CERN technology transfers to industry and society
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In the quest to find out what matter is made of and how its different components interact, high-energy physics needs very sophisticated instruments using technologies and requiring performance that often exceed the available industrial know-how. Technology has promoted and still promotes on all levels the injection of science into daily life in many different ways. Nobody would ever have thought that a phenomenon based on the theory of quantum mechanics—quantum entanglement—would find practical applications in the fields of cryptography, computing and teleportation, leading to the creation of new companies to secure information sharing. Moreover, technological developments most often require the involvement and interaction of experts in a large variety of domains such as information technology, microelectronics, superconductivity, vacuum, material sciences, and surface treatments, thereby resulting in technological cross-fertilization.

Thanks to the technologies developed for the purpose of its research activities, CERN, the European Organization for Nuclear Research, has produced improvements in many fields and, in doing so, has made our daily environment more functional, practical and comfortable.

This report is the first attempt to catalogue other products emanating from Technology Transfer, rather than procurements, with the aim of showing and keeping track of the results of the pro-active Technology Transfer policy endorsed by the Organization. This pro-active Technology Transfer policy will lead to many commercial products in the near future.
What is CERN?

Today CERN is the world’s largest particle physics laboratory with 2700 staff members, fellows and associates, and about 4500 users from Member States and about 1700 from non Member States. In 2004, the Organization celebrated the 50th anniversary of its founding. By bringing together the creativity of so many scientists from different nationalities, backgrounds and technical fields of research, CERN has been and continues to be a source of knowledge creation and knowledge transfer.

Is there a return to industry from Big Science centres such as CERN? The answer is yes, as firstly assessed at CERN and thereafter by the European Space Agency (ESA) in France, Fermilab, and the National Aeronautics and Space Administration (NASA) in the US. It was found that, for each monetary unit invested in purchasing technology goods, financial multipliers of the order of three are generated in the companies. The increase in turnover and cost saving is due to the availability of new products, improved marketing capability and quality of products, as well as improvement in production techniques and management procedures. A study carried out recently by CERN and the Helsinki Institute of Physics has evaluated the benefits in technological learning and innovation gained from the advanced technology for the next accelerator, the Large Hadron Collider (LHC). These range from technology acquisition to new product development and organizational changes. The increase in international exposure and the opening to new markets are also significant. The LHC will be the most powerful instrument ever built to investigate the properties of elementary particles and will lead to a ‘gold mine’ of CERN technologies. It represents a high-technology project of extreme complexity. Although the LHC is fully justified for particle physics research, it may also contribute to modifying our daily life through the resulting technological innovations.
Detectors and Accelerators in brief

Particle detectors are instruments used for studying particle interactions with matter. For each interaction, called an event, the goal is to count, track and characterize all the different particles that are produced and so fully reconstruct the process. Detectors consist of many different pieces of equipment, each one able to recognize and measure a special set of particle properties, such as charge, mass and energy. Tracking chambers, for instance, make the path of the particle visible. However, more information is needed and usually a tracking device is associated with a calorimeter. Calorimeters stop and fully absorb most of the particles, providing a measurement of their energy. Muons and neutrinos are often the only particles capable of escaping from a calorimeter. Muons can hardly be stopped, but at least they can be identified: special muon detectors are located outside the calorimeter, and only muons can emerge and leave a track there. Neutrinos, by contrast, escape and do not even leave a track, going through all the detectors undetected. However, as they are the only known particles that can escape, their presence can be inferred from an imbalance of the initial and final energies of the event. Assembling all the pieces of information from each track, physicists can fully characterize each particle, and by arranging all the tracks coming from a collision, they can reconstruct the event with great precision.

To make the collisions in the first place requires other important tools: the accelerators. Particle accelerators were invented in the 1920s for physics research. An accelerator usually consists of a vacuum chamber surrounded by a long sequence of vacuum pumps, radio-frequency (RF) cavities, magnets, high-voltage instruments and electronic circuits. Each of these pieces has its specific function. The vacuum chamber is a metal pipe where air is permanently pumped out to make sure the residual pressure is as low as possible. Inside the pipe, particles are accelerated by powerful electric fields. Powerful amplifiers provide intense radio waves that are fed into resonating structures, the RF cavities. Each time the particles traverse an RF cavity, some of the energy of the radio wave is transferred to them and they are accelerated. To make more effective use of a limited number of RF cavities, accelerator designers can force the particle beam to go through them many times, by curving its trajectory into a closed loop.

Curving the beam’s path is usually achieved by the magnetic field of dipole magnets which are used to steer the particles round a ring, so that they collect energy with each lap. This is because the magnetic force exerted on charged particles is always perpendicular to their velocity – perfect for curving the trajectory. The higher the energy of a particle, the stronger the field that is needed to bend it. This means that, as the maximum magnetic field is limited (to some 2 tesla for conventional magnets, some 10 tesla for superconducting ones), the more powerful a machine is, the larger it needs to be. In addition to bending the beam, it is also necessary to focus it. Just like a beam of light, a particle beam diverges if left on its own. Focusing the beam allows its width and height to be constrained so that it stays inside the vacuum chamber. This is achieved by quadrupole magnets, which act on the beam of charged particles in exactly the same way as a lens would act on a beam of light.

Beyond these basic ingredients, there are many more objects needed to make an accelerator, such as other magnets (to perform ‘fine tuning’ on the trajectory or of the focusing), injection / ejection elements (to put the beam into the accelerator or to take it out), measurement devices (to give the operators information on the behaviour of the beam), and safety elements.

There are many types of particle accelerator, from CERN’s enormous machines to an apparatus that is in most households, the cathode-ray tube used in TV sets. In addition there are accelerators that are today affordable in cost, small in size and robust enough to be part of any hospital. Other types of accelerators are used for medical diagnosis and care, or to sterilize medical equipment and food. They even appear on production lines for rubber gloves.
<table>
<thead>
<tr>
<th>Category of accelerators</th>
<th>Number in use</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-energy accelerators (E&gt;1 GeV)</td>
<td>~ 120</td>
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<tr>
<td>Radiotherapy accelerators</td>
<td>&gt;7500</td>
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<tr>
<td>Research accelerators incl. biomedical research</td>
<td>1000</td>
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<tr>
<td>Medical radioisotope production</td>
<td>~200</td>
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<tr>
<td>Accelerators for industrial processing and research</td>
<td>&gt;1500</td>
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<tr>
<td>Ion implanters, surface modification centres</td>
<td>&gt;7000</td>
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<tr>
<td>Synchrotron radiation sources</td>
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<tr>
<td><strong>TOTAL IN 2002</strong></td>
<td>~17370</td>
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</table>

This table shows how far accelerators had come by 2002
Technology Transfer at CERN

There are different ways of doing Technology Transfer (TT) in order to fuel innovation in Member States’ industry. One is through procurements and this has been the conventional mode used by CERN since its foundation. However, in order to promote a more active TT, CERN introduced a proactive TT policy in 2000 to identify, protect, promote, transfer and disseminate its innovative technologies in the European scientific and industrial environment. Once the technology and intellectual property are properly identified and adequately channelled, that is to say protected by the most appropriate means if required, they then enter a promotional step intended to attract external interest, thereby preparing the ground for the targeted dissemination and implementation. The dissemination and exploitation of CERN’s technologies are therefore at the heart of the TT process.

In addition to the conventional licensing mode for transferring the technology there is a policy of R&D partnership. This is in order to promote CERN technology more quickly and to further its dissemination outside particle physics. This type of transfer requires large investment for the development of a specific product, so tangible financial results are not certain.

The main steps in the TT process adopted by CERN are:

Technology assessment and evaluation

The assessment and analysis process is a concerted procedure, where the TT group acts on the advice of a number of people, including, as appropriate, the internal and external technical experts.

Intellectual property evaluation and protection

Intellectual property associated with CERN technologies needs to be evaluated and protected using processes and mechanisms such as Prior Art Search, Invention Disclosure Form and Market Survey. Intellectual property comprises industrial property, which includes inventions (patents), trademarks, industrial designs, and copyright.

Technology promotion

Technology promotion may be carried out in a variety of ways, and requires the TT group to carry out a prior study of the potential transferees of the technology. The promotional activities currently used by CERN include conferences, industrial workshops, posters and brochures, and meetings between inventors and industry. Indirect ways to promote CERN technologies include promotion by external Technology Transfer Officers (organized events, communications to national industry, etc.), Member States technology promoters, and CERN calls for tender.
Technology dissemination and implementation

The dissemination and implementation process reflects truly successful TT. This activity requires a formal framework, however, such as an agreement that corresponds to the maturity of the technology concerned and the readiness of the acquirers. The stages of ‘proof of concept’, ‘prototyping’ and ‘technology acquiring’ will be executed as necessary. In order to draft a suitable agreement, close collaboration is needed between the TT group, the technical experts, the external collaborators and those involved in the contract circulation procedure. The agreement tool may encompass pre-competitive collaborative R&D, partnerships, licences and services, and external funding.

Of 160 CERN technologies present in the CERN TT database (http://www.cern.ch/TechnologyTransfer) only those for which effective TT has resulted in industrial products will be illustrated in this publication. The products presented in the chapter “Examples of transfer” are those made available through either procurement or industrial partnerships that are contributing to fields outside high-energy physics (HEP).

Phases in the development of technologies and projects
The transfer of technology from the scientific to the public domain is one of the great benefits of fundamental scientific research. In physics research, solving scientific problems often requires considerable inventiveness. The innovation created by scientists and engineers working at the frontiers of particle physics can sometimes be used to carry out many tasks and be applied in many fields, such as communications and information technology, medicine, energy, environment, and education.

Communications and Information Technology

Information technology, which plays an essential role in scientific research achievements, has seen rapid development due to advances in electronics and network technologies. Through the implementation of the World Wide Web (WWW) and now of the Grid, information technology has paved the way to the next generation of computing. The WWW has become part of everyday modern communications with tens of thousands of servers providing information to millions of users and could be considered one of the most striking examples of TT in the past three decades. It is a worldwide TT that has largely modified the functioning and behaviour both of modern society and of individuals.

The Internet, namely the technical infrastructure of the global network system, was born in 1969 with the first node at the University of California, Los Angeles. However, it would not have been impossible to benefit from the advantages of the Internet without the research completed at CERN in the last decade of the 20th century. The WWW invented at CERN in order to share information between different computers was distributed to the Internet community and became a worldwide phenomenon.

As the Web was CERN’s response to a new wave of scientific collaboration at the end of the 1980s, the Grid is the answer to the need for data analysis to be performed by the world particle physics community. With the LHC the CERN experiments will have

to exploit petabytes of information and this has pushed them to apply the Grid concept of sharing distributed processing that was proposed first in the US. Many developments have been pursued both for the analysis and storage of the LHC data and for developing applications. One example is the EGEE (Enabling Grids for E-sciencE) project that builds on recent advances in Grid technology and aims at developing a service infrastructure for Europe available 24 hours a day.

The Grid is a very powerful tool tying computing resources distributed around the world into one computing service for all requesting applications. Thanks to the Grid, a new way of interaction among scientists and different domains will be made possible with faster dissemination of data, better quality control, and more efficient use of information sources. These characteristics will allow the rapid spread of the Grid in many different domains of application, from bioinformatics, genomics, astrophysics, epidemiology, pharmacology, biomedical sciences and environmental research.

A rapid and natural consequence of the Grid has been the use of distributed information in a three-year project called MammoGrid, under the Fifth Framework Programme of the European Community, in order to develop a Europe-wide database of mammograms. Led by CERN, MammoGrid involves the UK (the Universities of Oxford, Cambridge, Bristol, plus the Company Mirada Solutions of Oxford), and Italy (the Universities of Pisa and Sassari and the Hospitals in Udine and Torino). Today, 32 Mbytes per mammogram image giving a total of 128 Mbytes per person per visit (equal to two views per each breast) would have to be stored to keep information of a screened population for epidemiological as well as teaching purposes. Distributing this information among doctors and hospitals will be possible only by using Grid technologies.

Scientific disciplines that will benefit from EGEE

An ongoing transfer is the Network Emulator technology used to evaluate the performance of applications running over the Grid. The Network Emulator is a configurable Network-in-a-box that emulates end-to-end quality degradation likely to appear in wide-area networks with a wide range of applications including Internet telephony, file transfer and web browsing. Network emulation is a technique of reproducing the behaviour of computer networks that enables experiments with real applications in a controllable environment.
Many concepts and developments from particle physics find applications in health care. High-quality detector, accelerator, and beam technologies are essential for particle physicists to achieve their quest. These developments may be applied for better diagnostic tools and for providing tailored radiation treatment of disease, in particular in the fields of hadron therapy, isotopes, and medical imaging.

Hadron therapy

Hadrons, the subatomic particles that are influenced by the strong nuclear force and made up of quarks, such as the neutron and proton, were immediately identified as more appropriate particles for radiotherapy of deep-seated tumours due to the dose distribution in tissues. Pioneering studies were carried out at CERN in the late 1960s.

Nowadays many centres worldwide are using proton and mainly carbon ion therapy, from Europe, Japan to Russia and the US. So far some 35,000 patients have been treated with protons and many new centres are under construction. CERN physicist Ugo Amaldi strongly promoted the developments of new proton-ion accelerators; and in 1999 CERN, GSI (Gesellschaft für Schwerionenforschung) in Germany, Med-Austron in Austria, Oncology 2000 and TERA (TERapia con Radiazioni Adroniche) in Italy realized a study to design an ion synchrotron optimized for medical applications. This was PIMMS, the Protons Ions Medical Machine Study. A treatment centre based on an improved version of the PIMMS synchrotron, called CNAO (Centro Nazionale di Adroterapia Oncologica) is now being built in the north of Italy, by the CNAO Foundation, which is composed of five large hospitals and TERA. The INFN (Istituto Nazionale di Fisica Nucleare) is co-responsible for the construction of the accelerator. The treatment of deep-seated tumours requires variable proton energies up to 210 MeV. This is difficult to achieve with small cyclotrons. So, the Linac BOoster (LIBO) project developed a linear accelerator prototype that allows the energy of small cyclotrons to be boosted.

CERN is part of ENLIGHT, the European Network for Research in Light Ion Therapy, whose aim is to co-ordinate the development of a variety of projects at the European level for light ion therapy. From the technologies developed, collaborations have been established where the core expertise in the physics and engineering underlying accelerators and detectors can be used in designing new machines and equipment to benefit health. Measurements of the energy deposition by antiprotons were done at the LEAR (Low Energy Antiproton Ring) machine at CERN in 1985 and today biological investigations for future medical applications are being carried out at CERN using the Antiproton Decelerator (AD).
Isotopes

Many important isotopes were discovered and characterized, and separation techniques developed in the early years of nuclear physics. Now these are used daily in treatment or diagnostics on several million patients each year. Today, most of the isotopes used are produced in nuclear reactors, but there are many studies on the production of new types of isotopes using particle accelerators.

The transmutation of elements exposed to an enhanced neutron flux, such as demonstrated by the TARC (Transmutation by Adiabatic Resonance Crossing) experiment at CERN is a CERN patented technology (Neutron-driven element transmuter) which can be used for the production of radioisotopes for medical and industrial applications. Together with the technology mentioned above, ISOLDE (Isotope Separation On-Line), the world leading facility in producing samples of proton-rich and neutron-rich rare radioactive isotopes of extreme purity, can contribute to satisfy demands for new types of isotopes.

The advantages will be lower production costs, better quality products and facilities that can be built and operated more easily. This will satisfy the demands and requirements for new radioisotopes to label monoclonal antibodies, such as rhenium, lutetium, and holmium. Some isotopes may be more interesting for Positron Emission Tomography (PET) and others for targeted alpha or monoclonal antibody therapy. These methods of isotopes production are in the R&D phase.

Detection and imaging

Particle physicists regularly use collisions between electrons and their antiparticles, positrons, to investigate matter and fundamental forces at high energies. This is what happens in machines like the Large Electron Positron (LEP) collider. At low energies, the electron-positron annihilations can be put to different uses, for example to reveal the functioning of the brain using PET. Today PET is a common scanning technique in medical diagnostics. PET allows, for instance, detailed viewing of the functioning of distinct areas of the human brain at work while the patient is conscious and alert. It is possible to study the chemical processes involved in the functioning of healthy or diseased organs in a way previously impossible. Indeed, before the advent of the PET scanner, one could only infer what went on inside the organs from post-mortem examinations or animal studies. Thanks to the improvements of many associated technologies, PET represents a significant step forward in the way scientists and doctors visualize and monitor treatment on-line (i.e. the spatial distribution of radiotherapy treatment); and, when associated with Computer Tomography (CT) scanners, it is an essential tool for functional diagnostics. The CT scan is a technique now well established that produces 3D images using an external X-ray source and detector. A first image from a PET camera was made at CERN in 1977. Twenty years later, a combined PET / CT scanner has been advocated as the path to true image fusion.
Examples of ongoing CERN developments are the developments for a brain PET scanner based on photodiodes, being carried out in collaboration with the Cantonal Hospital of Geneva; the Compton Prostate Probe from the CIMA (Compton Imaging for Medical Applications) collaboration; and a Positron Emission Mammography (PEM) prototype using crystals (ClearPEM™) under development by the PEM Collaboration in the framework of the Crystal Clear Collaboration (CCC) with the aim of improving early-stage breast cancer diagnostic. The purpose of the CCC is to develop new scintillating crystals, used as detectors, and associated readout with fast electronics for high-energy physics applications and medical imaging.

Many detectors can be used in medical applications. In particular, the Gas Electron Multiplier (GEM) is a novel device introduced in 1996 at CERN and licensed for the development of dosimetry for radiotherapy. Besides medical imaging and dosimetry, GEM detectors are used for thermal neutron and gamma-ray detection in astrophysics.

The Medipix2 system is another example of a technology whose development was driven by the requirements of high-energy particle physics finding its way out of the Laboratory and into medical and industrial applications. Hybrid pixel detectors are a technology developed to enable physicists to make sense of the complicated interactions as revealed in CERN detectors. The Medipix2 Collaboration adopted the same technique to count and image X-rays whose energy falls within a given window. This novel X-ray imaging technique eliminates the background noise associated with more traditional X-ray imaging approaches and provides energy information that was previously lost. The system has already been transferred to a leading European company in the field of X-ray materials analysis equipment and several teams are looking into possible uses of the system in the medical imaging field.

Another technology, called Monopix, is being developed and has been patented by CERN. In this case the sensor material is deposited directly on the readout chip providing a potentially lower-cost approach to pixel readout.

Last but not least are the hybrid photodetectors (HPD), also called hybrid photodiodes. These detectors, combining the single-photon sensitivity of photomultiplier tubes with the spatial and energy resolution of silicon sensors, represent a new type of photodetector which surpasses traditional photomultiplier performances. Thanks to this characteristic they are ideal candidates for diagnostic applications and studies of metabolic disorder, such as in brain PET and digital mammography, requiring the detection of very low numbers of tracks combined with high spatial resolution. A demonstrator for PET devices is under construction.
Energy

Energy consumption in the industrialized world tends to increase together with economic development. Energy is another crucial domain where high-energy physics technology can provide new solutions. A first example is an innovation in the field of solar energy.

Solar energy as such has appealing qualities: it is environmentally friendly; it is virtually infinite and free of charge. However, its low power density requires wide collecting areas to reach reasonable power ranges. Furthermore, the energy flow from the sun is quite irregular, since it depends on alternating night and day, season, weather conditions and latitude. In spite of being naturally diluted (maximum power density on earth around 900 W/m²), solar energy may be used to obtain high temperatures for thermal, mechanical, or electric applications, either by light focusing and/or by reducing the thermal losses resulting from gas conduction/convection, mechanical contact, and radiation emission. Light focusing allows very high temperatures to be reached but, unfortunately, the diffused light (up to 50% in central Europe) cannot be focused and is lost.

Evacuated solar collectors, able to reach temperatures of the order of 250°C without focusing, are commercially available in the form of arrays of cylindrical elements. In comparison, flat evacuated solar collectors could offer many advantages, namely a reduced number of glass-to-metal seals, a larger absorbing area, an easier installation and maintenance, lower radiation losses. However, these collectors have not yet been built commercially because of many intrinsic difficulties of which the main one consists of providing a reliable vacuum seal for the front glass window to the metallic envelope that contains the absorber. Thanks to the mastering of ultra-high vacuum technology, a few prototypes of evacuated flat panel solar collectors have been built and extensively tested at CERN. An equilibrium temperature of 350°C is achieved for 900 Wm⁻² of incident solar power and a pressure lower than 10⁻⁴ Torr could be maintained over 20 years of operation without external pumping. This type of solar collector, patented at CERN, is particularly suited for small and medium-sized plants both for heating, possibly combined with seasonal heat storage, and for cooling/air conditioning. It may also be used for water desalination, agricultural applications (e.g. crop drying) and for the production of heat for industrial processes. Last but not least, it may produce electricity with efficiencies similar to those of photovoltaic cells with the advantage of a higher combined thermal and electric efficiency.

Another important solution in the energy field, proposed by Nobel laureate Carlo Rubbia, is the Energy Amplifier. This concept proposes to produce nuclear energy and/or to eliminate nuclear wastes in a subcritical nuclear assembly. In contrast with conventional critical reactors, the nuclear fission reaction chain in the Energy Amplifier is not self maintained.

The external neutron source is provided by a high-energy particle beam directed into the target of the nuclear assembly to interact with heavy nuclei inside so as to produce high-energy spallation neutrons. The neutrons thereby produced are multiplied in steady sub-critical conditions by the breeding and fission process carried out inside the assembly. These fissions provide the energy generated in the Energy Amplifier and eliminate the actinides, which are the most offending long-lived radioactive wastes. If the initial fuel composition is conveniently prepared, the breeding from fertile materials to fissile isotopes and its following fission reaches an equilibrium that, after an initial phase, keeps stable the rate between the fissile and fertile concentrations, resulting in stable long-term energy production.

The practical implementation of such a device requires some further technological development and a series of experiments and prototypes with increasing power are proposed, expecting to reach a major milestone with an Energy Amplifier demonstrator of 50-80 MW by 2015-2020. The final application of Energy Amplifiers, more energy production or more waste elimination, will strongly depend on energy demand, the political decision on the role of nuclear energy and the corresponding nuclear fuel cycle of the country in which it is implemented.

The Energy Amplifier opens the possibility of burning almost any unwanted long-lived radioactive wastes, which are a serious environmental problem, and transforming them into exploitable energy without any CO₂ emissions, thereby also avoiding the ‘green house effect’.
Environment

Since its birth, CERN has adopted a policy in order to respect and protect the environment. In particular, the Laboratory is committed to carrying out an environmental monitoring programme, agreed with the Host States’ authorities to inform the latter of the results and the environmental aspects of new projects. CERN also integrates pollution prevention, risk management, conservation of resources, and waste reduction into existing and planned activities, including the construction of accelerator and experiments in order to minimize their environmental impact.

In parallel with the construction of the CERN accelerators, a large number of materials have been tested as regards their resistance to ionizing radiation. An important part of this work on radiation damage studies was done in collaboration with industry and numerous results have been published. These studies were carried out in order to estimate precisely the lifetime of components of existing and new accelerators and to plan in a timely way the maintenance and improvement programmes. The studies also allow the specific selection of resistant materials for high-radiation areas. To carry out radiation damage tests requires knowledge in the degradation mechanism of the materials in high-energy radiation fields, the access to powerful radiation sources for irradiation and for testing. CERN has acquired extensive experience in this field and trained many students, engineers and physicists over four decades, which is beneficial not only to CERN but also to industry for application in other fields such as nuclear power plants, industrial and medical irradiation facilities, space programmes etc.

In the last few decades the use of plastic materials has developed enormously. At CERN the functioning of new experiments and accelerators requires insulation cables and pipes, and a large amount of insulating material. In the past, the use of most of these plastic materials brought about an increased risk of serious fire accidents and increased materials damage. Indeed, during a fire, halogen plastic materials or those containing some halogen combustibles produce irritating thick, acid, and often highly narcotic fumes.

Since the accelerator structures became more complex (long tunnels installed underground), CERN decided in the 1980s to use only materials without halogen and/or sulphur agents in order to limit the damage to personnel and material in case of exposure to corrosive and toxic fumes. CERN then encouraged industry to produce halogen-free cables and contributed to such development in collaboration with industry. The LEP accelerator and its experiments were equipped with halogen- and sulphur-free cables. Private companies benefited from these. Since then, the cost has gone down and the CERN stores offer only this type of cable. Most of the materials used in the LHC will also be halogen-free. CERN has thus been a precursor and today halogen-free cables are widely used.
Domains of transfer

Scientific and Technological Knowledge

CERN has been a centre of knowledge creation since its inception. Statistical data show that each year the Laboratory welcomes many students, researchers, and visiting scientists, that many publications are produced, and that some of these visitors then take their acquired experience and knowledge to industry. In particular, publications, as shown in the figure to the right, are a measure of the contribution in a scientific field and a tool for science policy decision.

Another form of CERN technology transfer to industry institutions and society comes implicitly through the transfer of knowledge or know-how of people. Some industrial firms have also asked CERN to host, at their own expense, engineers or applied physicists for training periods of several months to work on CERN projects in order to benefit from more frequent and diversified exchanges. This is demonstrated to be a valuable mechanism for technological learning and innovation. All people working at CERN have access to the rich programme of seminars and training courses held at CERN, covering a wide range of state-of-the-art topics.

A new model that describes knowledge creation, acquisition and transfer in the CERN context, has been recently proposed where the final realization of the scientific and technological processes, intertwined by the social process, are science and technology.

The model takes into account the two different levels involved in creating, acquiring, and transferring knowledge, namely individual and organizational learning. The best interaction between the individual and the organizational levels is represented by the balance between multicultural constraints and freedom typical of an international research organization such as CERN. Too much freedom involves a large financial implication and too many constraints result in a lack of ideas and subsequently reduce innovation. In the Laboratory, the technology transfer balance between constraints and freedom represents the interaction between pure scientific research and daily technological application. In Big Science centres the two types of individual and organizational knowledge creation are more closely correlated and interaction takes place as in conventional industrial environments.

Each year hundreds of young people join CERN as students, fellows, associates, or staff. Work experience at CERN brings more to both physicists and engineers in terms of the possibility to develop and acquire knowledge related to their
specific field of activity and also in terms of scientific and multicultural stimulation. Currently there are programmes with the Member States providing technological training for young people at CERN, and in addition young professionals receive recognition of their stay as a part of their education and training programme.

Technology training is an integral part of the experimental research process to which young scientists in a collaboration contribute to design, construct and set up experiments, thereby becoming acquainted with all the leading-edge technologies of physics instrumentation. Good examples of actions taken to increase the exchange of knowledge are the CERN Summer School of Computing, the annual CERN Accelerator School and the European School for Medical Physics. It is worth noting that the Accelerator and Computing schools are attended also by engineers and applied physicists from industry.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fellows</th>
<th>Unpaid associates</th>
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Fellows, unpaid associates, apprentices and students at the end of each year from 1993 to 2004
Improving industrial processes

CERN’s accelerators have always pushed different technologies at the leading edge of knowledge. The stringent technical requirements of CERN’s accelerator programmes, in particular for the LHC, are sources of TT and new industrial processes. Companies working on CERN contracts will often learn new techniques that they can apply to improve their technological performances.

Getter and Palladium Thin Film Coatings

Getters are one of the available tools to create and maintain vacuum. Thanks to a property well known since the 19th century, when introduced in a vacuum system, the getters may react chemically with the molecules of the residual gas. In this way these molecules become fixed to the surface of the getter, increasing the degree of vacuum. For the LHC, CERN has developed and patented an innovative and refined technology, that allows the entire internal surface of the accelerator vacuum chamber to be covered by getter thin film coatings, so transforming it into a pump. These coatings, produced by sputtering, may recover their chemical reactivity by heating at temperatures as low as 180°C, so their activation may be carried out passively during the standard bake-out procedure.
Non-evaporable getter (NEG) coatings suffer from two main drawbacks. The first one is a limited life: the high binding energy of most gases makes their adsorption thermally irreversible, resulting in a progressive accumulation of gas and deterioration of getter performance. The second drawback is that the activation requires heating: when exposed to ambient air, most metals form a surface oxide layer (passivation layer) which prevents any further gas adsorption. For NEGs, the passivation layer is removed by heating. These drawbacks are avoidable by using materials with reversible pumping that do not form a thick passivation layer on their surface. Noble metals with catalytic properties are promising candidates for new practical applications. Among them, palladium in particular has been found to provide the best vacuum properties, i.e. infinite life and pumping without heating after exposure to ambient air.

These new technologies have been covered by patents and are already applied, among others, at ESRF (European Synchrotron Radiation Facility) and in the Soleil project (France), at Jefferson and Brookhaven Laboratories (US), and Elettra-Sincrotrone (Italy).

These film getter coatings can be applied in different domains. To help diminish the greenhouse effect, they may be used to improve the thermal insulation of electric household appliances (especially refrigerators and ovens), and of buildings, minimizing relative thermal losses. They can also be applied not only to save energy but also to convert energy in high efficiency solar panels (see p. 13), allowing higher operating temperatures to be obtained, leading to higher thermal and thermodynamic efficiencies.

Hood Clamshell Tool

The Hood Clamshell Tool is another patented technology associated with vacuum, developed for inspection of the LHC magnets. In particular it is a device based on the ‘hood’ method to test the leak-tightness of vacuum systems. This method consists of using a leak detection device in which a metallic casing encloses the vessel under test so that a high-accuracy dynamic leak test may be carried out on a large portion of the external surface. The system is especially suitable for areas of restricted access and where pipes are extremely long. The device can be quickly installed and used by a single operator, incurs no risk of joint pinching, can be used on pipes of different diameters and over a wide range of pipe dimensions (from 30 to 300 millimetres). This technology has been licensed.

Because of these numerous advantages this technology can be applied in many different fields outside physics: in vacuum tightness for all installations and pipe work, in electronics and in cryogenics laboratories. It can be also used in production plants, for the transport of hazardous and natural fluids, and in medical, food and agricultural applications.

Titanium Electro-Polishing

CERN has developed a novel technology to electro-polish titanium and titanium alloys, which easily obtains a high degree of surface smoothness. The technology was developed because of an internal demand at CERN related to vacuum technology and cryogenics, but the process has a number of commercial applications as well. The polishing method is based on an electrolytic process in which material is removed from the surface by a chemical reaction powered by a low voltage. The novelty was in the chemical composition of the bath required by the electrolytic process, together with the process itself. Both the chemical bath composition and method for use are patented.

The surface polish obtainable using this process is superior to conventional electro-polishing titanium baths. The major features of the invention are: 1) the process can be run with low power consumption thus alleviating heat related issues; 2) there is practically no size limitation on the item to be polished; 3) the metal can be polished down to the nanometre level. The benefits include the detection of flaws and machining errors...
Improving industrial processes

unobservable by other means, a micro smooth surface (provides easy maintenance of hygienically clean surfaces due to reduced particulate adhesion), a shiny appearance without the high costs or limitations of mechanical polishing, less abrasion and wear, and metallic purity and chemical passivity.

There are a number of different applications for this surface technology, ranging from high-tech industrial products to attractive and shiny jewellery. These include medical implants and tools, vacuum technology (tubes, surfacing), aerospace (turbine blades), the chemical industry, the automotive industry, cryogenic equipment, jewellery manufacture, and spectacle frames and watches. The need for polished titanium is expected to increase steadily in the future and the decreasing price of titanium as a raw material is opening up new markets, widening the field and types of application.

ChemicalVia

The ChemicalVia process is a new inexpensive method for making microvia holes by chemical means on high-density and or high-resolution multilayer printed circuits of different types. Microvias are used to interconnect adjacent layers and consist of a small-diameter hole with a thin metallic deposit covering their cylindrical walls to ensure local conductivity between the two layers. A huge quantity of holes of any shape and typically below 50 µm diameter are produced using this technique. Currently the technology has been licensed to build a demonstrator and has been integrated in a Printed Circuit Boards (PCB) production line.

High-density circuits are widely used in miniaturized modern equipment from video cameras to mobile phones. In this global and fast growing market the manufacture of these circuits has been controlled by a few multinationals. The competitive advantage of ChemicalVia will provide smaller companies with the opportunity to enter this highly profitable market.
Profibus and WorldFIP

Communication networks, also known as fieldbuses, provide for digital communication between industrial facilities. They are also used to control and monitor ‘intelligent’ devices. These networks are essential to the operation of accelerators or automated machines. Commands transmitted via communication networks can be executed synchronously and data from the equipment can be accurately dated, allowing the temporal sequences to be reconstructed. Fieldbuses are a continuously evolving technology. The use of fieldbuses at CERN has been standardized since 1996. Profibus (Process fieldbus) and WorldFIP (World Fieldbus Internet Protocol) are two of the chosen standards and will play a vital role in the control systems of LHC accelerators and experiments. Standardized under the European Fieldbus, Profibus, with over three million nodes installed in over 300 000 applications, is a technology with a proven track record.

One example of a concrete development in the Profibus domain is collaboration between the Profibus users organization and European manufacturers of vacuum equipment, and vacuum experts from CERN. This collaboration has been initiated to define device profiles, specifying standardized communication mechanisms and device functionality for vacuum equipment manufactured by industry. The adoption and development of industry standards in this way intensifies collaboration between CERN and industry while bringing many benefits to industry, fieldbus users at the Laboratory and elsewhere in Europe.

The first applications of WorldFIP appeared during the 1980s, and distinguished themselves from the rest by their ‘deterministic’ approach. CERN is making extensive use of this protocol in the LHC. A 250-km WorldFIP network, comprising more than 15 000 nodes, to control facilities such as the quench protection systems for the superconducting magnets, cryogenic equipment, power converters, radio-frequency devices, etc. is to be installed in the LHC. The great potential of the WorldFIP concept has led to fruitful collaboration between CERN and the WorldFIP association. The requirements of research organizations like CERN have obliged the WorldFIP partners to enhance the performance levels of their networks still further in the field of control systems.

Technicians and engineers need to drive the performance of the accelerator control systems up to the desired level, often to the limit of what is feasible, and this has always been and will continue to be a source of cross-pollination and technology transfer.
The following examples are concrete cases of Technology Transfer achieved either through the dissemination and implementation policy established by CERN since 2000, or through the conventional procurement mechanism. High-technology suppliers communicated the results obtained through the latter mechanism, indicating product development benefits resulting from relationships with CERN during the period 1997-2001. In fact, CERN’s technological requirements often exceed available state-of-the-art technologies thereby generating fruitful interactions, technological learning and innovation for industry. In turn, this impacts positively on new market products.

Some innovative technologies transferred proactively from CERN to industry have been reported in the above sections. In particular, the sections “Detection and imaging” (Medipix2) and “Improving industrial processes” (Getter and Palladium thin Film Coatings, Hood Clamshell Tool and ChemicalVia), cover technologies which have had a particularly strong impact on the realization of new products as detailed below in pages 52, 65, 66, 67, 68, 69 and 74.
Since LEP, underground areas and experiments are equipped with halogen-free cables to minimize the side effects in case of fire. These types of cable will also be used in ATLAS, CMS, LHCb and other experiments.

Many of the 3M halogen-free cables were originally developed for CERN applications. 3M is also supplying CMS with high-speed Mini-Delta-Ribbon (MDR) cables assemblies (LVDS). These cables are used for data transfer between the FED (Front-end Driver) and the FRL (Front-end Readout Link) over a 10 m distance. Within ATLAS TRT, many MDR connectors are being used. MDR products are small, robust and provide excellent EMI protections due to complete metal shielding. MDR connectors have the easy ribbon Input / Output system.

The main ‘CERN specific’ 3M cable remains the famous blue and white coloured twist and flat cable no. 2100. It is available today as a standard item in the CERN stores.

APPLICATIONS
In industry the Company finds applications in ticket systems, transportation (train, tram, and coaches), elevators; and original equipment manufacturers in general use similar products to those designed for CERN. These are mainly 3M halogen-free cables (flat, twist-and flat, round, twin-ax, shielded), for which 3M is a leading company. All cables refer to the CERN fire safety standard IS 23. Many European and overseas research institutes like INFN, DESY, PSI, among others refer to this standard and use the products after they are tested and approved by CERN.

THE COMPANY
3M, founded in 1902, produced the world’s first waterproof sandpaper for automobile manufacturing. In 1925 the first of many Scotch® pressure-sensitive tapes was invented. Today 3M is a diversified technology company with 64 subsidiaries around the world serving customers and communities with innovative products and services. 3M Schweiz AG, with headquarters in Rüschlikon, was established in 1963 as an independent subsidiary company. The Company provides solutions for electronics, industrial, safety, security and protection, display and graphics, office and health care markets and is the provider of more than 15,000 products. Sales and marketing strategies have been adapted to miss needs. 3M is committed to actively contributing to sustainable development through environmental protection, social responsibility, and economic progress.

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The ATLAS detector includes two independent systems requiring cryogenic technologies: the superconductive magnet and the liquid argon calorimeter. The total cold mass of the magnet approaches 600 tonnes. The argon calorimeter contains three low-temperature liquid argon vessels with a total volume of 85 m³. Liquid nitrogen is used to cool down the calorimeter and is also used for the permanent cooling of the filled cryostats. LHC cryogenics will need 40,000 leak-tight pipe junctions, 12 million litres of liquid nitrogen will be vaporized during the initial cool down of 31,000 tonnes of material and the total inventory of liquid helium will be 700,000 litres. Superfluid helium will be used allowing kilowatts of refrigeration to be transported over more than a kilometre with a temperature drop of less than 0.1 K. The cryogenic installations are composed of different pieces of equipment to feed two LHC sectors with 4.5 K helium and superfluid helium at 1.9 K.

APPLICATIONS

A. SILVA MATOS METALOMEÇÂNICA S.A. constructed and installed for CERN 36 pressure vessels. These carbon steel vessels with a capacity of 250 m³ each and 20 bar working pressure were destined for the storage of gaseous helium, 30 of them for the cryogenic system of the LHC and 6 for the ATLAS project. As a consequence of this important supply to CERN, the Company greatly improved its capacity for the manufacture of cryogenic vessels, which are now being used for the LNG project.

THE COMPANY

A. SILVA MATOS METALOMEÇÂNICA S.A. was founded in 1980 to supply services for the food industry. Since then the Company has diversified to supply tanks for liquid combustibles, auto-gas storage and invested in the tooling and machinery to produce large dimension cryogenic-liquid tanks. Tubular heat exchangers as well as reactors, condensers and vaporizers are also amongst the products offered. Recently, wind generator towers for aeolian energy have been added to the available products. The Company has a reputation for high-quality products and high-quality control standards.

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The TDC-F1 was developed on behalf of and in collaboration with the Faculty of Physics of the University of Freiburg, Germany, for the COMPASS experiment at CERN. It is part of a general front-end readout driver and buffer module (CATCH) for the straw drift tubes. It is now used also in the NA48 experiment at CERN.

APPLICATIONS

Fields of application:
- Laser scanners,
- Two-coordinate position sensing devices,
- ESR medical instrumentation,
- OTDRs for telecommunication,
- CD-production test equipment.

THE COMPANY

ACAM messelectronic GmbH provides integrated circuits and systems for high-precision time interval measurement in the picosecond range. The aim is to establish TDC technology and its manifold potential in industry, automotive, consumer, and scientific applications.

ACAM offers standard products as well as custom-specific development accompanied by professional technical and commercial support.
Examples of transfer

Hydraulic Scissor Table
TO LIFT CONCRETE BLOCKS

Hydraulic scissor lift table designed specially to lift a 10-tonne concrete block used to shield radiations. The main demand was the need to reach reliable positioning by an indeterminate time onto the upper position. For security reasons the concrete block must be in the upper position when no laboratory tests are being made. To fulfil this demand, an electromechanical system was studied and designed that, in conjunction with the hydraulic system, can guarantee these conditions.

APPLICATIONS

New products of ACL now use some of the technology developed for this table lift. The part of technology used is the system to hold the table in the upper position, locked for long periods and without oil leakage.

Fields of application:
- Theatre lift stages,
- Big lift platforms in industry,
- Overcoming architectural barriers in buildings: small lift tables that must use the same locking device.

THE COMPANY

ACL – Alfredo Cardoso & Cª Lda is Portugal’s major manufacturer of lift equipment. This leading position was gained as a result of a concerted effort in research and constant development in hydraulic oil solutions. Fifty years of experience in light-duty metal mechanics and hydraulics and constant investment in human resources coupled with state-of-the-art solutions in production and assembly development have enabled the Company to supply innovative solutions tailored to customers’ needs and requirements. The application of ACL equipment is diverse, ranging from basic vertical lifting of loads to theatre stages and onto overcoming architectural barriers in buildings.

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CRISTAL (Cooperative Repositories & Information System for Tracking Assembly Lifecycle) is a JAVA application written to manage the gathering of production data during the ongoing construction of the electromagnetic calorimeter of the CMS experiment. Component parts are registered in the CRISTAL system, at which point they are given a workflow. These workflows order the characterization and assembly of crystals, photo-electric diodes, electronics and support structures into the ECAL supermodules which will be slotted into place in CMS.

This distributed data management system has been developed by CERN, the LAPP Laboratory in Annecy, and the University of West of England. The latest software version development has been in production since August 2003 in CMS-ECAL at CERN, and is also used for “preshower” construction in CERN, Greece, Russia, and Taiwan.

APPLICATIONS

The KERNEL software system of CRISTAL is used to manage specific business processes in specific enterprise environments. The functional architecture is around a 4-module structure (modelling, integration, execution and administration) allowing the complete management of process life-cycles. Applications are manifold from intelligent prototype construction planning, to airport maintenance scheduling, training course management, or pharmaceutical research and manufacture.

THE COMPANY

AGILUM S.A. is a start-up founded by four engineers, experts in system integration acquired in the best companies of this sector such as IBM, Cap, Accenture, Atos, Focal, etc.

AGILUM has received many awards for the innovative technology on which the applications are based and for its enterprise vision:

- National Laureate “ANVAR” - 2002,
- Laureate “Rhône Alpes Entreprendre” - 2002,
- Laureate “Annecy initiative” - 2003,
- Laureate “Fondation Total” - 2003,
- Labelled “Novacité” - 2003,
- “Prix de l’innovation Salon Progiciels” - 2003,
- Laureate “Start-up IMD” - 2003,

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Order treatment process
Crystals
Module assembly
The intensive collaboration between ANSALDO and CERN involved a significant transfer of technology from laboratory to industry. Vacuum electric furnace for components brazing, electron-beam welding machine, electro-polishing and chemical polishing plants, ultra-pure water plant, sputtering device, clean-rooms are only some of the high-tech equipment and plants necessary to ensure the excellent quality of ANSALDO production. In the mid 1950s, ANSALDO took part in the construction of the PS synchrotron, for CERN. In the mid 1980s the Magnet Division, independent in the design and production phases of conventional and superconducting magnets and special products, was created within the ANSALDO Group. At the end of 1990, ANSALDO drew up a supply contract for 72 superconducting cavities, equipped with cryogenic and RF components and assembled in 18 cryomodules for LEP.

APPLICATIONS

Besides other fields of applications, ANSALDO Superconduttori currently utilizes the vacuum pressure impregnation technique in the manufacture of magnets for thermonuclear fusion. The non-planar superconducting coils of W7-X magnetic system (IPP in Germany) are the latest example. The ANSALDO Superconduttori 70 kW-gun electron-beam welding equipment is one of the largest in Italy and is equipped with state-of-the-art programming and control systems. It can be used to weld steel up to a thickness of 130 mm in a single pass and to carry out high-quality surface treatments. Presently the plant is used for applications in the aeronautics field (welding of mechanical components of helicopters motors) and in the frame of high-energy physics and thermonuclear fusion projects.

THE COMPANY

ANSALDO Superconduttori S.p.A., now part of the Castel Group of the Malacalza family, is internationally recognized in the design and manufacture of conventional and superconducting magnets for research in high-energy physics and thermonuclear fusion. Recently the Company has delivered the Barrel Toroid coil winding systems for the ATLAS detector (INFN / CERN), and today, for the LHC project, is fabricating 416 dipoles.

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The corrector magnets of the LHC, small with respect to the main magnets, are wound with single strand cables and the coils are fully impregnated with epoxy, which reduces the cooling by helium. In order to achieve the field quality, small sextupole (MCS), octupole (MCO) and decapole (MCD) magnets (spool piece corrector magnets) are installed at the ends of the main dipole magnets to correct multipole field errors. Every aperture of each dipole magnet is equipped with a sextupole corrector coil, whereas only every second dipole magnet will be equipped with octupole and decapole correctors. ANTEC has collaborated with CERN in the fabrication and testing of different prototypes of superconducting corrector magnets for the LHC project such as sextupoles, octupoles and decapoles.

Among the products added to the catalogue due to CERN acquires expertise and know-how on magnetic design, precision manufacture and encapsulating techniques are:
- Magnets for scientific labs,
- Accelerators both superconducting and resistive,
- Cryostats.

The Company has built high-technology products (steel cores with high magnetic permeability, correcting magnets, focusing magnets, special coils, etc.) for different customers and applications in other European research laboratories such as COSY in Julich, CEA in Saclay, ESRF in Grenoble and a prototype for the future synchrotron of the Barcelona LSB.

ANTEC S.A. manufactures conventional products like industrial brakes; industrial magnets and magnet separators. Adding to their product line ANTEC also manufactures special products like: multi-pole magnets, accelerator magnets, high-precision magnetic cores, superconducting solenoids, superconducting coils, lab cryostats, superconducting applications such as current leads, current limiters, energy storage systems.

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Examples of transfer

Informatics Supervisory Solutions
FOR LHC CONTROL SYSTEMS AND MONITORING

At CERN, ARC Informatique's supervisory solutions have been in use since 1996 on various test benches. More recently they have been applied on applications for the LHC in redundant, client / server architectures, especially to monitor conformity with the SIL3 (IEC 61508 System Integrity Level 3) standard of stable operation. Examples of monitoring projects employing ARC Informatique’s solutions are: LHC cryogenics, the first-generation Unified Industrial Control System project, the CERN Safety Alarm Management project, and the Radiation Monitoring System for Environment and Safety project.

APPLICATIONS
The technological requirements from CERN projects pushed ARC Informatique to incorporate new functionalities into standard products. The adopted solutions have been employed in projects such as:
- The technical centralized management for airports in Paris,
- The management of the assembly hall of the A380 Airbus industry,
- The technical management of the Harilaos Trikoupis bridge in Greece.

THE COMPANY
ARC Informatique was one of the first European companies to develop SCADA and HMI solutions, with the benefit of its international presence. In the context of its quality approach, ARC Informatique obtained ISO 9001 (V2000) certification in June 2003 through the Swiss organization SQS. As an active partner of leading innovators among international companies in the field of new C&IT (Communication and Information Technologies), ARC Informatique’s products embrace the latest technologies such as Web Services, Microsoft Net, JAVA etc. With 20 years’ experience in the marketplace, ARC Informatique has established a wide range of consulting, assistance, training and support services to complement its product-based solutions and meet its customers’ needs.

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Printed circuit board layout studies may be made for CERN by specialized companies. AS&T Services uses the same CAD tools as those used by CERN and has adapted its working methods to meet precisely CERN's requirements. Several prototypes have been developed by AS&T Services. Examples are power converters, control systems and magnet instrumentation systems for various accelerators.

APPLICATIONS

Fields of application outside physics:
- Automotive,
- Semiconductors,
- Power generation,
- Telecommunications and
- Aerospace.

THE COMPANY

AS&T Service S.n.c. is a company operating in the areas of CAE/CAD/PCB situated in Monza (Milan- Italy). Born in 1975 as AS&T S.r.l., the Company has developed capabilities to realize professional masters for printed circuits requiring the high-test level of reliability and availability as built-in quality characteristics. AS&T Service is currently working with the most important companies in the telecomunication, automotive, power generation, aerospace and semiconductor areas. Certified UNI EN ISO 9001 – DEC. 2000 since 1998. To realize PCB and schematic capture, some of the most important CAD/CAE are used: Mentor Graphics, Cadence, PCAD and Intercept.

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ATOS has been collaborating with CERN for more than 20 years and has developed for CERN cabinets and PCB racks that are widely used all over the sites. The requirements both in terms of materials, solidity, and the need to be placed in a hostile environment have brought improvements and modifications in what are today products that fulfil international requirements and standards.

APPLICATIONS

The OSL mechanical systems developed for CERN electronics have been evolving in time and today are a standard item in the CERN stores and utilized widely by companies such as Alcatel, Sagem, Nortel, Thales, France Télécom, Alstom, Philips, SNCF, CEA, EADS, Airbus, Siemens, Cegetel and Lucent Technologies.

THE COMPANY

ATOS, a company dedicated to electronics and high-technology, whose competitiveness is based on the merging of ATG/Toolkit and OSL/Systems, is the provider of a considerable stock of equipment and a wide range of standard and customized metal enclosures (cabinets, cases, and PCB sub racks) and thin-sheet metal products. The industrial design offices, equipped with the best 3D pro sheet metal software, are located at Glos in the department of Calvados and at Carros in the Alpes Maritimes. The ATOS offer goes from prototype to mass production at its ISO 9002 certified plant at Glos in France. 300 employees work on two industrial sites to satisfy customer requirements in precision thin sheet metal: from the single part to complex pre-wired assemblies; press and laser cutting; computerized flexible production management.

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BABCOCK NOELL NUCLEAR started to collaborate with CERN for the design and realization of the "Lobster", the remote handling system for precision positioning (0.1 mm) of the 1640 LEP dipole magnets each of them weighing 12 tonnes. It also participated in the design, test and optimization during the 10-year prototype phase of the construction of LHC dipoles. During that phase the length of the dipoles was enlarged from 10 m to 15 m; because of this modification the dipole magnets are no longer straight, and must be adapted to the beam curvature. At present the company is successfully constructing one-third of the 1232 dipoles cold masses and delivered the vehicles controlled by a remote handling system for the transport of magnets in the tunnel.

APPLICATIONS

Know-how gained during the collaboration with CERN serves today for design, manufacturing and supply in various projects. For example:
The know-how for dipole magnets is used for other accelerator projects in different research centres.
The knowledge developed in the field of remote handling is helpful today for precise transport and positioning of heavy loads in fields of nuclear technology.

THE COMPANY

BABCOCK NOELL NUCLEAR GmbH is the centre of competence for nuclear technology with worldwide responsibility inside the Babcock Borsig Group. More than 30 years of experience, as well as cooperating closely with research establishments, makes the Company a competent partner in nuclear service, nuclear technology and magnet technology. With the project "Shut down of the nuclear ship Otto Hahn" at the end of the 1970s BABCOCK NOELL Nuclear established a promising position in dismantling thermonuclear plants. In the early 1990s BABCOCK NOELL NUCLEAR started with the development of large superconducting magnetic systems for high-energy physics and fusion experiments. Currently, work is being performed on contracts for the series magnets of the fusion experiment W 7-X (IPP) and for the LHC (CERN). High investments in production and coil-assembly facilities have been made for this purpose as magnet technology is gaining in importance for BABCOCK NOELL NUCLEAR GmbH.
Thanks to the know-how acquired within CERN on particle detector developments by the future company’s founder, BIOSCAN has produced a digital imaging and control systems for medical and industrial applications. This new system uses a large-area pixel matrix based on solid-state amorphous silicon detectors and CMOS technology.

**APPLICATIONS**

The main characteristics of the three new digital imaging and control systems are digital imaging in a dynamic mode (up to thirty images per second), with high contrast and resolution:

- **X-VIEW** has been developed for X-ray, real-time, non-destructive inspection in industrial applications: aeronautics, automotive, nuclear, electronics, space, oil and gas, including hostile environments, food, cultural and archaeological studies.
- **PIXRAY** has been developed for medical diagnosis and interventional radiology. It permits the acquisition of real-time images with significant dose reduction (up to 100 times compared to film) and better contrast resolution in comparison with the standard techniques.
- **IRIS** has been developed for cancer therapy to monitor the patient’s position during treatment with external gamma- and X-ray beams. IRIS improves the quality of the treatment and allows more accurate visualization for localization of the treatment area during radiotherapy.

**THE COMPANY**

Since 1990 the activities of BIOSCAN have focused on biomedical X-ray imaging and non-destructive testing (NDT). BIOSCAN designs, manufactures and commercializes new products using cutting-edge technology.

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A new non-magnetic stainless steel (BÖHLER P506) with high mechanical properties for extreme low temperature applications (4.2 K) was developed to be used as beam screen to shield the LHC magnet cold core from synchrotron radiation. The austenitic microstructure is stable down to cryogenic temperatures, in weld conditions too, with excellent magnetic impact and corrosion properties and no hot cracking during the processing.

APPLICATIONS

- General cryogenic applications in sophisticated energy production and transportation systems (e.g. superconductors, pump parts).
- Applications with requirements for extra low magnetic permeability in cold deformed construction parts.
- Scientific instrument industry.
- Petrol industry.

THE COMPANY

BÖHLER Edelstahl GmbH, a 100% daughter of the BÖHLER Uddeholm AG group is one of the world’s leading manufacturers of high-speed steels, tool steels and special materials. It concentrates its efforts on materials for highly demanding applications.

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Semi-finished products for pump production
For the first time diode laser welding technology was used for the manufacture of magnet beam screens. BUTTING, applying its core competences in forming and welding, has produced 50,000 metres of perforated and copper-lined oval pipes made in the Böhler material grade P506 (Beam Screens). These pipes of dimension 48.5 x 38.9 x 1/0.075 mm had to be made in lengths from 5900 mm up to 15,555 mm.

In order to achieve the very stringent tolerances of 40,000 metres of half-shells in stainless steel AISI 316LN -1.4429 to be used in the superconducting magnets, these shells of dimension 550 x 10 mm are manufactured in lengths of 15,450 mm. The company’s manufacturing capabilities and dimensional control facilities have been improved and valuable experience acquired. The technology knowledge gained can be applied to any other customer.

APPLICATIONS

The diode laser welding process is now also being used for the production of small-bore pipes for special requirements.

THE COMPANY

BUTTING is a German manufacturer of longitudinally welded stainless steel pipes for many different industries all over the world. It was founded in Crossen (now in Poland) near the river Oder in 1777 and was re-established in Knesebeck / Lower Saxony in 1946. In 1990, a subsidiary was founded in Schwedt / Oder in the federal state of Brandenburg. BUTTING has several sales departments in Knesebeck and Schwedt, a representative office in China and partners all over the world, e.g. Canada, Oman, Saudi Arabia, Egypt, Israel, South Africa, Korea and Indonesia.
Thanks to experience acquired in design and manufacture for CERN applications, CAEN and CAEN Aerospace are equipped with state-of-the-art facilities for the development of new tools, in particular low / high voltage power supplies and front-end and data acquisition digital electronics, for detectors, used worldwide in high-energy and nuclear physics. The products developed and put into the market are the result of expertise catalysed from various sectors and made possible by the continuous interaction of CAEN developers with physicists and engineers. The latest product CAEN V1729 gives the most accurate signal shape and timing identifications even for measurements in harsh environmental conditions (high-dose, high magnetic fields etc.). In addition to specific products put into the market for the physics community the interactions provided the company with opportunities to apply know-how and technologies in other domains (space, medical, textile etc.).

APPLICATIONS

The applications of most advanced digital electronic technologies for detectors are numerous outside the high-energy physics, synchrotron radiation and nuclear physics domains. The most important are:

- Space, where the high-reliability requirements and reduced cost as applied for LEP and LHC are important parameters which have been exported in the design and conception for such applications. CAEN Aerospace has successfully taken part in Wizard, Alteino, AMS1 and INTEGRAL / JEM-X and is currently involved in CPPS, AMS2 and PAMELA.

- Medicine. An example is the CaRDIS camera (Cardiological Real-time Low-Dose Imaging System). The detector used is a novel type of gamma camera based on the multi-wire proportional chamber, equipped with an advanced, high-rate digital electronic read-out system.

- Fabric for clothes based on optical sparkling fibres is the result of a close collaboration between CAEN S.p.A. and the Swiss company STABIO Textil SA. LUMINEX® is an international patent and trade-mark.

THE COMPANY

CAEN S.p.A. is one of the most important industrial spin-offs of INFN. The Company was founded in Viareggio (Italy) in 1980 by a group of senior engineers from the INFN and today still designs and manufactures sophisticated electronic equipment for nuclear physics research. CAEN is recognized worldwide as one of the leading companies in this field. The quality of its products is monitored by the UNI EN ISO 9001-2000 standard.
Cryogenic fluids are used by the ATLAS and CMS experiments. In order to provide the required cooling capacity, CERN has installed helium and nitrogen refrigerators (liquefiers) in the auxiliary caverns and transfer line distribution system near the experiments.

DeMaCo has a long collaboration with CERN. For 15 years it has been active in CERN either on a direct basis or in cooperation with Linde Kryotechnik / Air Liquide DTA.

The development of the DeMaCo multiple helium transfer lines could be done thanks to cooperation with all the parties concerned. While the CERN project staff made the basic engineering of the projects, DeMaCo was involved in the detailed engineering, manufacturing, project management and installation. This has resulted in advanced very cost-effective designs with the required extreme low heat-in-leak ratios as required by ATLAS and CMS.

APPLICATIONS

Besides transfer lines, DeMaCo has gained considerable knowledge in the field of valve boxes and phase-separators which together with the transfer lines form the most economic link between the liquefiers and the application. Needless to say, adjacent to the development for the helium transfer lines the product development for other liquid gases transfer has benefited to the same extent. The most important is, however, that DeMaCo as an organization has developed to such a level that complex projects can be executed on a worldwide basis for any cryogenic application and is today the worldwide supplier of transfer lines.

THE COMPANY

DeMaCo Holland bv is a partner in cryogenics, vacuum technology and special machine building, areas of professional expertise for which the Company has outstanding expertise and is continually investing in technological innovations. DeMaCo's scope ranges from small- to large-scale and from simple to highly complex tasks. The Company is accredited ISO 9001 and SCC** (Bureau Veritas) and creates top-quality total solutions in partnership. Whatever the nature of the assignment, 'Made by DeMaCo' stands for systems that excel in terms of quality, reliability, and durability.

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The CMS experiment relies heavily on optical links to transfer data from the detector to the ~65 m distant counting room. Optical data transmission is required in order to minimize detector power consumption, reduce the amount of material within the detector’s active volume, and allow the transfer of data at high rates while remaining immune to electrical interference. In order to meet the high cabling density required by all innermost CMS detectors, optical fibre ribbon is used. Compact ribbon-connectors such as those proposed by DIAMOND allow one to build patch-panels meeting extremely tight space constraints. The DIAMOND Multiple Fibre System (MFS) combines DIAMOND’s advanced polishing technology and the flexibility of the MT ferrule resulting in a high density and performance modular solution, which can be utilized in both back plane and front panel applications. Each single connector supports up to 12 fibres.

APPLICATIONS

The MFS is a standardized solution available on the market today and is compliant with EN 186310 and TIA/ EIA 604-15 and can be used in applications such as

- Patch cords and fan-out assemblies,
- Data and telecommunication networks.

THE COMPANY

DIAMOND S.A. was established in 1958 as a machinist of ultra-hard materials and a manufacturer of industrial jewels, record player styluses, and other high-precision components. The experience gained in these endeavours formed the basis of the company’s expertise in precision machining and volume production. The quest for diversification led DIAMOND into the field of fibre optics, where the Company quickly established an internationally recognized reputation as an innovator. DIAMOND is the world’s leading manufacturer of high-precision fibre optic connectors, and successfully serves the telecommunications industries of numerous countries worldwide. DIAMOND is renowned as a dynamic, innovative partner, able to develop custom-tailored solutions in response to customer demands.
The Induced Activity Monitor detector (a plastic ionization chamber) has to be installed in high radiation areas for remote measurements of the LHC machine and experiments during beam operation. As a consequence of the high exposure, its electronics must be detached from the detector that imposes the use of a reliable and accurate cabling. An integrated cable composed of two special coaxial cables and two twisted pairs inside an overall braided copper screen and the associated connectors have been developed. The SPA6 cable has been validated for the application for lengths comprised between 800 to 1000 metres with current as low as -0.1 pA for the inner signal coaxial cable and -1 kV for the high-voltage polarization of the ionization chamber. DRAKA, a leader in coaxial cable manufacturing, has developed a new product according to CERN specifications.

APPLICATIONS
The new product made available by DRAKA is now a standard item in the CERN stores and has found application or is being applied by other customers in:
- Ionization chambers developed for ILL in Grenoble, the world’s leading research centre for research using neutron beams,
- ESRF monitoring installation.

THE COMPANY
DRAKA Multimedia Cable GmbH is a company with more than 150 years of experience in cable manufacturing, located in Cologne, Germany. The core competence is development, production and sales of innovative cables for video, data and voice signals in office, studio, home, central office switching, industrial and CATV applications. A branch is specialized in radio-frequency (RF) and customer specific cables. For over 30 years DRAKA Multimedia Cable has been designing RF pulse cables for kicker magnets in cooperation with CERN. DRAKA is a worldwide provider and developer of coaxial cables. The Company is especially aware of quality and environment with their quality system in accordance with DIN EN ISO 9001 and their environmental management system in accordance with DIN EN ISO 14001.

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Since the construction of LEP in the 1980s, EFACEC has produced several types of electronic equipment for CERN, including the electronic modules and chassis for the SPS RENOVATION and MINIDISCAP programmes. More recently besides its standard solution for the power network management systems, the Company developed specific features for CERN, namely the Gateway to External Systems (GATE X) and Front-end interfaces to existing RTUs and other devices. This experience was very important to EFACEC, since it projected the company in the SCADA / DMS area and new functionalities were added to the core solution.

APPLICATIONS

Today’s fast changing world is pushing power distribution utilities to new challenges, where improving the efficiency of power system operation is one of the key issues. SCATE X improves network operation, analysis and planning. The system was designed according to the state-of-the-art and relies on the large experience of EFACEC in this field. The result from the development carried out for CERN is an advanced system where traditional SCADA functions are complemented by a set of distribution-network-oriented functions (DMS), namely network colouring, topology processing, power applications such as power flow, short circuit analysis, state estimation, as well as load forecasting, fault detection, etc. that have been integrated in the core products of the Company as shown below.

THE COMPANY

EFACEC Sistemas de Electrónica, S.A. is an EFACEC Group Company, devoted to Electronics and Information Technologies. Created in the 1940s the EFACEC Group is the biggest Portuguese industrial group in the domain of electricity and electronics, developing its activity in the areas of energy, transport, telecommunications, industry and buildings, service and maintenance, logistics and environment.
In metropolitan and access networks scalability, cost efficiency and easy installations are prime concerns. Micro cable systems based on air-blown installation techniques are therefore the perfect solution for that application. The design of the micro cable used is crucial to meet the demands in terms of duct utilization, installation performance and transmission performance. A completely new micro cable concept has been introduced, which facilitates a significantly reduced cable diameter and better installation performance compared to existing micro cable designs and yet delivers optical and environmental performance equivalent to traditional loose tube duct cables.

**Optical Fibres**

**THE RIBBON CONCEPT FOR ATLAS AND CMS**

Optical links are required to exchange data between the detector front ends and the control rooms of ATLAS and CMS. The ribbon concept with single-mode or multimode optical fibres has been accepted for an installation in the harsh environment. The ATLAS experiment will use approximately 25,000 digital optical links based on 50 µm-fibre and 850 nm VCSEL emitters while the CMS experiment will operate about 150,000 optical links. A novel ribbon cable with eight 12-fibre ribbons has been designed and tested. The 12-fibre ribbon is of the encapsulated type with a thin outer layer, the ribbon matrix. The pictures show two examples where ERICSSON has benefited from the knowledge acquired from CERN purchases. There are other examples as well. In work with CERN during the last few years, ERICSSON has learnt about material properties in general and for harsh environments in particular.

**APPLICATIONS**

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**THE COMPANY**

ERICSSON has been active worldwide since 1876 and is today present in more than 140 countries, with headquarters located in Stockholm, Sweden. ERICSSON is the largest supplier of mobile systems in the world and supports all major standards for wireless communication. The Company drives the telecoms industry and is shaping the future. The world’s 10 largest mobile operators are among its customers and some 40% of all mobile calls are made through ERICSSON systems. ERICSSON provides total solutions — from systems and applications to services and core technology for mobile handsets.

**Examples of transfer**

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**Examples of transfer**

**Optical Fibres**

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A new Web application for organizing conferences has been developed within the CERN Document Server (CDS). Following the tradition of CDS Agenda, the tool allows scheduling of conferences, from single talks to complex meetings with sessions and contributions. Moreover, it also includes an advanced user delegation mechanism, allowing the reviewing of papers, archiving of conference information and electronic proceedings. FONTISMEDIA, as a provider of Conference Organization support, is using the system to respond efficiently to customer needs.

APPLICATIONS
In 2004 the Company used a customized version of InDiCo to provide necessary support to an international scientific conference on electrochemistry organized by the International Society of Electrochemistry.

THE COMPANY
FONTISMEDIA S.A., founded in 2000, provides a full range of services related to the communication of scientific and technical information, with expertise in the areas of publishing, marketing, event organization (including scientific conferences), and logistical support. The nature of scientific publishing is evolving rapidly, and income from journals and conferences is under pressure. New technologies are emerging almost on a monthly basis, with the Internet at the heart of these developments. FONTISMEDIA works in close relation with the customers to find the solution that uses these technologies to the best advantage, whether it be for a specific project or as a long-term service provider.

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Advanced geodetic techniques to fulfill the needs for precision alignment of beam line elements during assembly or positioning have been developed at CERN for more than 40 years. Among these techniques, the alignment of the elements based on high-accuracy length and wire offset-measurements and carried out with special instruments are very good examples. The DISTINVAR allows distance measurements using invar wires up to 50 m long, with an accuracy of 0.2 mm (RMS). The wire offset measurements are carried out with the ecartometer. The wire can be stretched up to 100 m or more, and the instrument automatically detects the position of the wire with an accuracy of a few hundredths of a millimetre (RMS). Measurement conditions have to be carefully controlled in order to avoid any systematic errors.

Applications
The developed device is applied in particle accelerators, nuclear power stations, radio-astronomy antennas, dams and rocket launching bases. Transfer of competences and know-how from CERN has also resulted in others product, the latest being the MAGNOFF-SENSOR® which has been used for the metrology measurements and installed in the anchoring towers of the Harilaos Trikoupis bridge in Greece.

The Company
Founded in 1928 the company J Baechler & Fils has always been a leader in the field of measurement and is today a manufacturer of high-precision material for the acquisition and measurements in industrial geodesy and civil engineering. The Company is also a founder member of the Office of Industrial Promotion. GEODESIE INDUSTRIELLE S.A. manufactures and sells precision instruments resulting from the research and development carried out in organizations and large physics laboratories such as CERN, ESRF, ESA, Synchrotrons in China, the US and Japan, and for industry and for Aerospatiale: Toulouse, Kourou.
As a provider of control and monitoring systems for CERN projects, GTD has acquired a vast experience in the design, development, installation and commissioning of turn-key critical systems. An outstanding example is the control system for LHC cryogenics. The object of this project is to provide the Process Control Systems (PCS) for the cryogenic equipment of the LHC accelerator as well as of ATLAS and CMS magnets. The control software developed for this project is provided separately from, but concurrently with, the equipment deliveries, and is referred to as UNICOS (UNified Industrial Control System). The development of the PCS is on the basis of an Object Library. It was developed and validated in collaboration with CERN.

APPLICATIONS
The broad experience gained by GTD in this project is being used in a wide diversity of state-of-the-art control projects for the space, avionics and manufacturing industries. The control of ground facilities at the European Spaceport in Guyana is largely inspired by the LHC cryogenics design. Protocols based on those developed for LHC cryogenics have also been applied to Mercedes and Volkswagen manufacturing plants and for aeolic power plants supervision. The supervisory functions and resources developed have found applications in Spanish central and regional governments.

THE COMPANY
GTD Ingeniería de Sistemas y de Software, founded in 1987, with headquarters in Barcelona is one of the most important European companies for software and system engineering in economic sectors such as space, defense, aeronautics, industry, science and telecommunication. The activity of GTD centres on the conception, design, development, installation and maintenance of all types of control and information systems, always within the most demanding requirements of its clients. From the initial consultation and basic engineering, to the delivery of turn-key systems, the services of GTD are supported by an experience demonstrated in the development of global solutions. The flexibility to implement the most appropriate solutions in order to satisfy its clients is a strong asset of the company. Presently the GTD organization includes a staff of over 200 people.

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HABIA KABEL realized the power supply cables for the silicon detectors in the inner core of CMS. Cables used inside the tracker volume are of the aluminium type (Ø 8.4 mm) and about 5 metre long. The silver-plated aluminium multi-strand conductors are used because of their light weight. The cable is composed of 28 individual conductors and provides multi-services such as low-voltages, high-voltages, sense wires, drain wires and connections to environmental probes for temperature and humidity. All selected materials are resistant to high-radiation levels. The cable development was done in close collaboration with CERN/CMS to satisfy their specific requirements.

APPLICATIONS

Owing to the better measurement performances achieved in radiation areas, this new development has resulted in a new multi core product and finds application in nuclear production and handling as well as waste processing treatment.

THE COMPANY

The Company established in 1941 is today part of the Beijer Alma group of companies and focuses on the production of components for customers in high-technology sectors. HABIA KABEL GmbH provides development, design and manufacture of high-performance cables and cable systems for demanding applications with a high level of services. The wires and cables have to meet the requirements of international standards and customer specifications. The special demands on the cables are water resistance, fire protection, low / high temperature, small dimensions, light weight, radiation resistance, halogen-free, oil / chemical resistance, vibration, mechanical strength. The application areas include control and instrumentation, nuclear, industrial, transport, telecom and defense sectors.

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Very stringent measurements of direct currents in high-voltage transmission systems are made for the regulation, protection and costing of the energy transmitted. The LHC superconducting accelerator requires ultra-high-precision current measurement systems operating with the zero-flux principle and high-accuracy resistive current measuring systems. In 1972 HITEC adopted a CERN idea for very precise DC current measurement, which was based on the zero-flux principle. The company was the first to manufacture such products for scientific applications and has been doing so very successfully ever since. Over the years the company and CERN have stayed in close contact. Many innovations came from these contacts. It finally resulted in a brand-new, state-of-the-art, measuring system that is going to control the most critical power supplies in the LHC project.

APPLICATIONS

The system is widely used in nuclear research projects, plasma physics experiment applied scientific research, industry, industrial calibration workshops, medical applications and high-voltage DC transmission systems. It is a standard for high-precision DC measurements. A zero-flux system is for use in high-voltage DC transmission systems. With these transmission systems energy is transported over very long distances or via undersea cables. Insulation voltages can sometimes be up to 500 kV. The Zero-flux™ is available for current up to 30 000 A, with accuracies not in the ‘percentage’ scale but in the incredible ‘ppm’ range.

THE COMPANY

HITEC Power Protection bv has grown from a small Dutch company to a global enterprise that designs, manufactures, distributes, and services best-in-class Continuous Power Supply (CPS) and Uninterruptible Power Supply (UPS) systems for customers around the world. The Company installed UPS systems with a total power close to 1 000 MVA. The Company was originated from such well-known companies as HEEMAF, Hazemeyer and Holec. Its experience of electro-technical products goes back more than a century.

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http://www.hitecups.com

Zero-flux™ measuring systems
In conjunction with CERN, OUTOKUMPU Superconductors, Fermilab, Marti Supratec and others, has developed the Continuous Rotary Extrusion or CONFORM™ method of cladding superconductors, both braided and single strand, to produce aluminium stabilized superconducting cables of extremely high quality with little or no degradation in lengths that have exceeded 4 km. Recent collaboration with CERN (LHCb, ALICE) has led to the development of long-length, large-cross-section, aluminium tubes for magnet windings to be used as part of the LHC project. Innovative methods of extrusion and coil winding were developed to allow these large-cross-section extrusions to be produced in truly continuous lengths with uniform properties.

APPLICATIONS
The company has supplied nearly 100 lines throughout the world. This method, developed in conjunction with CERN, OUTOKUMPU Superconductors, Fermilab, Marti Supratec and others, has allowed OUTOKUMPU HOLTON CONFORM™ to acquire new markets in applications such as:
- Utility power cables,
- Transport,
- Telecommunications and data cables,
- Hybrid cable products,
- Domestic applications,
- Aerospace,
- Medical,
- Metallurgical,
- Recycling.

THE COMPANY
HOLTON Machinery Ltd. was formed in the mid 1970s to exploit a manufacturing licence from the UK Atomic Energy Authority for HOLTON CONFORM™ continuous rotary extrusion machines. Holton has been part of the OUTOKUMPU group since 1991. OUTOKUMPU HOLTON Ltd. is a manufacturer of CONFORM™ continuous extrusion equipment. The development allowed OUTOKUMPU HOLTON to open new markets and serve new customers whilst also benefiting existing CONFORM™ users.

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An advanced silicon detector providing very precise tracking, called the Vertex Small Angle Tagger (VSAT) calorimeter was developed and built, near the collision point of the DELPHI experiment, to detect very short lived particles by extrapolating the tracks back towards the interaction point. Microstrips and readout electronics based on the 128-channel chip ‘Viking’ IDEAS, were used.

APPLICATIONS
The know-how acquired on amorphous silicon detectors and readout electronics has allowed the company to develop components for applications such as:
- LumaGEM camera for scintimammography,
- Cardiology CdZnTe camera,
- Single-photon counting detector for medical use,
- Biomolex for molecular biology,
- SWIFT Gamma-Ray Burst Mission (NASA) equipped with an optical and X-ray telescope and a CdZnTe / XA1.2 based coded aperture gamma camera.

THE COMPANY
IDEAS ASA, founded in 1992, employs today 27 people. IDEAS’ unique expertise lies in the area of radiation detection and imaging technology, developing and supplying high-technology products for use in nuclear medicine, security and safety, medical X-ray, biomedicine, industrial inspection and physics. IDEAS is a world-class centre for research and commercial development of solid-state camera heads and detection modules to provide high-quality and high-resolution digital images. The Company also delivers standard products which utilize semiconductor sensors combined with advanced readout electronics, as well as customized solutions. Within the area of biomedicine, IDEAS has together with the Norwegian Radium Hospital established Biomolex AS, a Norwegian company working with methods and systems for functional genomic and proteomics.

IDEAS ASA
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Almost 20 years ago IMBACH, a forgemaster with wide experience, was contacted by the CERN mechanical workshop to supply flanges in aluminium and specifically in AlMg 4.5 Mn for the LEP project. Technical information on forging and ring rolling process for such material did not exist and even the supplier of the basic material was surprised that it could be forged or ring rolled at all. Technical solutions had to be found for forging and ring rolling the material which could instead be easily machined. Amongst the many difficulties to be overcome during the processing were the ring cracking and bursting associated with the high content of Natrium. These developments allowed the Company to start its aluminium rolled rings business.

APPLICATIONS

AluRingTec is a registered trademark in 13 countries and is now synonymous with high quality aluminium rings. Owing to the specific structure and qualities, these are used in many applications. One example is the aluminium forged, CNC-rolled and finished machined aluminium coil former for a high-field NMR at Bruker Biospin in Switzerland.

THE COMPANY

IMBACH & CIE AG was founded in 1888 and today the management of the Company lies in the hands of the fourth generation of the IMBACH family. The Company views the customer as a ‘development and systems partner’. Central to the Company competence and skills are the various forging technologies which include open-die forging, drop forging and ring rolling (RingTec) using a broad variety of materials like steels, nickel alloys, copper alloys, aluminium or titanium and the machining technologies which include rough machining, finish machining, tool making (CAD/CAM). The Company develops high-quality products and services, puts them cost-effectively into action and continuously optimizes them. In order to improve the overall performance of the large-scale drop-forging hammer, a new rotary furnace was commissioned in January 2002 with a bed diameter of 3.7 m and a new forging manipulator was installed in September 2004.

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Rolled rings in Aluminium
One installation at CERN
700 MHz UltraShield Plus NMR magnet by Bruker Biospin Switzerland for state-of-the-art spectrometry
IMT has been providing CERN and similar facilities with large electrically conductive sensor plates with patterns acting as anodes and cathodes called Micro Strip Detector Plates. Through cooperation with CERN the company has accrued the know-how in manufacturing electrically conductive layers. In close cooperation with the designers and users, IMT supplies Micro Strip Sensor Plates with conductive structures in chrome, gold and aluminium. Patterns as small as 8 µm and on a variety of substrates as large as 400 mm x 400 mm in thicknesses down to 0.4 mm are available.

APPLICATIONS
IMT has been faced with a very wide range of technical requirements for the Micro Strip Detector Plates (electrically conductive structures on thin glass used as sensor plates in the gas chamber detector). These developments have found applications in:
- Gas chamber detectors in particles accelerators,
- Gas chamber detectors in satellites.

The know-how acquired in the field of electrically conductive layers now, among others, benefits IMT customers in the fields of custom-made electro-optic modulators.

THE COMPANY
IMT Masken und Teilungen AG is a supplier of high-grade custom-made microstructures on glass and other substrates. IMT operates a 1000 m² clean room facility near Zürich and in October 2004 employs a staff of 59 experts in the field of microlithography, optics and physics.
Archibald is a development inspired by the work and academic lectures at CERN from 1974 to 1976. It is an intelligent electronic assistant with voice recognition that controls electronic appliances directly through the 220 V electrical network so there is no need for communication cables (X-10 protocol). Archibald was awarded the European Information Technology Prize 97 in Brussels (25th November 1997).

A new generation, Archibald 2, was developed in cooperation with the Universities of Lausanne, Geneva and Lyon using the EHS protocol (European Home Systems). Archibald 2 can now perform any digital or analog function within any electric power consumer.

APPLICATIONS
This system helps the handicapped, convalescents and the elderly to achieve independence, security and comfort. Here are some examples of what it is possible to ask Archibald to do:
- call a friend or your nurse,
- dial a telephone number,
- call for help,
- keep a watch on the neighbourhood,
- be your ‘body guard’,
- switch on / off or regulate electrical appliances.

House or apartment owners can use Archibald:
- to switch on-off or regulate all electrical appliances,
- to open or close doors, windows, the garage or the gate,
- to save energy and time,
- for infrared or camera surveillance,
- as a burglar alarm,
- to start up the garden watering system, air-conditioning, heating, or fill the swimming pool, etc.

All this can be done simply with vocal or macro commands, or by telephoning instructions to the assistant.

The general manager or the production manager can use Archibald for the following tasks:
- control production processes,
- surveillance of offices and workshops,
- timing procedures,
- checking,
- control temperature, air-conditioning, shutters.

THE COMPANY
INTELLART S.A. is offering two products based on more than 20 years of R&D in artificial intelligence.
The silicon tracker is a key element of the ATLAS detector at the LHC. The system is designed to operate with a 40 MHz bunch crossing frequency in a high particle flux density and hard radiation environment. The inner tracker measures the paths of electrically charged particles. Its innermost sensors are semiconductor devices providing position accuracy of 0.01mm.

APPLICATIONS
An R&D development project started in 2002 for:
- Digital X-ray camera Original Equipment Manufacturer (OEM) market,
- Computer Tomography (CT).

The novel ideas of INTERON allow low-cost, high-reliability, high-speed, true-colour / higher-quality imaging, and less patient radiation exposure.

THE COMPANY
INTERON AS is a Norwegian technology company working with new technologies for X-ray imaging. It was incorporated in 2002 and has currently eight employees and affiliates. Its base of operation is in Asker, in the outskirts of Oslo. Soon after the incorporation, a close cooperation with CERN was established. This collaboration has been formalized through a partnership agreement and a commercial licence agreement. About half of the staff of INTERON works currently on the CERN site. INTERON has two pending patents on ‘Color X-ray’ camera-on-a-chip technology. The long-term vision of INTERON is to prove the principles of these patent-applied ideas, and to offer products where the electronic component is intended to be sold as part of a complete system to one or more of the global leading CT manufacturers. While the R&D is ongoing INTERON is developing and supplying somewhat less ambitious electronics to a few key partners and customers in the X-ray imaging market.

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In cooperation with the ATLAS collaboration the ISEG company developed a high-voltage multi-channel system for use in the liquid argon calorimeter. The excellence of the system is:

- Highest density per channel, in total ca 4000 ch, 2.5 kV;
- Excellent electrical specification matching all requirements of the detector;
- System SW implemented into the slow control of LHC experiments.

In addition to the ATLAS requirements, ISEG developed HV PS for ALICE, CMS, LHCb and COMPASS.

**APPLICATIONS**

As a result of this co-operation, the Company continues to provide HV needed not only for applications in particle physics and many more fields in physics but also in applications for industry, e.g. testing, analysing, X-ray, medical, optical etc.

**THE COMPANY**

The ISEG Spezialelektronik GmbH Company specializes in the development and production of high-voltage power supplies for industry and research. This is based on 20 years of experience in the development and use of technologies of modern high-voltage generation. Through the development of a new generation of high-voltage power supplies in modern, patented resonance mode technique, it is possible to offer customers very efficient HV units with small dimensions and excellent electrical parameters. This new generation besides using modern circuit techniques is also directed to modern component and manufacturing technologies, in order to arrive at cost-effective production and high quality. All units are available as standard version or optionally with digital interfaces allowing integration into computer-based systems.

**Products**

- High-voltage power supply SHQ xxx up to 6 kV
- MMC - Modular multichannel high-power HV system
- High-voltage multichannel system for CERN ATLAS

**Contact Information**

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Since 2000 ISQ and CERN have developed a complete set of quality inspection methodologies and quality assurance processes to be applied in the equipment construction of large scientific facilities at CERN and manufacturing of LHC superconducting cables, magnets, cryogenic components and cryostats. These methodologies have been used in a multiplicity of services provided by more than 20 ISQ engineers working for the needs of the LHC in nine different countries and many others. These services are aiming to improve the quality and safety in the operation of this equipment and components, leading to optimized construction costs and accomplishment with technical specifications.

APPLICATIONS
The benchmarking and adaptation of quality and safety inspections methodologies and procedures for the LHC equipment, resulted in the acquisition of a very special know-how and specific expertise in the areas of quality and safety of cryogenics. This has allowed the application by ISQ of the know-how acquired working with CERN in the ALMA project, being developed by ESO (European Southern Observatory) in Germany, and the GTM (Grande Telescope Milimetro) at the Guyana Space Centre of ESA.

THE COMPANY
ISQ is a non-profit and independent organization founded in 1965, providing services on construction, supervision and inspection, maintenance inspection, testing, non-destructive testing, metrology, etc. With around 800 employees worldwide, ISQ operates in more than 20 countries.

ISQ – Instituto de Soldadura e Qualidade
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LINCOLN ELECTRIC started cooperation with CERN, CTE and Servorobot in 1998 for a welding press system able to weld an open and variable gap for the production of dipole magnets for the LHC. Several challenging problems were faced during the selection of the technology because of the need to weld continuosly the 16 metres of the magnet, with the required high-quality and mechanical characteristics. STT technology was selected as the welding power source, because of its capability to cope with the stringent requirements and was interfaced to an automatic laser tracking system. There are now three welding presses: Italy (Ansaldo Genova), France (Alstom Belfort), and Germany (Noell Zeitz).

APPLICATIONS
Surface tension transfer technology in conjunction with a laser tracking system can be applied to other industries. Tests and evaluations are in an advanced stage in the food and automotive industry.

THE COMPANY
LINCOLN ELECTRIC's commitment to provide the most innovative, cost-effective, quality welding and cutting solutions has guided the Company since its foundation in 1895. In the company’s centennial year, a new, state-of-the-art motor facility opened in celebration of the John C. Lincoln Appreciation Day, achieving for 1995 one billion dollar in sales.

Dipole magnet for the LHC with a welding press
Surface tension transfer, behaviour

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For more than 40 years LINDE has provided cryogenic equipment and services to CERN. The maximum performance and complexity has been reached with the design and construction of the large helium refrigeration plants for the LHC project. Parts of the system are cold boxes housing a four-stage cold compression system providing cooling at a temperature of 1.8 kelvin. For the realization of this project LINDE Kryotechnik and the partner company were honoured by CERN with the Golden Hadron Award.

APPLICATIONS

The longstanding interactions between LINDE and CERN experts resulted in fruitful two-way knowledge transfer which started with the first cryogenic projects at CERN back in the late 1960s. LINDE designs and builds cryogenic systems for a wide range of applications covering basic research and industry, cooling superconductors and cold neutron sources, fusion and fission applications, liquefaction of helium and hydrogen.

THE COMPANY

LINDE Kryotechnik AG is the world's leading manufacturer of cryogenic equipment. Its core business consists in the planning, design and construction of helium and hydrogen liquefiers as well as refrigerators. At LINDE engineering centre in Pfungen, near Winterthur and Zurich, experienced and dedicated engineers, technicians and specialists are engaged in making high-tech equipment. LINDE Kryotechnik AG is a subsidiary of LINDE AG, Wiesbaden, Germany.
The current gas-cooled resistive current leads were designed and built according to CERN specifications and following new design principles for cryogenics magnet applications.

The illustrated leads are for 600 A, the insertion length is 1.4 m, design pressure 20 bar and high voltage requirement 1 kV in a helium environment. As shown in the figures, the current leads and the warm terminals are seen ready to accept the external connection. The cooling gas outlet connection faces away. Cable connections seen at the top are for instrumentation.

APPLICATIONS
In close collaboration with CERN, MARK & WEDELL has designed, engineered and built a new type of current lead design with special focus on solving operational drawbacks known from conventional designs and optimization with respect to heat in leaks. The resulting concepts can and have been advantageously applied also to HTS current leads. Given the opportunity to build relatively large series of such current leads, the manufacturing process was also optimized ending with very competitive solutions from a technical as well as a financial point of view. To date, current leads for 600 A and 15 kA have been built for CERN and are a new product for the market. Current leads for 60 kA are close to completion for other institutes in high-energy physics.

THE COMPANY
The basic idea of MARK & WEDELL AS is to generate and realize novel technical solutions. Its main fields cover special machinery for industrial applications and measurement and sampling equipment for mainly coal-fired power plants.

The Company offers services in design, prototyping, test, engineering, manufacturing and field test and can be the partner in all phases of projects, being part of the realization phase.
The calibration of SPS magnets required a high-precision teslameter. The instrument developed by METROLAB PT2025 was the result of the interactions of the Company with CERN. It utilizes the Nuclear Magnetic Resonance (NMR) of protons or deuterons in a magnetic field and it achieves 5 ppm absolute accuracy and 0.1 µT (1 mG) resolution for measurement or mapping of uniform magnetic fields in the range 0.043 T (430 G) to 13.7 T (137 kG). Optional probe multiplexers enable readout of up to 64 probes. The instrument is reliable and easy to use. This has established the PT2025 as the instrument of choice for MRI and spectrometer magnet mapping, precision field control, and magnetic sensor calibration.

**APPLICATIONS**

The developed teslameter is widely used by:
- Laboratories,
- MRI manufacturers,
- Electromagnet and permanent component and system manufacturers,
- Environmental standards and safety laboratories and departments.

**THE COMPANY**

METROLAB Instruments S.A. was founded in 1985 to commercialize NMR magnetic field measurement technology developed at CERN. METROLAB has continued to add innovative products and is now the world's leading manufacturer of very high-precision instrumentation for magnetic field measurement and control.

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The required precision for the LHC beam positioning and the solutions to this problem need a high level of creativity in the design of the calibration support systems. METRON DESIGNS has supplied products designed to a specification and was able to design an improved commercial version resulting from close cooperation and pioneering work with CERN. The most significant product was the I-REF2 CERN, a current calibration standard. This provides a precision 10 mA reference source which is used in three configurations to maintain the magnet current to an accuracy of around 1 part in a million and nothing like it was available commercially.

The CERN 22-bit Delta-Sigma analog to digital converter is a key component for the dynamic maintenance of magnet currents and was designed by CERN. METRON DESIGNS was asked to help in its evaluation (along with Signal Conversions Ltd.) and to help with the implementation of some improvements.

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METSO Powdermet is supplying end-covers manufactured from powder metallurgy for the LHC dipole magnets. The strict requirements such as the high toughness and high tensile strength near absolute zero temperature (4 K), the fully dense, porosity-free material preventing the leakage of liquid helium, and the extremely tight dimensional tolerances of the components, led to the use of hot isostatically pressed powder (stainless steel AISI 316LN). The realized fine, homogeneous microstructure ensures ultimate mechanical properties throughout the whole component. The use of 100% dense material without any welds minimizes the need for non-destructive testing and the near net shape manufacturing minimizes the need for machining.

The Company also supplies machinery and systems and provides after sales services.

APPLICATIONS
New swivels for the offshore oil industry. Thanks to the unique design and the CERN acquired know-how, it was possible to overcome the very complicated internal passages needed to pump oil, gas and water in swivels.

THE COMPANY
METSO Corporation, founded in 1999, is a global supplier of process industry machinery and systems, as well as know-how and after sales services. The Corporation’s core businesses are fibre and paper technology, rock and minerals processing, and automation and control technology. METSO’s business areas are METSO Paper, METSO Minerals, METSO Automation, and METSO Ventures which is comprised of:
- METSO Panelboard - production lines, equipment and services for the panelboard industry,
- METSO Drives - mechanical power transmission systems for the process and energy industries,
- Foundries,
- Valmet Automotive - contract manufacturing of specialty cars,
- METSO Powdermet - material technology expert services.
Over three hundred stepping motors and two hundred resolvers are used for beam instrumentation purposes in the SPS and LEP rings and transfer channels. Most of these instruments are beam intercepting and therefore require very reliable drive electronics. The coincidence of the upgrading of the SPS controls in 1993 and of the energy upgrade of LEP (LEP 2 project) was the ideal opportunity to standardize the motor control systems for both accelerators and to acquire an industrial system which would fulfil the requirements for the two machines in the most economical way. The system had to interface to two different environments, be compatible with the existing application software, and deal with two different ways of operating the motors. It proved to be extremely reliable.

APPLICATIONS
The control system consisting of step-to-step motors with stringent electro magnetic interference requirements for the motor controllers and the system interface for both applications with a reading system of synchro-resolver able to function at a distance up to 1000 m have been used whenever else such types of performance were required. The know-how acquired is today integrated in components made available by the firm to other customers.

THE COMPANY
Founded in 1985, MIDI INGENIERIE is a company mainly composed of consulting engineers, which provides consulting services and undertakes research and development studies in the field of electronics. Today, MIDI INGENIERIE is an European leader in stepper motor electronic drives and controls. The Company designs and markets a complete range of standard products: from low-cost to highly sophisticated drivers, controllers, motors and feedback encoders and supplies a wide spectrum of applications: space industry, medical, nuclear and physics experiments, silicon processing. It also proposes to develop and supply a ‘turnkey’ system that integrates all the necessary electronic cards, motors, information technology and associated mechanical functions.
Since 1984 several new technologies have been developed by the Company, thanks to the experience that the founders’ team has gained at CERN and subsequent contracts with CERN. The Company has recently become specialized in projects with small accelerators for water purification, process control, and artificial intelligence applications as well as nanotechnologies.

APPLICATIONS
Small communities like villages in Europe and Africa can be autonomous for energy, where cost and energy saving is important.

THE COMPANY
NEWTECH S.A. is a project-oriented company and is offering products based on renewable and cost saving energy. The products offered, in addition to equipment to clean water using a small electron accelerator, are hydraulic turbines style Kaplan 30 kW, water hills 30-50 kW and combined solar / hydraulic greenhouses.

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Since the 1970s O.C.E.M. has been providing and developing with and for CERN power converters to fulfil CERN-specific needs for conventional and superconducting magnets, high-voltage modulators and state crowbars up to 150,000 V – 30,000 A 1ppm and is established in a technical partnership relation to satisfy CERN demands. Most of the CERN machines including the Antiproton decelerator are using O.C.E.M. power converters. Existing installations such as the PFW power converters of the PS complex and LEP converters have been re-adapted to fulfil LHC machine requirements and O.C.E.M. is working in close contact with CERN experts in these operations.

APPLICATIONS

The know-how acquired and the need to satisfy CERN’s sophisticated high-precision requirements in the power supplies field, as defined for LEP, permitted the firm to expand their offer to the airport sector. Furthermore, both the LEP and LHC main supplies have resulted in new products being put on the market worldwide such as dipole power supplies, capacitor charging power supplies and dipole and quadrupole diode stacks.

THE COMPANY

Since the birth of the Company in the mid 1940s, O.C.E.M. S.p.A. has focused on the research, development and production of electronics for industrial and laboratory research applications. O.C.E.M.’s headquarters and manufacturing facilities are located in S. Giorgio di Piano, a small town near Bologna, Italy. O.C.E.M.’s competence in research and development and in the production area is quite diversified and it covers the following areas:

- Power supplies for universities and laboratories involved in plasma and particle physics,
- AC constant current power supplies for airfield and street series lighting systems,
- Automated aerodrome traffic control and monitoring systems for safe and efficient movement of aircraft and vehicular traffic on the ground,
- Airfield lighting systems for night and low visibility guidance of aircraft to, from and within airfields.

O.C.E.M. is on the market today with a group of four Companies Augier (F), OCEM S.p.A. and Sadel s.r.l. (I) and MultiElectric (US).
Superconducting cable consists of multifilamentary strands of niobium-titanium alloy and copper. This cable, made to a highly demanding technical specification, is a critical component of the dipole and quadrupole magnets that generate the necessary magnetic fields for the LHC.

With the experience gained by OUTOKUMPU in the development and production of superconducting products for CERN, the company is well prepared to take up the next big challenge of manufacturing conductors for ITER in Japan.

APPLICATIONS
Superconductors produced by OUTOKUMPU are used in the HEP arena for particle accelerator magnets and detectors. These products are widely employed in MRI for medical diagnostics, NMR for material analysis, magnet systems to grow large silicon crystals for the computer chip industry, superconducting magnetic energy storage devices and many specialty magnet systems.

THE COMPANY
OUTOKUMPU Poricopper Oy is one of the leading metals and technology companies specializing in stainless steel and copper. With its extensive knowledge, innovations and experience in metals processing, OUTOKUMPU supplies globally a broad range of high-value added products.

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Semiconductor pixel technology for various kinds of imaging applications is derived from developments for particle physics experiments. In trackers made of pixel detector layers, the position and time of particles are recorded when they pass through. This enables single events to be selected and particle tracks to be reconstructed. Medipix2 is a single-photon-counting pixel detector readout chip. This technology represents the first of a new generation of energy-sensitive photon counting systems allowing the counting of single photons. The information, which is contained in the energy of the incoming photons, is used to reject noise from detector leakage current or background light and to count only those photons which deposit energy within a given energy window. The resulting images are practically noise free. In addition, the fact that linear response is obtained up to a million photons per second per pixel makes it possible to use it also in applications where a large amount of photons is present.

**APPLICATIONS**

X-ray diffraction and fluorescence spectroscopy equipment used in the materials industry.

**THE COMPANY**

PANALYTICAL is the world’s leading supplier of analytical instrumentation and software for X-ray diffraction (XRD) and X-ray fluorescence spectrometry (XRF), with more than half a century of experience. The materials characterization equipment is used for scientific research and development, for industrial process control applications, and for semiconductor metrology. PANALYTICAL, formerly Philips Analytical, employs around 750 people worldwide. Its headquarters are in Almelo, the Netherlands.
A CERN / PPARC project offers the opportunity to develop a new generation of optimized scintillators for large physics experiments, as well as for medical imaging devices, an important spin-off of high-energy physics developments. The project consists of evaluating and characterizing samples of rare earth silicate materials produced by the Scottish company PML to assess the possible optimization of their performance and industrial production of crystals for different applications. The main purpose being to understand what defects or phenomena impair the light output and energy resolution, and determine what should be modified in order to improve energy resolution and light output.

APPLICATIONS
The developments and improvement on rare earth silicate materials are essential for medical imaging devices like PET.

THE COMPANY
PHOTONIC MATERIALS develops and manufactures single crystal components for a range of applications in medical imaging and optoelectronics. Founded in 1999, PHOTONIC MATERIALS is based near Glasgow in Scotland. PHOTONIC MATERIALS’ mission is to develop crystal components for emerging high-volume technology applications and supply them reliably and cost-effectively to customers around the world. PHOTONIC MATERIALS is ISO: 9001-2000 and Investors in People certification.

Matrices of 64 LYSO and 64 LuYAP crystals each scintillating under UV light exposure
One PET detector-head made of 64 LYSO and 64 LuYAP pixels glued on 64-channel photomultiplier
LYSO boules – property of PML

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The LHC has the particularity of having not one, but three vacuum systems: insulation vacuum for the magnets, insulation vacuum for the helium distribution line (QRL), and beam vacuum. The requirements for the beam vacuum are stringent so that an adequate beam lifetime can be ensured in a cryogenic system, where heat input to the 1.9 K helium circuit must be minimized and where significant quantities of gas can be condensed on the vacuum chamber. A sensitive leak testing device of helium header welds has been developed based on hood methods and the device and its concept have been patented. PXL INDUSTRIES has contributed to making such a device available in the market with some practical adjustments.

APPLICATIONS
The device, a single-unit sealing system adaptable to different diameters, can be installed and used by a single operator. It can be easily and quickly installed also in areas with restricted access and has found applications outside high-energy physics in the cryogenic industry.

THE COMPANY
PXL INDUSTRIES is a mechanics oriented Company manufacturing and distributing rubber seal gaskets, bellows for applications in different sectors such as the hydroelectric, off-shore, steel, automotive and paper industries.
The ClearPET™ small-animal PET system is a project of the Crystal Clear Collaboration, an interdisciplinary network of 11 Institutes including CERN and 92 world experts in different aspects of material science, in which the German company RAYTEST is the commercial partner. The ClearPET™ applies the non-invasive PET (Positron Emission Tomography) technique to in-vivo imaging of small animals. Recently developed small-animal PET systems have a high spatial resolution of about 2 mm. The ClearPET™ system is a 2nd generation high performance PET scanner which for the first time combines high resolution and high sensitivity by using new technologies in crystals and electronics.

APPLICATIONS
Small-animal PET for rodents and small primates for in-vivo whole body investigations under physiological conditions. This includes:
- Functional and diagnostic studies,
- Study of new tracers,
- Study of new drugs for therapy application and in brain and cancer research for testing treatments and new drugs.

THE COMPANY
RAYTEST GmbH has 40 years of experience in design and development of new scientific instrumentation. Therefore RAYTEST uses every opportunity to talk to researchers in science and industry. The life time of experience and ongoing improvement of RAYTEST technology enables the Company to make the finest instruments which produce the best results. Therefore RAYTEST can find the best solutions for scientific instrumentation of radio-chromatography and bio-imaging. On 16 June 1998, RAYTEST achieved the ISO 9001 certification. With ISO 9001 certification, RAYTEST has established a definitive quality process that ensures reliability and consistency from the initial idea phase to the release of innovative new products, furthering the company’s position within the international scientific community.

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CERN collaboration with SAES Getters began in the late 1970s, at the time of the design of the vacuum system of LEP, when a Non-Evaporable Getter (NEG) strip based on the SAES Getters St101 getter alloy was selected as the main pumping system of the storage ring. As a result, a total of about 23 km of such a strip was supplied by SAES Getters to CERN. Later, during the 1990s, merging together expertise and knowledge on NEG and sputtering, the latter matured in the frame of the development and production of the niobium coated RF cavities for LEP2, CERN developed and patented the thin film NEG coating which delivers both in situ gas pumping and reduced outgassing in a vacuum chamber. This was a breakthrough in the pumping technology for particle accelerators. During 2000, SAES Getters signed a licence agreement with CERN for the transfer of this technology, which is now marketed by SAES Getters under the trade name of ‘IntegraTorr’.

APPLICATIONS
IntegraTorr represents a revolutionary way to integrate non-evaporable getter pumping into a particle accelerator vacuum chamber and finds applications in:

- Particles accelerators,
- Heavy ion rings,
- Synchrotron radiation facilities,
- Insertion devices,
- Beam lines.

Several NEG coated chambers have so far been delivered by SAES Getters and installed in a variety of machines in Europe, the US and Asia. This technology nicely complements the more traditional SAES Getters NEG pumps product line, thus allowing SAES Getters to offer a complete portfolio of getter solutions for particle accelerators and high-energy applications.

THE COMPANY
Pioneering the development of getter technology with the invention of a technique for producing stable getter alloys in 1950, the SAES Getters Group is today the world leader in a variety of scientific and industrial applications where stringent vacuum conditions or ultra high pure gases are required. Starting in 2004, by leveraging the core competencies in special metallurgy and material science, the SAES Getters Group is expanding its business in the advanced material niche markets, with the introduction of the optical crystal product line, shape memory alloys, and the metalorganic material product line. An outstanding R&D structure, based at the Group’s headquarters in Milan, Italy, a total production capacity distributed at 8 manufacturing plants spanning across 3 continents, a worldwide-based sales and service network, and nearly 1000 employees allow the Group to combine multicultural skills and expertise to form a truly global enterprise.
The first example of the collaboration between SIGMAPHI and CERN is in the domain of superconducting magnets. The Company manufactured 30 MCBX superconducting correctors able to produce a dipolar field of 3 T in two directions. The second is the realization of 30-tonne coils using 50 X 50 mm conductors for ALICE and LHCb detectors which allowed the Company to improve the manufacturing tools and procedures.

APPLICATIONS
Thanks to the knowledge acquired from CERN, the Company was able to set up an R&D programme with Saclay (France) to further develop specific aspects of superconductivity. The acquired knowledge with conductors allowed the company to realize large-size coils for the TRIUMF laboratory (Canada).

THE COMPANY
SIGMAPHI has been specialized for more than 20 years in the design and manufacture of resistive and today superconducting magnets for particle accelerators. The Company team of 50 experts covers the range from the design outline performance and assessment specifications to magnetic measurements. 80% of company sales are exported to Europe, North America and Japan.
Examples of transfer

Various components for the LHC machine and experiments, such as vacuum vessels, QRL piping, ATLAS and cup cryostat, CMS test cryostat, QRL service and return modules, cold boxes, valve boxes, bottom trays, have been provided by SIMIC which acquired and broadened its competencies as scientific plant manufacturer and producer of gas liquefiers and cryostats, among others, designed to test equipment for electrical energy transmission.

In July 2004 SIMIC received the golden hadron award which is given by CERN to companies, not only for their technical and financial achievements but also for their compliance with contractual deadlines. The award was for manufacturing the 937 vacuum vessel cryostat components of the superconducting dipole magnets.

APPLICATIONS

In the field of structural non-destructive testing, SIMIC attained a deep knowledge in vacuum tests, helium leak tests, cryogenic tests. The Company has manufactured, designed and manufactured, or is manufacturing equipment, vessels or plants listed below:

- Oil remover system installed in the RAS LAFAN factory (Qatar) for the production of liquid helium,
- Valve boxes for the Soleil plant in Qatar,
- Cold boxes for KHNP in Korea,
- Cryostat for testing - in Liquid N$_2$ and Liquid Ne - prototypes of fault current limiters for CESI in Italy,
- Cryostat & assemblies for radio frequency for VECC in Kolkata.

THE COMPANY

SIMIC S.p.A. is a recognized leader in the design, realization and installation of large industrial and naval plants. The Company manufactures industrial equipment, turbines, heating facilities, cryogenic vessels, and pipes. The Company’s valuable assets reside in the mechanical engineering expertise and capability of the factory as well as in the delivery of turn-key plants.
The reliability of the LHC will depend not only on the superconducting magnets but also on the interconnections between magnetic sections. The expansion bellows, composed of very thin corrugated shells, have been pushed to operate beyond the elastic limit, where plastic deformation occurs. Thus, for the first time in the history of accelerators, interconnection bellows ‘plastify’. This process is associated with the evolution of plastic strain fields in the ‘concertina’ of the bellows convolutions, which is accompanied by micro-damage and, at low temperatures, a strain-induced phase transformation (from a face-centred-cubic to a body-centred-cubic material structure).

To minimize the intensity of this phase transformation, the bellows convolutions are made from a special flexible austenitic stainless steel. The SKODOCK bellows, on account of their characteristics, also fulfil the required sealing functions.

APPLICATIONS
Flexible austenitic stainless steel bellows, expansion joints and hoses are in use in nearly all fields of modern industry, such as vacuum high-voltage switches, valves, bellow couplings, heavy-duty presses, calenders and gas pipelines in the Arabian Desert, inside the Ariane missile, the Helios satellite or in a number of nuclear power stations, as well as LHC at CERN, in the measurement device of space gravitation waves (the largest ever built flexible metal hose in the world), in ocean tankers and oil drilling platforms, heavy duty diesel-engines, in industrial heating systems or at steel mills.

THE COMPANY
In 1929, an Engineer, Mr Hans SKODOCK from Hanover, patented a technology to manufacture parallel-corrugated pipes. Today SKODOCK GmbH with approximately 100 dedicated employees belongs to the Hansa-Flex-Group. SKODOCK is a worldwide-approved specialist for tailor-made solutions. SKODOCK specialists develop, manufacture and sell metal hoses, bellows and compensators (expansion joints) in sizes from 6 mm diameter up to 2400 mm diameter. SKODOCK is certified according to DIN EN ISO 9001:2000, homologated and validated by a large number of audit organizations and certification bodies in all relevant industrial branches. SKODOCK designs and manufactures according to the European Pressure Vessel Guideline 97/23/EG and are authorized by the TÜV to carry out tests.
SOURIAU developed for CERN a circular connector according to special CERN specifications, resistant against radiation with Ryton PPSR-4 and with special silkscreen marking. It belongs to the family of the Trim Trio connectors, but using size 16 contacts (1.6 mm). The product ranges have developed to various sub series and different design-variations. In parallel with the size 16 contacts, there has also been an evolution on high density versions using size 20 contacts (1.0 mm) and on mixed signal / power versions. All circular Trim Trio connectors are intermateable, interchangeable and intermountable. The Trim Trio interconnection system is a fully integrated system, in which 4 contact types can be used in a variety of connector styles and sizes from 4 pin up to 75 pin with a current rating: max. 13 A / contact for industrial applications.

APPLICATIONS
The physical characteristics and performances of the Ryton PPSR-4 radiation-resistant connector are appreciated in applications such as:
- Medical instrumentation at PSI in Switzerland,
- Nuclear Research Centres.
It has become a worldwide known standard product from the Trim Trio family.

THE COMPANY
In 2003 SOURIAU S.A.S. was launched through a management buyout of FCI, so returning to the roots of the Company established in 1917. The Company unites under the prestigious name of SOURIAU the products and technologies of SOURIAU (Aerospace and industrial connectors), Jupiter (Marine and heavy industry connectors), and Burndy (Industrial Trim Trio range and proprietary aerospace connectors). SOURIAU is focused on the supply of connection technologies for severe environments. The Company has a presence in the world’s major aerospace programmes and is strongly positioned in the railways (France and Switzerland), geophysical, robotics, industrial and instrumentation markets.
The ChemicalVia process, patented by CERN, provides a new method of making microvias in high-density multilayer printed circuit boards of different types. The process uses chemical etching instead of laser, plasma or other etching techniques and can be implemented on a production line. This results in an overall reduced operation and maintenance cost and a much shorter hole production time as compared with other microvia processes. The technology can be used to produce multilayer printed circuit boards (PCBs) with microvias (metallized holes connecting different layers).

TECHTRA, a Polish company based in Wroclaw has implemented the technology in an industrial environment with the financial help of the Lazy Eight Foundation.

APPLICATIONS

Using the chemical via technology, printed circuit boards can be produced with an on-line process. TECHTRA can offer the industrial implementation of the technology in several forms:

- Building of the full Micro-Chemical-Via production line at the client's site,
- Transfer of the know-how with the necessary documentation for the production process,
- Production of microvia printed circuit boards according to the client's specifications including GEM foils.

THE COMPANY

TECHTRA Ltd. was established as a consulting, managing and production group (company) working with high-technology industry and research centres in Poland. Its activities are focused on:

- Silver processing (high-temperature superconductor components manufacturing) department in Chrzanow,
- High-density PCB (microvia) production line, department in Wroclaw,
- Finding the partners for the high-technology companies and R&D Centres in Poland, office in Wroclaw.

Microvia produced at TECHTRA
Magnification 300x
50 mm holes of double cone shape in 50 µm thick polyimide foil (GEM)

Microvia technology demonstrator constructed by TECHTRA
Currently, TESLA is manufacturing over 3000 superconducting magnets of 4 different types for the LHC.

APPLICATIONS

Thanks to the long standing relation with CERN, know-how on magnetic design and precision measurements techniques are today allowing the Company to offer improved products with better characterization of magnetic performances. This is particularly important for the construction of:

- Magnets and gradient coils for clinical applications and research in MRI,
- New accelerators.

The Company is currently manufacturing 254 quadrupole magnets for the British Diamond Light Source using measurement techniques and equipment from CERN.

THE COMPANY

TESLA Engineering Ltd. has been designing and building accelerator elements since 1973 and has supplied electromagnets for most of the major high-energy physics institutes, including Argonne, CERN, DESY, ESRF, Fermilab, and the Max Planck Institutes. TESLA has recently opened a new factory in Lancing, West Sussex. The facility is entirely dedicated to the production of magnets for the LHC and features clean assembly facilities, and cryogenic test equipment. The Company manufactures resistive and superconducting electromagnets for particle accelerators of all types, and produces specialized gradient coils for MRI scanners. TESLA also supplies electromagnets for emerging applications, such as fusion research and the semiconductor. The facilities include state-of-the-art 3D CAD/CAM packages and analysis software, an extensive machine shop, and a modern logistics function. The TESLA group now comprises four companies; TESLA Engineering Ltd, Radway Engineering Ltd, Futura Composites and Everson TESLA Inc. These companies have synergies in magnets, high-vacuum, composites and cryomagnets.
The CERN LHC experiments will have to exploit petabytes of information. The Grid is a very powerful tool tying computing resources distributed around the world into one computing service for all requesting applications. An ongoing transfer is the Network Emulator technology used to evaluate the performance of applications running over Grid. The Network Emulator is a configurable ‘network-in-a-box’ that emulates the end-to-end quality degradation likely to appear in wide-area networks.

A CERN / PPARC project offers the opportunity to carry out such industrial development.

APPLICATIONS

The Network Emulator has a wide range of applications, such as:

- Safety critical systems: to determine conditions when such systems may fail,
- Large scale multi-protocol distributed networks: to emulate networks (Grid, ATLAS data collection system and remote computer farms) to evaluate the performance of applications running over such networks,
- Ad-hoc wireless emergency systems: to determine their reliability and performance characteristics,
- Performance assessment of widely-spread network applications: e.g. Internet telephony (VoIP), file transfer and Web browsing, etc.

THE COMPANY

U4EA Technologies Ltd., founded in 1999 to commercialize a new technology to deliver efficient, reliable and flexible converged packet networks, is privately held and funded by IIU Nominees, ISIS Asset Management, Henderson Technology, Singer & Friedlander and its directors. U4EA has since developed a broad spectrum of interests in the networking industry. Tracking developments in the market, particularly the rapid expansion of broadband access and the increasing interest in converged network technologies such as VoIP, U4EA made a strategic decision in 2002 to focus on licensing its unique QoS technology, called GoS, targeting manufacturers of LAN / WAN edge devices. This led to a major success with Ericsson AB of Sweden, who licensed the technology for their multi-service device. Initially based in Bristol, England, U4EA added sales offices in the US and a test centre in France to take advantage of the depth of networking experience available in the Sophia Antipolis area. Recently, U4EA has opened a second development centre in Fremont, CA.
Cooperation between CERN and VARIAN Vacuum Technologies on joint development on ion pumps dates back to 1967, and the first ion pumps ever manufactured in the VARIAN Turin plant were the 300 ion pumps (400 l/s each) for the ISR project. This was the start of the long story of the ion pumps in Turin, which has become the sole VARIAN centre for development, design, manufacturing and application support of ion pumps worldwide.

The StarCell® ion pump, specifically designed to fulfil the vacuum requirement of the LEP project was developed in Torino, and has been extensively tested by VARIAN and CERN engineers together on the CERN premises (1983). As a result, more than 1,000 StarCell® ion pumps have been built for the LEP project alone.

APPLICATIONS

The StarCell® ion pump has proved to be the most important ion pump development for 30 years and is now the worldwide recognized standard for creating and maintaining ultra high vacuum in several applications, ranging from research to industry, including particle accelerators, synchrotron light sources, electron microscopes, surface analysis and focused ion beams. Electron microscopes and focused ion beams are used to analyse, qualify and repair several kinds of devices used in the semiconductor industry, such as microprocessors used in computers, flat panel display used in TV screens or memory devices. These instruments are widely used for yield enhancement in semiconductor fabrics as well as in process development.

THE COMPANY

Since the 1950s, VARIAN, Inc. has been an integral player in the vacuum technologies space, establishing the company as a pioneer and worldwide supplier of total vacuum solutions that are application-oriented and aimed at specific market requirements. In 1957 VARIAN Associates, Inc. invented the Nobel VacIon pump, the first electronic device to operate without fluids or moving parts and resistant to power failures. In 1967 the new headquarters of VARIAN S.p.A. opened in Turin, Italy. CERN selected VARIAN VacIon pumps for its operation. In 1983 VARIAN Associates’ Vacuum Division developed the StarCell® ion pump and established Turin as the centre for ion pump research and development. In 2002 VARIAN, Inc. expanded its vacuum campus in Turin to add more space for research and development capabilities.
The Radio Frequency (RF) all-metal gate valve uses an RF-bridge to close the gap in the open position of the valve. This provides a low RF resistance, as in accelerators and storage rings. The RF aperture often has a customer-specific geometry. The static seals and the seal of an ‘all-metal valve’ are both made of metal. They are hence used in extreme UHV applications.

In the early 1970s VAT started the development of all-metal gate valves for UHV applications. CERN was the first customer for this type of vacuum valve and the collaboration with CERN was an important contribution to this successful development. These valves were first used in the SPS machine at CERN and the development is the result of a good and fruitful collaboration.

APPLICATIONS

The all-metal gate valves are applied in high-energy physics, accelerators, storage rings, synchrotrons, laser technology and surface analysis. VAT has developed and permanently continued to advance the technology of all-metal vacuum valves and has become the worldwide leader over the years. The valves use the VATRING all-metal sealing configuration where the conically arranged seal ring allows for large sealing forces with relatively small closing or axial forces. The sealing parts are stainless steel and only elastically deformed. In the meantime, accelerators in all of the high-energy physics laboratories in the world have been equipped with these valves.

THE COMPANY

Since its foundation in 1964 in Switzerland by Mr. Siegfried Schertler, VAT Vakuumventile AG has completely specialized in vacuum valve technology. Maintaining this strong focus has allowed VAT to develop and maintain a market leading position. VAT offers today more than 1000 standard valves and develops in collaboration with customers tailored vacuum valves. The Company is committed to remaining the world’s number one choice for vacuum valves and the leader in vacuum sealing technology well into the 21st century. The headquarters is nestled among the mountains of eastern Switzerland, VAT is truly global — with subsidiaries in the United States, Japan, Germany, France and Great Britain and representatives in many other countries. All manufacturing operations remain in the ISO 9001 certified facility in Switzerland.
The Quench Protection System (QPS) is a key element to ensure the integrity of the superconducting equipment of the LHC machine. Quench relief valves have to protect the installation against quenches by opening in less than 80 milliseconds. In case the second quench relief valve does not open, a set of warm safety relief valves would discharge to atmosphere protecting the low-pressure recovery of the refrigerator. These valves play an important role also during cooldown and warm-up of the magnets.

APPLICATIONS
VELAN supplied more than 2000 cryogenic valves to control liquid helium in the superconductor magnets cooling systems. VELAN supplied nearly 500 safety relief cryogenic valves, called quench valves, used to protect the whole installation. To meet the severe performance inherent to the LHC requirements, VELAN initiated cooperation with the Laboratory for Low Temperatures (SBT) of CEA at Grenoble to finalize the valves’ design. It resulted in the Safety Relief Valve (quench valve) that is unique in the world. This reference acts as the showcase VELAN needed to open up and to compete on high technology projects presently in preparation in India, Korea, Japan and China.

THE COMPANY
Located in Lyon, France, in a modern 15,000 m² plant, VELAN S.A.S., the French subsidiary of VELAN Inc group, is organized around the departments: Cryogenic Valves & Marine, Valves for Energy, ADAREG™ Control Valves, and Maintenance & Services. VELAN Inc. is one of the world’s leading independent manufacturers of steel gate, globe, check, butterfly and ball valves. Founded in 1949 in Montreal, Canada by Czech-born Mr. A.K. VELAN, VELAN Inc. employs over 1500 people worldwide with 13 specialized manufacturing plants in Canada, the USA, France, Portugal, Germany, the UK, South Korea, Taiwan.
CERN’s Technology Transfer bears fruit
## List of acronyms and SI units

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AD</td>
<td>Antiproton Decelerator</td>
</tr>
<tr>
<td>AISI</td>
<td>American Iron and Steel Institute</td>
</tr>
<tr>
<td>ALICE</td>
<td>A Large Ion Collider Experiment at CERN</td>
</tr>
<tr>
<td>ALMA</td>
<td>Atacama Large Millimeter Array</td>
</tr>
<tr>
<td>AMS</td>
<td>Alpha Magnetic Spectrometer</td>
</tr>
<tr>
<td>ATG</td>
<td>Art Technology Group</td>
</tr>
<tr>
<td>ATLAS</td>
<td>A Toroidal LHC ApparatuS</td>
</tr>
<tr>
<td>ATLAS TRT</td>
<td>A Toroidal LHC ApparatuS Transition Radiation Tracker</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CAE</td>
<td>Computer Aided Engineering</td>
</tr>
<tr>
<td>CAM</td>
<td>Computer Aided Manufacturing</td>
</tr>
<tr>
<td>CaRDIS</td>
<td>Cardiological Real-time low-Dose Imaging System</td>
</tr>
<tr>
<td>CATCH</td>
<td>COMPASS Accumulate Transfer and Control Hardware</td>
</tr>
<tr>
<td>CATV</td>
<td>Community Antenna TV</td>
</tr>
<tr>
<td>CCC</td>
<td>Crystal Clear Collaboration</td>
</tr>
<tr>
<td>CD</td>
<td>Compact Disc</td>
</tr>
<tr>
<td>CDS</td>
<td>CERN Document Server</td>
</tr>
<tr>
<td>CEA</td>
<td>Commissariat à l’Energie Atomique</td>
</tr>
<tr>
<td>C&amp;IT</td>
<td>Communication and Information Technologies</td>
</tr>
<tr>
<td>CESI</td>
<td>Centro Elettrotecnico Sperimentale Italiano</td>
</tr>
<tr>
<td>CIMA</td>
<td>Compton Imaging for Medical Applications</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary Metal Oxide Semiconductor</td>
</tr>
<tr>
<td>CMS</td>
<td>Compact Muon Solenoid</td>
</tr>
<tr>
<td>CNAO</td>
<td>Centro Nazionale di Adroterapia Oncologica</td>
</tr>
<tr>
<td>CNC</td>
<td>Computer Numerical Control</td>
</tr>
<tr>
<td>COMPASS</td>
<td>COmmon Muon Proton Apparatus for Structure and Spectroscopy</td>
</tr>
<tr>
<td>COSY</td>
<td>COole SYnchrotron</td>
</tr>
<tr>
<td>CPS</td>
<td>Continuous Power Supply</td>
</tr>
<tr>
<td>CPPS</td>
<td>Central Payload Power Supply</td>
</tr>
<tr>
<td>CRISTAL</td>
<td>Cooperative Repositories &amp; Information System for Tracking Assembly Lifecycle</td>
</tr>
<tr>
<td>CT</td>
<td>Computer Tomography</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
</tbody>
</table>
DELPHI
DEtector with Lepton, Photon and Hadron Identification

DESY
Deutsches Elektronen-SYnchrotron

DIN
Deutsches Institut für Normung

DMS
Document Management System

EBW
Electro-Beam Welding

ECAL
Electromagnetic CALorimeter

EG
Europäischen Gemeinschaften

EGEE
Enabling Grids for E-sciencE

EHS
European Home System

EMI
Electro-Magnetic Interference

EN
Europa Norm

ENLIGHT
European Network for LiGht Hadron Therapy

ESA
European Space Agency

ESO
European Southern Observatory

ESR
Electron Spin Resonance

ESRF
European Synchrotron Radiation Facility

FED
Front-end Driver

FRL
Front-end Readout Link

GEM
Gas Electron Multiplier

GoS
Guarantee of Service

GSI
Gesellschaft für Schwerionenforschung

GTM
Grande Telescope Milimetro

HEP
High-Energy Physics

HMI
Human Machine Interface

HPD
Hybrid Photo-Detector or Hybrid Photo-Diodes

HTS
High Temperature Superconductor

HV
High Voltage

IEC
International Electrotechnical Commission

ILL
Institut Laue-Langevin

IMD
International Institute for Management Development

InDiCo
Integrated Digital Conference

INFN
Istituto Nazionale di Fisica Nucleare

INTEGRAL / JEM-X
INTERnational Gamma-Ray Astrophysics Laboratory / Joint European Monitor X-Ray

IPP
Institut für Plasmaphysik

IS
Instruction de Sécurité

ISO
International Organization for Standardization

ISOLDE
Isotope Separation On-Line

ITER
International Thermonuclear Experimental Reactor

ISR
Intersecting Storage Rings

KHNP
Korean Hydro-Nuclear Power

LAN / WAN
Local Area Network / Wide Area Network

LAPP
Laboratoire d'Annecy-le-Vieux de Physique des Particules
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEAR</td>
<td>Low Energy Antiproton Ring</td>
</tr>
<tr>
<td>LEP</td>
<td>Large Electron Positron collider</td>
</tr>
<tr>
<td>LHC</td>
<td>Large Hadron Collider</td>
</tr>
<tr>
<td>LHCb</td>
<td>Large Hadron Collider beauty</td>
</tr>
<tr>
<td>LIBO</td>
<td>LInac BOoster</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
</tr>
<tr>
<td>LSB</td>
<td>Laboratori del Sincrotró de Barcelona</td>
</tr>
<tr>
<td>LVDS</td>
<td>Low-Voltage Differential Signal</td>
</tr>
<tr>
<td>MCBX</td>
<td>Multipole Corrector in the Inner Triplet</td>
</tr>
<tr>
<td>MCD</td>
<td>Multipole Corrector Decapole</td>
</tr>
<tr>
<td>MCS</td>
<td>Multipole Corrector Sextupole</td>
</tr>
<tr>
<td>MCO</td>
<td>Multipole Corrector Octupole</td>
</tr>
<tr>
<td>MDR</td>
<td>Mini Delta Ribbon</td>
</tr>
<tr>
<td>MFS</td>
<td>Multiple Fibre System</td>
</tr>
<tr>
<td>MINIDISCAP</td>
<td>MINI DIScharge CAPacitor</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>MMC</td>
<td>Modular Multi-Channel</td>
</tr>
<tr>
<td>MT</td>
<td>Mechanically Transferable</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NEG</td>
<td>Non-Evaporable Getter</td>
</tr>
<tr>
<td>NIKHEF</td>
<td>Nationaal Instituut voor Kernfysica en Hoge Energie Fysica</td>
</tr>
<tr>
<td>NMR</td>
<td>Nuclear Magnetic Resonance</td>
</tr>
<tr>
<td>NTD</td>
<td>Non Destructive Testing</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>OSL</td>
<td>Optically Stimulated Luminescence</td>
</tr>
<tr>
<td>OTDR</td>
<td>Optical Time Domain Reflectometer</td>
</tr>
<tr>
<td>PAMELA</td>
<td>a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PCS</td>
<td>Process Control System</td>
</tr>
<tr>
<td>PEM</td>
<td>Positron Emission Mammography</td>
</tr>
<tr>
<td>PET</td>
<td>Positron Emission Tomography</td>
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<tr>
<td>PFW</td>
<td>Power Fail Warning</td>
</tr>
<tr>
<td>PIMMS</td>
<td>Proton Ions Medical Machine Studies</td>
</tr>
<tr>
<td>PPARC</td>
<td>Particle Physics and Astronomy Research Council</td>
</tr>
<tr>
<td>Profibus</td>
<td>Process fieldbus</td>
</tr>
<tr>
<td>PS</td>
<td>Proton Synchrotron</td>
</tr>
<tr>
<td>PSI</td>
<td>Paul Scherrer Institute</td>
</tr>
<tr>
<td>QL</td>
<td>Quadrupole</td>
</tr>
<tr>
<td>QPS</td>
<td>Quench Protection System</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>QRL</td>
<td>Cryogenic Ring Line</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>--------------</td>
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</tr>
<tr>
<td>RF</td>
<td>Radio-Frequency</td>
</tr>
<tr>
<td>RMS</td>
<td>Root Mean Square</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote Telemetry Unit</td>
</tr>
<tr>
<td>SBT</td>
<td>Service des Basses Températures</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
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<tr>
<td>SCC</td>
<td>Safety Certificate Constructors</td>
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<tr>
<td>SI</td>
<td>Système International d’unités</td>
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<tr>
<td>SIL 3</td>
<td>System Integrity Level 3</td>
</tr>
<tr>
<td>SME</td>
<td>Small Medium Enterprise</td>
</tr>
<tr>
<td>SMI</td>
<td>Small Medium Industry</td>
</tr>
<tr>
<td>SPS</td>
<td>Super Proton Synchrotron</td>
</tr>
<tr>
<td>SQS</td>
<td>Swiss association for Quality and management Systems</td>
</tr>
<tr>
<td>STT</td>
<td>Surface Tension Transfer</td>
</tr>
<tr>
<td>SW</td>
<td>Software</td>
</tr>
<tr>
<td>TARC</td>
<td>Transmutation by Adiabatic Resonance Crossing</td>
</tr>
<tr>
<td>TDC</td>
<td>Time to Digital Converter</td>
</tr>
<tr>
<td>TERA</td>
<td>Terapia con Radiazioni Adroniche</td>
</tr>
<tr>
<td>TIA / EIA</td>
<td>Telecommunications Industry Association / Electronic Industries Alliance</td>
</tr>
<tr>
<td>TT</td>
<td>Technology Transfer</td>
</tr>
<tr>
<td>TRIUMF</td>
<td>TRI-University Meson Facility</td>
</tr>
<tr>
<td>TÜV</td>
<td>Technischer Überwachungs-Verein</td>
</tr>
<tr>
<td>UHV</td>
<td>Ultra High Vacuum</td>
</tr>
<tr>
<td>UNICOS</td>
<td>UNified Industrial Control System</td>
</tr>
<tr>
<td>UNI</td>
<td>ente italiano UNIficazione</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterruptible Power Supply</td>
</tr>
<tr>
<td>UV</td>
<td>Ultra Violet</td>
</tr>
<tr>
<td>VCSEL</td>
<td>Vertical Cavity Surface Emitting Laser</td>
</tr>
<tr>
<td>VECC</td>
<td>Variable Energy Cyclotron Center</td>
</tr>
<tr>
<td>VoIP</td>
<td>Voice over Internet Protocol</td>
</tr>
<tr>
<td>VPI</td>
<td>Vacuum Pressure Impregnation</td>
</tr>
<tr>
<td>VTAG</td>
<td>Vertex Small Angle Tagger</td>
</tr>
<tr>
<td>W7-X</td>
<td>Wendelstein 7-X</td>
</tr>
<tr>
<td>WorldFIP</td>
<td>World Fieldbus Internet Protocol</td>
</tr>
<tr>
<td>WWW</td>
<td>World Wide Web</td>
</tr>
<tr>
<td>XRD</td>
<td>X-ray Diffraction</td>
</tr>
<tr>
<td>XRF</td>
<td>X-ray Fluorescence</td>
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</tbody>
</table>
List of acronyms and SI units

- p
- n
- µ
- m
- k
- M
- G
- P
- ppm
- kg
- m
- s
- A
- Hz
- J
- W

1000 grams
1 kilogram
1 tonne

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Symbol</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Pico</td>
<td>p</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>Nano</td>
<td>n</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>Micro</td>
<td>µ</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Milli</td>
<td>m</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Kilo</td>
<td>k</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Mega</td>
<td>M</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Giga</td>
<td>G</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Peta</td>
<td>P</td>
<td>$10^{15}$</td>
</tr>
</tbody>
</table>

1000 kilograms

The kilogram is the basic unit of mass. It is the mass of an international prototype in the form of a platinum-iridium cylinder kept at Sevres in France.

The metre is the basic unit of length. It is the distance light travels, in a vacuum, in $1/299792458$th of a second.

The second is the basic unit of time. It is the length of time taken for $9192631770$ periods of vibration of the caesium-133 atom to occur.

The ampere is the basic unit of electric current. It is that current which produces a specified force between two parallel wires which are 1 metre apart in a vacuum.

The hertz is the SI unit of the frequency of a periodic phenomenon. One hertz indicates that 1 cycle of the phenomenon occurs every second. For most work much higher frequencies are needed such as the kilohertz [kHz] and megahertz [MHz].

The joule is the SI unit of work or energy. One joule is the amount of work done when an applied force of 1 newton moves a distance of 1 metre in the direction of the force.

The kelvin is the basic unit of temperature. It is $1/273.16$th of the thermodynamic temperature of the triple point of water.

The volt is the SI unit of electric potential. One volt is the difference of potential between two points of an electrical conductor when a current of 1 ampere flowing between those points dissipates a power of 1 watt.

The watt is used to measure power or the rate of doing work. One watt is a power of 1 joule per second.