Chapter 10

Knowledge and Technology: Sharing With Society

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10.1 A Core Mission of CERN

Education and basic research are large costs to society, which governments, in general, accept as a necessary long-term investment. Still, it is fair to ask how this investment can be used to the best overall benefit for society.

Many excellent reports and talks [1–5] describe how basic research, motivated by "curiosity" — the desire to extend our understanding of nature — contributes as much to innovation as do the applied sciences, which focus on solving specific problems. Both stimulate industry and advance technology.

Consider the core technologies of high energy particle physics. Accelerator applications range from killing bacteria and treating cancer, to welding and cutting, hardening materials, reducing harmful gas emissions from thermal power plants, and much more. Particle detectors are not only ubiquitous in medical imaging; they are also used, for example, by volcanologists and archaeologists to image sites of potential interest. Computer simulation toolkits developed for particle physics have become essential in other fields, including medicine, aerospace, and nano-science.

Complex instruments and cutting-edge technologies are required for the construction and operation of accelerators and intricate detectors, as well as for managing the wealth of data they produce. When existing technologies are inadequate to meet requirements, developments are triggered that often give rise to technological innovations. Most famously, the World Wide Web, which was invented at CERN in the late 1980s to allow automatic sharing of information for scientists, has revolutionized global communication with enormous social and economic impact. Three decades later, data-handling and analysis needs for research at the LHC continue to push forward the evolution of worldwide distributed grid computing, bringing benefits to bio-computing and health sciences, astrophysics, environmental studies, and others.

One of the missions of CERN is to disseminate the results of its research and technological development, to trigger and prepare possible applications outside particle physics and to be a forum for the exchange and scrutiny of ideas for this purpose. Since its origins, CERN has shared knowledge with students, visitors, collaborating institutes and industrial partners [6]. Today, the Organization and the collaborating universities and institutions are together enhancing their efforts in knowledge-transfer and education, aiming to trigger innovation and improve the understanding of basic research as a motor for new and relevant technologies.[a]

Knowledge-transfer mechanisms

The commitment to formalizing the transfer of knowledge acquired at CERN has grown steadily over the decades, with an increasing availability of services and support for inventors and external partners, and for multidisciplinary ventures [7]. During this time, a number of knowledge-transfer mechanisms have been implemented in order to profit from the worldwide network of competencies in universities and high-tech industries in the Organization's Member and Associate Member States. The following gives an overview of these mechanisms together with illustrative examples.

Knowledge transfer through people

CERN's 12000 user-scientists are the most important knowledge-transfer mechanism, together with the educational programmes for students, fellows, and technical trainees. The Laboratory is a hub for knowledge sharing, with visiting researchers, teachers and industrial partners taking expertise back to institutes, universities and industry. Via training, education, and large-scale collaboration, CERN propagates this culture of knowledge sharing, which is considered one of its major contributions to society.

Training and education form one of CERN's core missions. A prominent example is the Summer Student Programme for physics and engineering students (Fig. 10.1), who join research teams for several weeks and attend lectures in particle physics, accelerator technologies and computing. The technical student programme allows engineering and applied physics students to spend up to 14 months at CERN. The Laboratory also provides the research base for large numbers of doctoral and diploma students from institutes around the world, who work on topics in accelerator physics, applied physics, and experimental and theoretical particle physics. Each year, close to a thousand doctoral degrees are awarded on the basis of work carried out at CERN experiments and accelerators.

[a]The editorial team thanks Giovanni Anelli for his contributions to this chapter.

Fig. 10.1. Each year CERN welcomes some 300 undergraduate students to its long-established Summer Student Programme, where they work with research teams and attend lectures in particle physics, accelerators and computing.

The skills thus acquired are highly attractive for work in other fields. One study found that more than 40% of students went on to work in the private sector [8].

CERN has a long-standing tradition in organizing conferences, workshops and high-level schools in the Member States and beyond. The CERN School of Physics, which originated in the early 1960s, went on to become the European School of High Energy Physics, and inspired the similar CERN–Latin-American Schools and the Asia Europe–Pacific Schools. The CERN School of Computing and the CERN Accelerator School followed in the 1970s and 1980s, respectively. CERN initiated the European Particle Accelerator Conference series, which has merged with other major events to become the International Particle Accelerator Conference. The Laboratory also brings its research and technology to the public and into classrooms, through guided tours, exhibitions and programmes for several hundred high school teachers each year, including courses, frequently in their national language.

For the effective transfer of expertise to different fields, it is essential not only to identify potentially interesting technologies, but also to assess their relevance to society. This can be achieved through multidisciplinary networks and collaborations, where scientists from different fields and industry discuss ideas to establish a common roadmap. This has proved particularly true in healthcare. A prime example is the initiative taken to set up the inaugural meeting for a light-ion-therapy network in Europe, ENLIGHT [9], at CERN in 2002, which implemented the concept of multidisciplinary collaboration, and led to growing interest, for example, in hadron therapy.

A more recent development is IdeaSquare [10], a facility located in a dedicated building that brings together researchers, engineers, industry and students to stimulate new ideas inspired by CERN's on-going detector and accelerator R&D. IdeaSquare also hosts innovation-related courses and events, such as the Challenge Based Innovation (CBI) course. Benefiting from the technical knowledge of the researchers and engineers working at CERN, this dedicated MSc-level programme is targeted at multidisciplinary student teams.

Knowledge transfer through purchasing and outsourcing contracts

Procurement contracts with industry amount to nearly 60% of CERN's annual budget. These can range from off-the-shelf products (e.g. office furniture) to R&D contracts requiring cutting-edge technologies for the accelerators. According to surveys [11], a majority of companies that have supplied products or services to CERN have indicated that their contract with the Organization led to an increase in their expertise, often resulting in new business opportunities. The benefit to industry in terms of "economic utility", defined as increased turnover plus cost savings, was estimated to be about three times the value of the CERN contracts. Traditionally, this has been the major route to technology transfer.

The CERN Member States expect a "fair return" for their financial contribution to the Organization through industrial contracts. To assist CERN in these efforts, links to industry are maintained via "industrial liaison officers" from each Member State who participate in the knowledge-transfer activities.

Knowledge transfer through joint ventures and collaboration agreements

CERN has a well-established tradition of collaboration with research institutes and companies, with the primary objective of generating technological results for use both by the partners and at the Laboratory, but also with an eye to the potential for commercial exploitation [12]. Through R&D ventures and agreements, CERN has often acted as a catalyst and an active promoter of international standards, notably in electronics and information technology.

Since its foundation, CERN has played an important role in the exchange of ideas between scientists who are studying a topic or planning, constructing, and performing experiments and analysing the results. Over the years, about a thousand experiments have taken place at the Laboratory, with both CERN and the users' institutions benefiting from the mutual experience [13]. In addition, the Organization recognizes experiments in fields allied to particle physics, such as astroparticle physics, that are being performed elsewhere, and are not necessarily accelerator-based. They obtain a modest level of support, including the use of test beams, provided this does not affect the in-house programme. As of 2016, there are 26 such "recognized experiments", including, for example, AMS, IceCube, MICE, and LIGO. CERN also benefits from the associated contacts.

The Organization also has a tradition of providing staff and facilities for development work on behalf of other institutes. In an early example, the organization provided tangible help in establishing the European Southern Observatory (ESO). With its experience in building large-scale apparatus and in dealing with industry, CERN was able to bring useful expertise to the project and for several years, the ESO Telescope Project Division was based at CERN.

In other instances, people have come from elsewhere to work side-by-side with a CERN specialist using material provided by their own institute, in particular for the design and construction of components for their accelerators. Examples include: magnet design and measurement for the ELETTRA Sincrotrone Trieste research centre in Italy; klystron modulators for the linac of the European Synchrotron Radiation Facility (based on the modulators for the LEP pre-injector); magnet measurements and supply of some magnets for the Italian Hadron Therapy Centre (CNAO); design and measurement of magnets, vacuum technology, beam diagnostics, and RF (based on the latest solution for the PS Booster at CERN [Highlight 3.4]), for the MedAustron facility in Austria [Highlight 10.2].

Knowledge transfer through new companies

In recent years, transferring CERN technology through the establishment of new companies is gaining interest. The Organization encourages the formation of spin-off companies — start-ups whose activity is based wholly or partly on CERN technologies and which wish to exploit these technologies commercially. CERN does this by giving measured support to its personnel and to external entrepreneurs who wish to establish a spin-off company in a Member State.

To assist entrepreneurs in taking innovative ideas using CERN technology or expertise from concept to market reality, a network of Business Incubation Centres (BICs) [14] has been set up in several countries. The Laboratory supports companies in BICs through technical visits to CERN and preferential rates for licences of CERN Intellectual Property. The incubators advise on establishing a business plan and provide logistical, financial and administrative support.

CERN's activities in entrepreneurship and start-up creation have also gained momentum, and first successes are appearing on the horizon. For example, as a result of a strategic partnership with NTNU Trondheim, each year students in entrepreneurship spend a week at the Laboratory to evaluate the potential of CERN technologies for starting a company. In 2014, a team of NTNU students started a company that provides professional services and consultancy for Invenio — software originally developed at CERN to manage the increasing volume of digital information. Invenio has grown into a fully featured digital library platform, and a number of large institutions worldwide are now customers.

Knowledge transfer through licensing

As a principle, CERN has not taken patents on its technological inventions. However, in 1999, this patent policy was revised, not in view of a possible financial return, but rather to protect the Organization's intellectual property and facilitate the transfer of innovations to industry. CERN's patent portfolio now contains a few tens of patents, many of which have been licensed to industry. Most concern the application of CERN's competences and inventions to problems relevant to society. Examples of such transfer through licensing are described in the following sections.

The KT Fund

Part of the revenue originating from knowledge-transfer (KT) activities at CERN (charges for contract research and services, licensing and consultancy) is allocated to the KT Fund. This provides financial support in the early stages of KT projects, regardless of their field of application, provided they are of potential use to society. Proposals for projects that meet the eligibility criteria are submitted to the KT Group and evaluated by the KT Fund Steering Committee. Together with a technical description of the project, proposers must outline the market potential. Proposals are evaluated based on their quality, likelihood of dissemination, potential impact, and scientific value. Gas-electron multiplier (GEM) detectors [Box 4.6] for flame detection and early earthquake prediction, radio-frequency absorbers for energy recovery, and exotic radioisotopes for medical applications are among the projects that have been partially funded under this scheme.

Transfer of CERN technologies

Transfer originating in CERN core activities

The technological innovations described in this book have been motivated by the needs of CERN core activities. For this reason most of these innovations have found applications in laboratories with a mission similar to that of CERN. In these cases, the transfer occurred naturally via scientific publications and communications. However, in some cases the innovations have been transferred to a wider community as described above.

Whenever industry was not able to provide the required solutions for a particular goal, development work was undertaken in-house and then transferred to industry, through a production contract awarded via competitive tendering. As a result of this process, the selected industries were able to offer this same solution to other customers. In this, the most frequent case, the transfer occurred through procurement. Examples of this process are the ISR vacuum gauges [Highlight 4.3] and superconducting quadrupoles [Highlight 4.4], and the LEP niobium-coated RF cavities [Highlight 7.4].

In other cases the initial development was done jointly with industry, which then proceeded with the production phase for CERN (and also, possibly, for other clients). Examples include the flexible cryogenic transfer line [Highlight 4.5], and cryogenic system [Highlight 8.3]. In the case of the LHC superconducting magnets [Highlight 8.2] the joint development work also served to whet the appetite of industry for the forthcoming large series of costly devices.

Finally, when tight schedules prevented industrial involvement, the production was carried out at CERN, the innovative solution was protected by patent and the technology transfer done by licensing. In this case the solution was also made generally available. The getter coatings developed for the LHC [Highlight 8.5] provide an example of such transfer. In another approach, the prototypes and an initial 10% of the production were made at CERN, with the remainder supplied partially by purchase from industry via competitive tender, and partially "in-kind", based on build-to-print specifications [Highlight 8.4].

Transfer motivated by social utility

CERN's expertise can also be valuable in fields outside the Organization's core mission. A small fraction of the CERN budget is made available for the development of innovative applications in fields that are outside nuclear and high-energy particle physics, but which have particular relevance for society in general, as described in examples below.

Medical applications[b]

The application of CERN expertise in accelerators to the field of cancer therapy, which goes back to the 1980s, has been particularly fruitful. Not only has the laboratory hosted important studies that have contributed to the design of treatment centres that are now operational, it has also been involved in training personnel for the facilities, for example, at MedAustron. With a view to bringing such initiatives more formally into its range of activities, in 2014 the CERN Medical Applications (CMA) Office was set up to stimulate and coordinate activities in medical physics. One major initiative is an open-access facility for biomedical research, OPENMED, to be based on the Low Energy Ion Ring (LEIR), a low-energy accelerator at CERN that supplies heavy ions to the LHC injector chain, for a few weeks each year. Another accelerator-based project is CERN-MEDICIS. Building on a long-standing development of methods of isotope production via the ISOLDE

[b]The editorial team thanks Manjit Dosanjh for her contributions to this chapter.

facility [Highlight 3.8], CERN-MEDICIS will deliver novel radioisotopes for research and applications in therapy and imaging.

Developments in particle detectors have had a big impact on medical imaging, making procedures easier, faster, more accurate and less invasive. Instruments based on the MWPC [Box 4.4], developed at CERN by 1992 Nobel Laureate Georges Charpak, are being used in biology and nuclear medicine. Indeed, Charpak himself immediately saw the possibility of applications in medical imaging. Such activity continues at CERN with the development of the GEM technology [Highlight 4.8] in devices for fast tracking and readout that can be applied to dose-mapping during radiation therapy using X-rays. Medical imaging projects based on other types of particle detector have been initiated at CERN via multidisciplinary collaborations. The Medipix Collaboration [Highlight 10.3] has its roots in hybrid silicon pixel detectors developed for particle tracking in the late 1990s. In one application, a spin-off company in New Zealand is working on using the latest generation of these detectors. The Crystal Clear Collaboration [Highlight 10.4], initiated to develop calorimetry at LEP and the LHC [Highlights 7.9 and 8.8], has adapted these detectors for a variety of medical applications of positron emission tomography (PET).

Computing applications

Data-handling techniques and simulation tools from high energy particle physics now find applications in areas ranging from medicine to financial analysis. In the biomedical field they are applied to help in understanding medical detectors, conducting clinical trials, devising protocols and establishing personalized treatment plans. Grid computing, which allows multiple users to share computing power and storage capacity over the internet, is an ideal tool for a wide range of biomedical fields, from screening of drug candidates, to image analysis, to sharing and processing health records.

FLUKA and Geant4 [Highlight 9.5] are two major simulation packages in particle physics that are widely used in the medical field, amongst others. FLUKA, which is used for calculations of particle transport and interactions with matter, has many applications in high energy physics and engineering, from shielding and detector design to cosmic-ray studies and radiation protection. A number of commercial companies, typically medical hardware and software developers, are FLUKA licensees. The Geant4 toolkit, which allows detailed simulation of particle interactions with matter for a wide range of particle types and energy, also finds applications in medical and space science, as well as in LHC experiments.

Environmental applications

An early transfer of technology to industry was an improved getter technique developed at CERN to fulfil the demanding vacuum conditions for stored beams in colliders [Box 7.3]. This was later applied to vacuum-insulated solar thermal collectors, which are particularly suited to colder, less sunny climates where they are more efficient than traditional solar panels [Highlight 10.5].

In the 1990s, a strategy was proposed to validate new technological concepts (Accelerator-Driven subcritical Systems or ADS) based on the use of particle accelerators to destroy nuclear waste, to produce clean and safe energy, and deliver radioisotopes for nuclear medicine and industry. This led to a trilogy of programmes on basic studies in neutron physics. The First Energy Amplifier Test (FEAT) experiment [15] elucidated the concept of the Energy Amplifier [16], and was followed by the TARC experiment [Highlight 10.6] to study neutron transport in lead and test new ideas for transmutation. The third strand in the trilogy is the CERN neutron time-of-flight facility, n_TOF [Highlight 3.9].

In another, surprising, example of the transfer of CERN know-how — in this case precision engineering expertise — the multi-disciplinary CLOUD Collaboration studies the formation and behaviour of clouds. It uses a beam at the CERN PS to assess the influence of cosmic rays on aerosols and their impact on cloud formation [Highlight 10.7], and is gathering information and developing models that are important for studies related to climate change.

The changing dimension of CERN's mission

This chapter started by asking how the investment in research and education can be best put to use for society. Some of CERN's answers address this through the sharing of technology, knowledge and expertise. However, this raises a related question: is CERN doing this well, too much, or too little?

During the first 40 years, technology transfer occurred naturally through industrial contracts, providing substantial returns for many of the industrial partners. Since then there has been a plethora of initiatives involving technology transfer and knowledge sharing. Is this a distraction from achieving the primary goal of the Organization as defined in the Convention?

To set the scale: the size of CERN's Knowledge Transfer Group is approximately 2% of the CERN staff, with an annual expenditure of the order of 1% of the total material budget. To this one should add the personal effort of knowledge sharing of many of the staff, at the level of some percent overall.

However, the question is not so much whether an organization like CERN, or for that matter a university or an individual scientist, should devote a fraction of the available resources to effective knowledge sharing: today it is considered an integral part of our social responsibility. This sharing and communicating has to happen at all levels: with peers, with the public, with the decision makers and politicians. More than ever, scientific culture is part of our society and scientists have to be at the forefront of fostering this scientific culture. A scientifically literate public will be the best insurance that politicians follow the lead, appreciate the needs, and allocate appropriate funds to scientific education and research.

Summary

The value of CERN as the host laboratory for worldwide collaborations of scientists and engineers that use its various facilities extends far beyond basic research. CERN and the collaborating universities and institutions are together enhancing their efforts in knowledge transfer and education, triggering innovation and communicating the role of basic research as a motor for new technologies of relevance to society.

10.2 Medical Accelerators: A Tool for Tumour Therapy

Kurt Hübner

The interest in using charged particle beams to treat human cancer stems from the observation [17] that the ionization density, i.e. dose deposition, is very high at the end of the track of a proton or an ion stopped in a tissue (Bragg peak), whereas electrons, X or γ-rays and neutrons deposit the dose decreasingly over the whole range (Fig. 10.2). Thus, protons and light ions stripped of all electrons seem to be very well suited for the well-targeted (conformal) treatment of deeper-seated localized tumours with minimal impact on the surrounding tissue. In particular, carbon ions are of interest due to their enhanced Relative Biological Effectiveness (RBE), a measure of the damage by ionizing radiation per unit of energy deposited in biological tissues. For heavier ions the RBE is less favourable [18].

CERN's contribution to this field started with a study of dedicated medical accelerators in the late 1980s. The study team examined two types of accelerator: a cyclotron with a superconducting magnet and a synchrotron similar to LEAR [Chapter 3.1]. It recommended that the best choice would be a synchrotron providing light ions of 400 MeV/u, ranging from carbon to neon [19]. As for other facilities under construction at that time [20, 21], a synchrotron was preferred for its inherent flexibility in energy and for being based on well-known technology.

In the early 1990s, CERN hosted and contributed to a study of an accelerator-driven spallation source, which included a synchrotron providing fully-stripped carbon or oxygen ions up to 425 MeV/u for hadron therapy [22]. After this project was shelved, CERN and partners from Austria, the Czech Republic and Italy