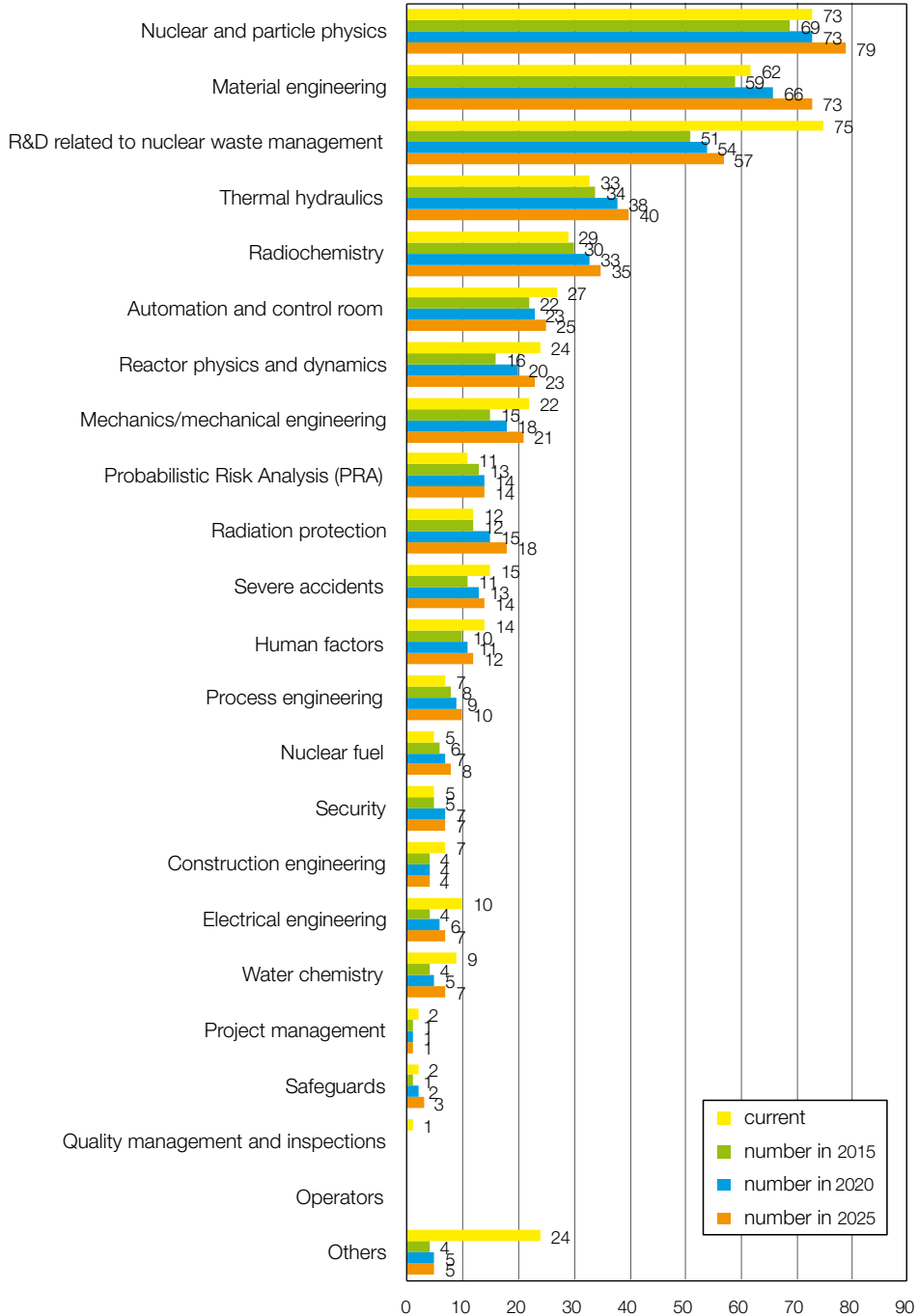
Degree	Number in 2015	Number in 2020	Number in 2025
Higher university/polytechnic degree (Master)	442	494	535
Licentiate, postgraduate degree	19		
Doctorate, postgraduate degree	166		
Lower university/polytechnic degree (Bachelor)	28	34	46
Secondary-level vocational qualification	18	21	25

**Figure 6. Future need for personnel.**

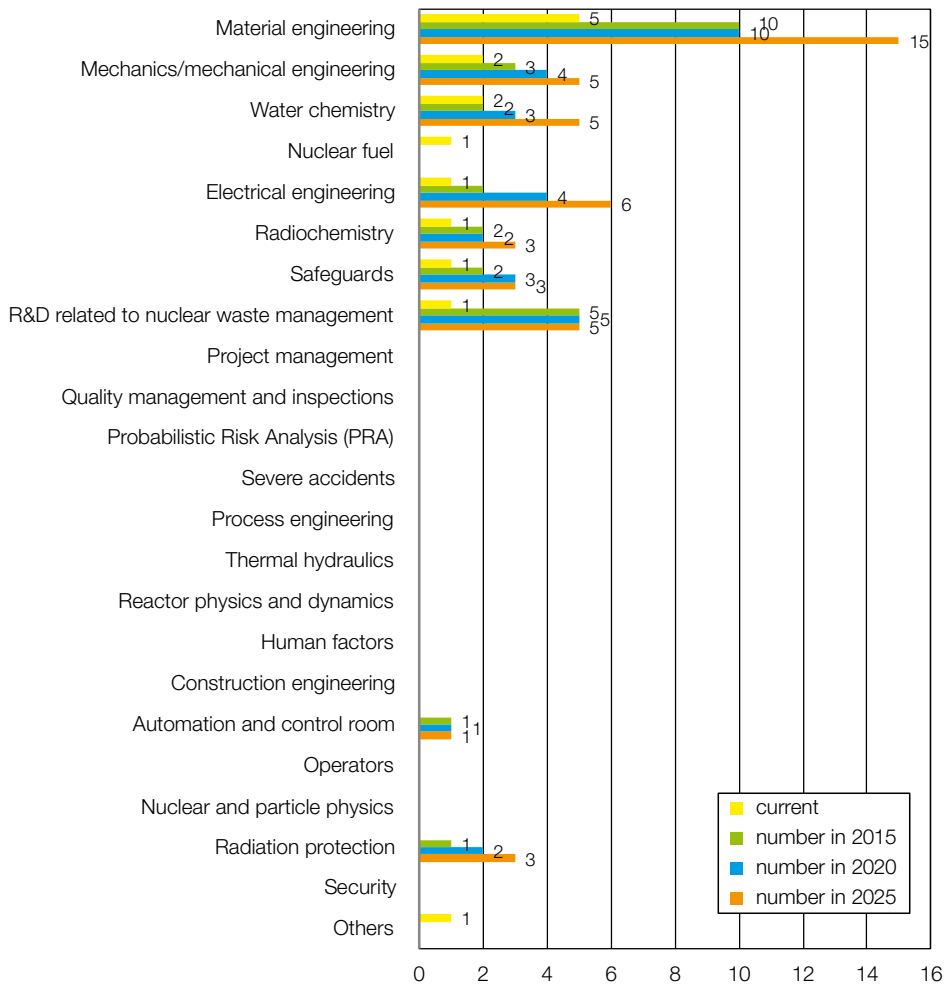


## 2.2 Need for Personnel by Area of Competence and Level of Education

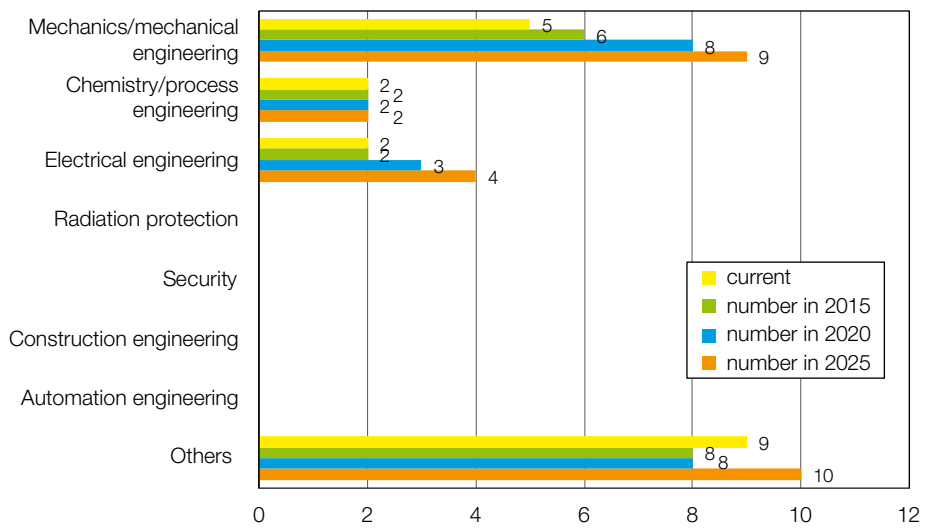
Figure 7. Future need for personnel, those with a higher university or poly-technic degree.



**Figure 8.** Future need for personnel, those with a lower university or poly-technic degree.



**Figure 9.** Future need for personnel, those with secondary-level vocational qualification.



## Appendix 8

### List of Abbreviations

Abbreviations have been deciphered and translated in relation to their importance. Some of the abbreviations have been deciphered in the text. Not all abbreviations are included in this list, such as names of individual projects.

- ANDES - Accurate Nuclear Data for nuclear Energy Sustainability  
Andra (France) - Agence nationale pour la gestion des déchets radioactifs; nuclear waste management organisation of France  
APROS - Advanced Process Simulation Software; Finnish modelling tool for power plant process simulation  
AREVA - A French conglomerate that supplies nuclear power plants  
ATHLET - Analyse der Thermohydraulik von Lecks und Transienten, (Analysis of THERmal-hydraulics of LEaks and Transients)  
AVERKO - On-line distance learning system of Central Ostrobothnia University of Applied Sciences  
BAT - Best Available Technology  
BBA - Bachelor's degree: Bachelor of Business Administration  
BELBaR - Bentonite Erosion: effects on the Long-term performance of the engineered Barrier and Radionuclide Transport; EURATOM research project  
BENTO programme - Development programme of competence concerning bentonite  
BMWi (Germany) - Bundesministerium für Wirtschaft und Technologie  
BNCT - Boron Neutron Capture Therapy; treatment method used at the Otaniemi research reactor  
BOA project - assessment of bentonite buffer properties  
CABRI - research facility for severe reactor accidents at Cadarache, France  
CAMP - Code Assessment and Maintenance Program; software codes (thermal hydraulics)  
CATHARE - Code for Analysis of THERmalhydraulics during an Accident of Reactor and safety Evaluation; software code (thermal hydraulics)  
CEA - Commissariat à l'Énergie Atomique et aux Énergies Alternatives; nuclear research centre of France  
CEID - The Centre of Computational Engineering and Integrated Design  
CEMIS - Centre for Measurement and Information Systems  
CENTRIA - R&D and supplementary education unit of Central Ostrobothnia University of Applied Sciences  
CERN - Particle physics research centre in Geneva, Switzerland  
CFD - Computational Fluid Dynamics  
CFM - Colloid formation and migration project



CIEMAT (Spain) - Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas; Spanish research centre  
CINCH - Cooperation in education In Nuclear CHEmistry  
CNRA - The Committee on Nuclear Regulatory Activities CNRA; OECD/NEA committee  
COOLOCE - Coolability of Cone; experimental facility (severe reactor accidents)  
Covra - COVRA NV.; nuclear waste management organisation of the Netherlands  
CROCK - Crystalline rock retention processes, sorption of radionuclides  
CSARP - Cooperative Severe Accident Research Program, US NRC  
CSNI - Committee for Safety for Nuclear Installations, OECD/NEA nuclear safety committee  
CST - LUT Chemistry's Centre for Separation Technology  
CTBT - Comprehensive Nuclear-Test-Ban Treaty  
DEMO - demonstration power plant  
DNS - Direct Numeric Simulation  
DP - Deployment Plan  
DTP<sub>2</sub> - Divertor Test Platform  
ECTS - European Credit Transfer and Accumulation System  
ECVET - European Credit system for Vocational Education and Training  
EdF - Électricité de France; French electricity company  
EERRI - Eastern European Research Reactor Initiative  
EFDA - European Fusion Development Agreement  
ELFORSK - Svenska elföretagens forskning och utveckling; R&D organisation of Swedish electricity companies  
ENEN - European Nuclear Education Network; an education network initiated by the EU  
ENRESA (Spain) - Empresa Nacional de Residuos Radiactivos, S.A.  
EnSTe - Finnish Doctoral Programme in Environmental Science and Technology  
EPR - European Pressurised Reactor, such as Olkiluoto 3  
ESRF - European Synchrotron Radiation Facility  
EURADOS - European Radiation Dosimetry Group  
EURATOM - The European Atomic Energy Community  
FEBEX - Collaboration in the Full-Scale Engineered Barrier Experiment in Crystalline Host Rock  
FEG-STEM - Field emission gun scanning transmission electron microscope  
Fluent - software code (thermal hydraulics)  
GAP - Greenland Analogue Project  
GEN<sub>4</sub>FIN project - Finnish research network for GenIV energy systems  
GETMAT - EU project on Gen IV and transmutation materials  
GFR - Gas-cooled Fast Reactor  
GTK - Geological Survey of Finland  
HALDEN - Reactor Project - OECD research programme in Halden, Norway

HAMLAB - Research laboratory in Halden, Norway (MTO)  
HECLA - thermo-chemical interaction between metallic melt and concrete  
HPLWR - High Performance Light Water Reactor (EU project); reactor type  
HRP - Halden Reactor Project  
IAEA - International Atomic Energy Agency  
IGD-TP - Implementing Geological Disposal of Radioactive Waste Technology Platform  
ILL - Institut Laue-Langevin  
ILW silo - Intermediate-level operating waste silo at Olkiluoto  
IRSN (France) - Institut de radioprotection et de sûreté nucléaire  
ITC-School (Switzerland) - International Training Centre School for Underground Storage and Disposal - association  
ITER - International Thermonuclear Experimental Reactor; fusion reactor in Cadarache, France  
JAEA (Japan) - Japan Atomic Energy Agency  
JET - Joint European Torus; fusion reactor in Great Britain  
JHR - Jules Horowitz research reactor in Cadarache, France  
JHR MTR - Jules Horowitz Materials Test Reactor  
JYFL - Department of Physics at the University of Jyväskylä  
JYFLTRAP - Penning ion trap  
KYT2014 - Finnish Research Programme on Nuclear Waste Management  
LCS - Long-term Cement Studies  
LES - Large Eddy Simulation  
LFR - Liquid Lead Reactor; reactor type  
LISSAC - pressure vessel head model specimen tests  
LLW silo - Low-level operating waste silo at Olkiluoto  
LONGLIFE - Treatment of long term irradiation embrittlement effects in RPV safety assessment (EU project)  
LUT - Lappeenranta University of Technology  
MATTER - Materials testing and rules (EU project)  
MEE - Ministry of Employment and the Economy  
MELCOR - software code (severe reactor accidents)  
MELODI - Multi-disciplinary European Low Dose Initiative  
MIKES - Centre for metrology and accreditation  
MTI - Ministry of Trade and Industry  
Nagra (Switzerland) - Nationale Genossenschaft für die Lagerung radioaktiver Abfälle; nuclear waste management organisation of Switzerland  
NDA - Nuclear Decommissioning Authority; nuclear waste management organisation of Great Britain (authority)  
NDC - Nuclear Development Committee; OECD/NEA committee  
NDT - Non-destructive testing  
NEA - Nuclear Energy Agency; OECD agency

NEPTUNE CFD – a new software platform for advanced nuclear thermal hydraulics

NERIS – European Platform for European Nuclear and Emergency Preparedness and Response

NETNUC – New Type Nuclear Reactors; Finnish Gen IV project

NKS – Nordic nuclear safety programme

NOG – Nordic Owners Group

NPSAG – Nordic Probabilistic Safety Assessment Group

NRI – Nuclear Research Institute Rez plc, UJV (Ústav jaderného výzkumu Řež); nuclear research institute of the Czech Republic

NSC – Nuclear Science Committee; OECD/NEA committee

NUCPRI – NUClear Power Research Infrastructure: Lappeenranta University of Technology project funded by the Academy of Finland

NULIFE – Nuclear plant life prediction, EU project

NURISP – NUClear Reactor Integrated Simulation Project; EU project

NWM – Nuclear Waste Management

OECD – Organisation for Economic Co-operation and Development

OKM – Ministry of Education and Culture (former OM)

OMO – Olkiluoto Monitoring Programme

ONDRAF/NIRAS (Belgium) – The Belgium Agency for Radioactive Waste and Enriched Fissile materials; nuclear waste management organisation of Belgium

ONKALO – Underground rock characterisation facility at Olkiluoto (Posiva)

PACTEL facility – Parallel Channel Test Loop; Lappeenranta University of Technology’s research facility

PERFORM60 – Prediction of the Effects of Radiation for Pressure Vessel and in-core Materials using multi-scale Modelling – 60 years foreseen plant lifetime; EU project

Petrus network – Programme for Education, Training and Research on Underground Storage

PFL DIFF – Posiva Flow Log, difference flow logging method

PFL TRANS – Posiva Flow Log, transverse flow logging method

PINC – Programme for Inspection of Nickel-based components; International US NRC research project

PINC – An Illustrative Nuclear Programme (the abbreviation PINC stems from the French name of the programme, Programme Indicatif Nucléaire de la Communauté).  
Reference: Euratom Treaty, article 40

POOLEX – Lappeenranta University of Technology’s research facility

PORFLO – A mathematical model for fluid flow developed at VTT

POSEK – Pori Regional Development Agency Ltd

Posiva (Finland) – Posiva Ltd; an expert organisation responsible for the final disposal of spent nuclear fuel of its owners

PPOOLEX – Pressure POOLEX; Lappeenranta University of Technology’s research facility

PRA model – Probabilistic Risk Assessment

PSAR - Preliminary Safety Assessment Report  
 PURAM (Hungary) - Public Limited Company for Radioactive Waste Management; nuclear waste management organisation of Hungary  
 PWR PACTEL - Lappeenranta University of Technology's research facility  
 RAWRA/SURAO (Czech Republic) - Radioactive Waste Repository Authority; nuclear waste management organisation of the Czech Republic  
 REDUPP - REDucing Uncertainty in Performance Prediction (dissolution rates of spent fuel)  
 RELAP5 - software code (thermal hydraulics)  
 RIA - Reactivity-Initiated Accident  
 RSC - Rock Suitability Criteria  
 SAFIR - Finnish national research programmes on nuclear power plant safety  
 SAFIR<sub>2014</sub> - Safety of nuclear power plants - Finnish national Research programme 2014; the ongoing research programme on nuclear power plant safety  
 SARNET project - Euratom project (severe reactor accidents)  
 SCIP - Studsvik Cladding Integrity Project; OECD/NEA research programme on fuel cladding  
 SCN/CEN (Belgium) - The Belgian Nuclear Research Centre  
 SCWR - Super Critical Water Reactor; reactor type  
 SEM - Scanning electron microscope  
 Serpent - Neutronic calculation code developed at VTT  
 SKB (Sweden) - Svensk Kärnbränslehantering AB; Swedish nuclear waste management company  
 SMABRE - software code  
 SNETP - Sustainable Nuclear Energy Technology Platform; part of Euratom's Fission programme  
 SRA - Strategic Research Agenda of a technology platform  
 STUK - Radiation and Nuclear Safety Authority  
 STYX (particle bed coolability tests) - VTT test facility (severe reactor accidents)  
 SusEn - Energy research programme of the Academy of Finland  
 SYTYKE - Doctoral Programme in Environmental Health in Finland  
 TAGS - Total Absorption Gamma Spectroscopy; analysis method  
 TASS - Total Absorption Spectrometry  
 TEF - Technical Evaluation Forum  
 Tekes - The Finnish Funding Agency for Technology and Innovation Tekes  
 TKK (current Aalto University) - Helsinki University of Technology TKK  
 TRACE - software code (thermal hydraulics)  
 TUKES - Finnish Safety and Chemicals Agency  
 TUT - Tampere University of Technology  
 TVO - Teollisuuden Voima Oyj  
 VHTR - Very High Temperature Reactor; reactor type  
 VLJ Repository - Final disposal facility for operating waste

VTT - VTT Technical Research Centre of Finland  
VVER reactor - Russian pressurised water reactor  
VYR - State Nuclear Waste Management Fund  
WENRA - Western European Nuclear Regulators' Association  
WPDD - Working Party on Decommissioning and Dismantling  
YJH - Nuclear Waste Management (NWM)  
YK - training course in nuclear safety  
YTERA - Doctoral Programme for Nuclear Engineering and Radiochemistry  
YVL guides - STUK guidelines concerning safety of nuclear facilities, nuclear materials and nuclear waste, as well as safety and security arrangements required by the use of nuclear energy  
Äspö International Task Force - international research group related to SKB hard rock laboratory Äspö

## Appendix 9

### Finnish Nuclear in a Nutshell

#### Profile of Finland

Independent republic since 1917

Member State of the European Union since 1995

Capital: Helsinki

Neighbouring countries: Estonia, Norway, Russia and Sweden

Area: 338,000 km<sup>2</sup>

Population: 5.4 million

Population density: 15.9 persons per km<sup>2</sup>

Monetary unit: euro (EUR)

GDP per capita (2010): EUR 33,600

Total primary energy consumption (2010): 34.5 Mtoe

Energy consumption per capita (2010): 6.5 toe

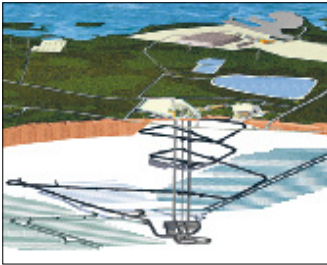
Total electricity consumption (2010): 87.5 TWh

Electricity consumption per capita (2010): 16,500 kWh

Share of nuclear energy in Finland (2010):

25.0 per cent of total electricity consumption

28.4 per cent of domestic electricity production



#### WASTE MANAGEMENT:

- Repositories for LLW & MLW in operation at Olkiluoto and Loviisa
- Initial Decision in principle for spent fuel repository at Olkiluoto ratified by Parliament in 2001
- Confirming underground rock characterisation studies underway in ONKALO facility at Olkiluoto



#### OLKILUOTO, EURAJOKI

Owner: Teollisuuden Voima Oyj  
Reactor units 1&2: BWR 2 x 880 MWe (net)  
Operation started: 1979, 1982  
Production: 14.2 TWh (2010)  
Load factor: 93.5 per cent (2010)  
Under construction  
Olkiluoto 3: EPR (PWR) 1600 MWe  
Planned: Olkiluoto 4



#### HANHIKIVI, PYHÄJOKI

Owner: Fennovoima Oy  
Planned: Hanhikivi 1



#### HÄSTHOLMEN, LOVIISA

Owner: Fortum  
Reactor units 1&2: PWR 2 x 488 MWe  
Operation started: 1977, 1981  
Production: 7.7 TWh (2010)  
Load factor: 91.1 per cent (2010)

Helsinki

Hästholmen  
Loviisa

The Finnish public limited company Teollisuuden Voima Oyj (TVO) was granted a construction licence for the Olkiluoto 3 pressurised water reactor (type EPR, European Pressurised Water Reactor) in February 2005. The reactor's thermal output will be 4,300 MW, and electric output about 1,600 MW.

Construction of the plant unit started in the summer of 2005, and by the end of 2011 the civil construction works had to a large extent been completed. The major components of the reactor plant, such as the reactor pressure vessel, pressuriser and four steam generators, have all been installed, while welding work on the primary coolant circuit pipeline has also been completed. Work currently in progress includes other component installation, pipeline welding work, pressure tests at the reactor plant, commissioning tests on the automation cabinets at the turbine plant, and planning of reactor plant automation.

The Areva-Siemens Consortium, which is constructing the OL3 plant unit on a fixed-price turnkey delivery contract, informed TVO in December 2011 that the unit was scheduled for regular electricity production in August 2014. Commercial electricity production had originally been planned to start in 2009.

Fortum Power and Heat Oy (Fortum) was granted new 20-year operating licences in July 2007 for its Loviisa 1 and 2 PWR units. Fortum is planning a lifetime of 50 years for both units, which would mean an end to their operational lifetime in around 2030.

In June 2007 a new company, Fennovoima Oy, initiated a nuclear new build project. This new power company was created by a consortium of industrial and energy companies, with the German company E.ON holding a 34% share. The aim of the company is to construct a new NPP in Finland that could be operational by 2020.

The climate and energy strategy adopted by Finland contains nuclear power as an option, with the provision that the initiatives come from industry. As stipulated in the Nuclear Energy Act, an EIA process must be completed before an application for a decision-in-principle (DIP) can be submitted to the Government. The TVO and Fortum EIA processes were completed in 2008, and the Fennovoima process in 2009. The coordinating authority for the EIA processes is the Ministry of Employment and the Economy (MEE).

TVO filed its DIP application for the construction of Olkiluoto 4 in April 2008, and Fortum for Loviisa 3 in February 2009. Fennovoima's DIP application was filed in January 2009. In the same year, upon request of the MEE, Fennovoima's listed candidate sites - Simo and Pyhäjoki - stated their willingness to host the Fennovoima plant. The Radiation and Nuclear Safety Authority (STUK) has since confirmed the suitability of both these greenfield sites.

Posiva Oy, the organisation established and jointly owned by TVO and Fortum to manage spent fuel disposal, also filed DIP applications for enlargement of the Olkiluoto final disposal facility, to accommodate spent fuel from the proposed new reactors (Olkiluoto 4 and Loviisa 3).

The MEE processed all five DIP applications during 2009-2010, and the Government made its decisions in May 2010. The five applications fulfilled all safety and environmental requirements. As specified by the Nuclear Energy Act, decisions on all DIPs were based on the project being for the overall good of the society, on projected national energy needs in 2020, and on the prevailing limit of two new nuclear power plants.

The Olkiluoto 4 and Fennovoima new build projects received positive DIPs, as did Posiva for the final disposal project's enlargement regarding Olkiluoto 4 spent fuel. Loviisa 3, and Posiva's proposal for further expansion of final disposal facility to accommodate Loviisa 3 spent fuel, were issued negative DIPs. The three positive DIPs were ratified in Parliament on 1 July 2010.

Positive DIPs were issued to the two utilities (TVO and Fennovoima) that will produce cost price electricity for the needs of the Finnish industries funding these new build projects. The Government also took Fortum's stake (about 25%) in TVO into account when deciding upon the DIPs.

The positive DIPs for TVO's Olkiluoto 4 and for Fennovoima were ratified in Parliament on 1 July. Posiva also obtained a ratified DIP on that date on its application for Olkiluoto 4 spent fuel disposal. Fennovoima chose the municipality of Pyhäjoki as the preferred site in October 2011, announcing that the unit will be named Hanhikivi 1, after the peninsula where the unit is to be sited. Fennovoima invited bids for the power plant in July 2011 from Areva and Toshiba, the bids being received in January 2012. Finalisation of the main contracts is expected later (the units are thus not yet "firmly committed" according to the OECD/NEA criteria).

In 2004, Posiva Oy started construction of the underground rock characterisation facility ONKALO. The laboratory is intended for the final disposal of spent nuclear fuel generated by TVO's Olkiluoto and Fortum's Loviisa plants, and to form part of the final repository. By the end of 2011 ONKALO excavations had reached the final depth of 420 metres and a length of more than four kilometres. Posiva plans to apply for the construction licence for the final disposal facility before the end of 2012. The work is expected to commence in 2014, with the start of disposal operations planned for 2020.



<b>Tekijät   Författare   Authors</b>  Osaamistyöryhmä (OTR) Puheenjohtaja Riku Huttunen Sihteerit Jorma Aurela ja Eriika Melkas 3/2011 asti ja 3/2011 lähtien Jaana Avolahti	<b>Julkaisuaika   Publiceringstid   Date</b>  Toukokuu 2012	
	<b>Toimeksiantaja(t)   Uppdragsgivare   Commissioned by</b>  Työ- ja elinkeinoministeriö Arbets- och näringsministeriet Ministry of Employment and the Economy	
	<b>Toimielimen asettamispäivä   Organets tillsättningsdatum   Date of appointment</b>	
<b>Julkaisun nimi   Titel   Title</b> Kansallisen ydinenergia-alan osaamistyöryhmän raportti		
<b>Tiivistelmä   Referat   Abstract</b>  Työ- ja elinkeinoministeriö asetti lokakuussa 2010 työryhmän kartoittamaan ydinenergia-alan pitkän aikavälin osaamis- tarpeita. Selvitystyö toteutettiin ydinenergia-alaa laajasti edustaneella asiantuntijajoukolla. Keskeinen johtopäätös oli korkeatasoisen ja kattavan kansallisen osaamisen tarve niin alan yhtiöissä, tutkimuslaitoksissa kuin viranomaistenkin osalta. Asiantuntijoiden koulutus ja alan tutkimustoiminta edellyttävät pitkäjänteistä panostusta ja yhteistyötä sekä kotimaisten toimijoiden kesken että kansainvälisesti.  Ydinenergia-alan asiantuntemuksen tarve Suomessa on kasvava. Käytössä olevat ydinvoimalaitosyksiköt sekä rakenteilla oleva Olkiluoto 3 -yksikkö tarvitsevat jatkuvasti osaavaa työvoimaa. Posivalla tulee olla valmius käytetyn polttoaineen loppusijoituksen aloittamiseen vuonna 2020. Erityisesti asiantuntijoiden tarvetta lisäävät uudet ydinvoimahankkeet, TVO:n Olkiluoto 4 ja Fennovoiman ydinvoimalaitos, jotka saivat valtioneuvoston myönteisen periaatepäätöksen vuonna 2010.  Vahvistaessaan periaatepäätökset 1.7.2010 eduskunta edellytti lausumassaan, että hallitus luo osaltaan edellytyksiä suomalaisen työvoiman, osaamisen ja yrityskehityksen mahdollisimman laajalle hyödyntämiselle ydinvoimahankkeissa. Asettamiskirjeessä 27.10.2010 Osaamistyöryhmälle annettiin seuraavat tehtävät: 1) selvittää ydinvoima-alan toimijoiden nykyiset henkilöresurssit, 2) kartoittaa laajasti suomalaisen perus-, jatko- ja täydennyskoulutuksen tarve, 3) selvittää suomalaisen osallistumisen mahdollisuudet tulevissa suurissa ydinlaitoshankkeissa, 4) kartoittaa ydinvoima-alan toimijoiden käytössä oleva tutkimusinfrastruktuuri, 5) kartoittaa Suomen osallistuminen kansainväliseen tutkimustyöhön ja 6) käydä läpi VTT:n tutkimusreaktorin tilanne.  Työ toteutettiin kuudessa jaostossa, jotka myös vastasivat raportin tekstistä. Tausta-aineiston saamiseksi toteutettiin kysely, joka lähetettiin noin 300 alan organisaatioon. Kyselyn tulokset on esitelty laajasti tässä raportissa, joka julkaistaan sekä suomeksi että englanniksi. Työryhmässä olivat edustettuina TEM, YM, STM, OKM, STUK, VTT, Aalto-yliopisto, Jyväskylän, Oulun ja Helsingin yliopistot sekä Lappeenrannan teknillinen yliopisto. Voimayhtiöistä edustettuina olivat Fennovoima, Fortum, TVO, Posiva sekä FinNuclear ry. Eri jaostojen työhön osallistuivat lisäksi useat muut organisaatiot ja raportin kirjoittamisprosessiin on osallistunut yli 150 henkeä. Raportissa on esitetty kattava joukko suosituksia ydinenergia-alan osaamisen kehittämiseksi pitkällä aikavälillä.  Työ- ja elinkeinoministeriön yhdyshenkilö: Energiaosasto/Jorma Aurela, puh. +358 50 5922109 tai +358 29 506 4832 (14.6.2012 alkaen)		
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<b>Kokonaissivumäärä   Sidoantal   Pages</b> 299	<b>Kieli   Språk   Language</b> Suomi, Finska, Finnish	<b>Hinta   Pris   Price</b> 38 €
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<b>Tekijät   Författare   Authors</b>  Kompetensarbetsgruppen Ordförande: Riku Huttunen Sekreterare: Jorma Aurela, Eriika Melkas (t.o.m. 3/2011) och Jaana Avolahti (fr.o.m. 3/2011)	<b>Julkaisuaika   Publiceringstid   Date</b> Maj 2012 <b>Toimeksiantaja(t)   Uppdragsgivare   Commissioned by</b> Työ- ja elinkeinoministeriö Arbets- och näringsministeriet Ministry of Employment and the Economy <b>Toimielimen asettamispäivä   Organets tillsättningsdatum   Date of appointment</b>	
<b>Julkaisun nimi   Titel   Title</b> Rapport av den nationella kompetensarbetsgruppen på kärnenergiområdet		
<b>Tiivistelmä   Referat   Abstract</b> <p>Arbets- och näringsministeriet tillsatte i oktober 2010 en arbetsgrupp för att kartlägga behovet av kunskande på kärnenergiområdet på lång sikt. Utredningsarbetet utfördes av en omfattande grupp experter som representerade olika parter inom kärnenergiindustrin. En viktig slutsats av utredningen var att det finns behov av täckande kunskap av hög kvalitet på nationell nivå vid såväl bolagen, forskningsanstalterna som myndigheterna. Utbildningen av experter och forskningen inom sektorn förutsätter långsiktiga satsningar och långtgående samarbete både mellan finländska aktörer och internationellt.</p> <p>Behovet av expertis på kärnenergiområdet ökar i Finland. De kärnkraftverksenheter som är i drift samt enheten Olkiluoto 3 som håller på att byggas har ett ständigt behov av yrkeskunnig arbetskraft. Posiva ska ha beredskap för att inleda slutförvaringen av använt bränsle år 2020. Behovet av experter accentueras särskilt av de nya kärnkraftverksprojekt som är aktuella: TVO:s Olkiluoto 4 och Fennovoimas kärnkraftverk, som båda fick ett positivt principbeslut av statsrådet år 2010.</p> <p>När riksdagen fastställde principbeslutet den 1 juli 2010 förutsatte riksdagen att regeringen skapar förutsättningar för att finländsk arbetskraft, finländsk kompetens och finländska företag ska kunna utnyttjas i stor utsträckning i kärnkraftsprojekten. I tillsättningsbrevet av den 27 oktober 2010 fick kompetensarbetsgruppen i uppdrag att 1) kartlägga befintliga personalresurser hos aktörerna inom kärnenergiindustrin, 2) kartlägga på ett omfattande sätt behovet av fortbilning och kompletterande utbildning i Finland, 3) utreda möjligheterna för finländskt deltagande i omfattande framtida kärnanläggningsprojekt, 4) kartlägga den forskningsinfrastruktur som står till förfogande för aktörerna inom kärnenergiindustrin, 5) kartlägga Finlands möjligheter att delta i det internationella forskningsarbetet och 6) gå igenom situationen för VTT:s forskningsreaktor.</p> <p>Arbetet utfördes i sex sektioner, som också svarade för rapportens innehåll. I syfte att samla bakgrundsmaterial för utredningen genomfördes en enkätundersökning som skickades till cirka 300 organisationer inom branschen. Resultaten av enkätundersökningen presenteras i detalj i denna rapport som publiceras på både finska och engelska. I arbetsgruppen ingick företrädare för arbets- och näringsministeriet, miljöministeriet, inrikesministeriet, undervisnings- och kulturministeriet, Strålsäkerhetscentralen (STUK), Teknologiska forskningscentralen VTT, Aalto-universitetet, Jyväskylän universitet, Uleåborgs universitet, Helsingfors universitet samt Villmanstrands tekniska universitet. Av kraftbolagen hade Fennovoima, Fortum, TVO, Posiva samt FinNuclear företrädare i arbetsgruppen. Dessutom deltog flera andra organisationer i arbetet i sektionerna och drygt 150 personer deltog i sammanställningen av rapporten. I rapporten framläggs en hel rad rekommendationer för utveckling av kompetensen på kärnenergiområdet på lång sikt.</p> <p>Kontaktperson vid arbets- och näringsministeriet: Energiavdelningen/Jorma Aurela, tfn +358 50 5922109 eller +358 29 506 4832 (fr.o.m. 14.6.2012)</p>		
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# Report of the Committee for Nuclear Energy Competence in Finland

In October 2010, the Ministry of Employment and the Economy set up a committee to examine the long-term competence needs of the nuclear energy sector. The study was implemented by a group of experts ensuring extensive representation of the nuclear energy sector. One of the key conclusions was that comprehensive high-standard national competence is needed by nuclear sector companies and research institutes, as well as authorities. Training of experts and sector-specific research activities calls for long-term investments and cooperation both between domestic operators and on an international scale.

There is a growing need for nuclear expertise and infrastructure supporting this in Finland. The nuclear power plant units presently in operation, as well as the Olkiluoto 3 unit under construction, require competent labour force on a continuous basis. Posiva must have readiness for commencing final disposal of spent fuel by 2020. Especially the new nuclear power projects – TVO's Olkiluoto 4 and Fennovoima's nuclear power plant, which were given favourable decisions-in-principle by the Government in 2010 – will increase the need for experts.

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