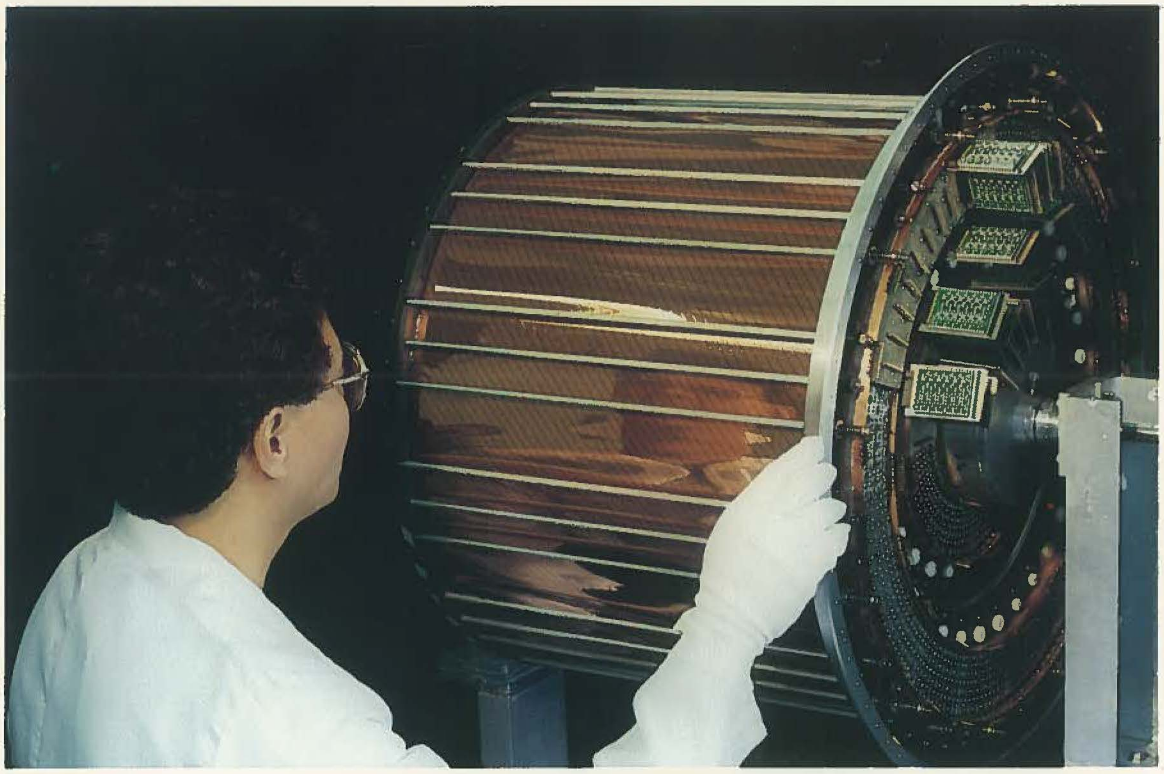
TRIUMF 1991–92

Annual Financial & Administrative Report



Including summaries of

Pure Research Activities and

Practical Applications of Research

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TRIUMF is Canada's national meson facility, managed as a joint venture by a consortium of Canadian universities. It is operated under a contribution from the National Research Council of Canada.

Consortium Members
University of Alberta
University of Victoria
Simon Fraser University
University of British Columbia

Associate Members
University of Manitoba
Université de Montréal
University of Regina
University of Toronto

COVER PHOTO

Central part of detector for Experiment 787, built at TRIUMF

A curved copper surface reflects the face of technician Chapman Lim, as he examines the core of a new detector built at TRIUMF for Experiment 787 at Brookhaven (USA), in which TRIUMF is a major participant. The experiment examines some very rare kaon decay modes. Wire chambers track the trajectories of decay products from the kaons, allowing identification of these particles. Low-mass aluminum wires and thin cathode foils minimize disturbance to the trajectories of the particles. The 12-layer chamber contains approximately 5,000 hand-tensioned wires. See page 9.
Back cover: The whole detector

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The 1991–92 Financial & Administrative Annual Report is prepared by the

TRIUMF Information Office

Editor: Michael La Brooy

Board of Management

March 1992

Science moves on rapidly, propelled by people and ideas, and in its path it strews opportunities for high technology and jobs. This truism is one of the marvels of our age, linking directly the highest levels of human creativity with the economic competitiveness of the largest nations. A large national laboratory such as TRIUMF, serving a worldwide community of scientists, achieves its success by closely coupling to the trajectory of the world's best fundamental science and by cultivating the resultant opportunities for spin-offs in high technology.

This annual report is intended not only to record TRIUMF's financial and administrative statistics but also to give some impressions of how TRIUMF evolves and achieves its life as such a laboratory.

TRIUMF's expanse of fundamental science is so broad that we cover each component only once in about half a dozen years. The tools are varied—beams of pions, muons, protons, neutrons, radioactive isotopes, etc.—and the questions addressed range from the understanding of what lies at the heart of matter to how the living brain functions. The focus in this annual report is on experiments with protons and neutrons and how we elucidate these interactions using the concept of "mirror" symmetries.

The marvelous universe in which we live is full of symmetry and beauty heightened by imperfection. When we observe the universe about us we, as humans, respond strongly to symmetry. This appeal may have its origin in the way our brains are constructed. We certainly embed symmetry in the mathematics which our brains construct. In turn, this mathematics is unaccountably effective in describing nature. Perhaps that is all we can do, in that the only questions we know how to ask in the physical description of our universe pertain to the symmetry and harmony intrinsic to our thought processes.

When we confront the interactions of the tiny building blocks of nature—the quarks and leptons and the composites of quarks called protons and neutrons—we must use the rules of quantum mechanics, which are extraordinarily rich in their use of symmetry. These are not arbitrary rules: some of them relate to the deepest properties of space-time.

TRIUMF is a very valuable laboratory in the world effort to elucidate the symmetries of the fundamental forces. It has a variety of very intense beams which make possible precision experiments. In art, our eyes find heightened beauty in slightly flawed symmetry. In the quantum mechanics of fundamental forces, broken symmetry leads to deeper understanding. In this annual report a few examples are given of the search for symmetry-breaking at TRIUMF.

The engine which drives TRIUMF is world-class fundamental science. To maintain the excellence of the science, the experimental facilities must be constantly improved. This report describes a few recent facility improvements in TRIUMF which will carry the science programme forward in the coming years.

Great fundamental science leads to better opportunities for applied science and to technology transfer. Each year we give examples of these. In its direct impact on high technology for Canadian industry, TRIUMF has a singularly successful record.

Erich W. Vogt

We acknowledge the contributions of Dr. L.G. Greeniaus and Dr. W.T.H. van Oers in the preparation of this report.

Exploring Nature's Subtleties

TRIUMF Experiments with Polarized Neutrons and Protons

Nature seems to have so many forces. At one time or another, we have all experienced their power. After centuries of study, however, physicists have concluded that they are simply variants of four basic forces.

Two of these, *gravity* and *electromagnetism*, cause the vast majority of the phenomena we experience here on earth. The other two, the *strong* and the *weak* forces, act only at the incredibly tiny distances that measure the realm of subatomic particles. We are not normally even aware of these two forces in our daily lives.

Nucleons

Protons and neutrons are the well-known components of all atomic nuclei, and are therefore called nucleons. Whenever two or more nucleons come together, the effect of the gravitational force is negligibly small. We may safely ignore it for most purposes. The interaction between the nucleons therefore is due mainly to the strong force, with small contributions from the *weak* and the *electromagnetic* forces. All these have been studied for over half a century, and the fundamentals are well known. We have now moved to the stage of observing very subtle effects as we try to pinpoint the role played by each of these forces in the presence of the others.

Charge Symmetry

TRIUMF's scientists have, for several years, explored the validity of "charge symmetry". An interacting system of nucleons has charge symmetry if, when one changes all protons into neutrons and neutrons into protons, it retains the same interactions due to the *strong* force. Of course, we must subtract effects due solely to the charge on the proton, such as the *electromagnetic* repulsion between two protons.

Do interactions exist where the "charge symmetry" rule is broken? This is not a trivial question. What it really examines is the way the *strong* force is affected by the quark components of the nucleons. We know today that nucleons are not fundamental particles. Each is made up of three quarks: the proton contains one *down* and two *up* quarks, and the neutron contains one *up* and two *down* quarks.

These two kinds of quarks are the main ingredients of all ordinary matter. The *up* and *down* quarks have different electric charges, and we believe they have different masses. Thus, since these two nucleons differ in their quark content, this mass difference of their quarks may be the basis of charge symmetry breaking.

It is impossible to look at isolated quarks because for all practical purposes, individual quarks cannot leave the confines of a nucleon; so it is really the interaction of pairs of nucleons that presents the basis for understanding nuclear matter generally. Any difference caused by the breaking of charge symmetry will obviously be very small, and the observable effects will be subtle. This kind of puzzle is not easy to solve. Theory tells us that one area where differences might be seen is in the way a polarized beam of nucleons is scattered when it strikes a stationary target. During the past decade, physicists at TRIUMF have therefore sought answers by studying the interactions of polarized protons and neutrons.

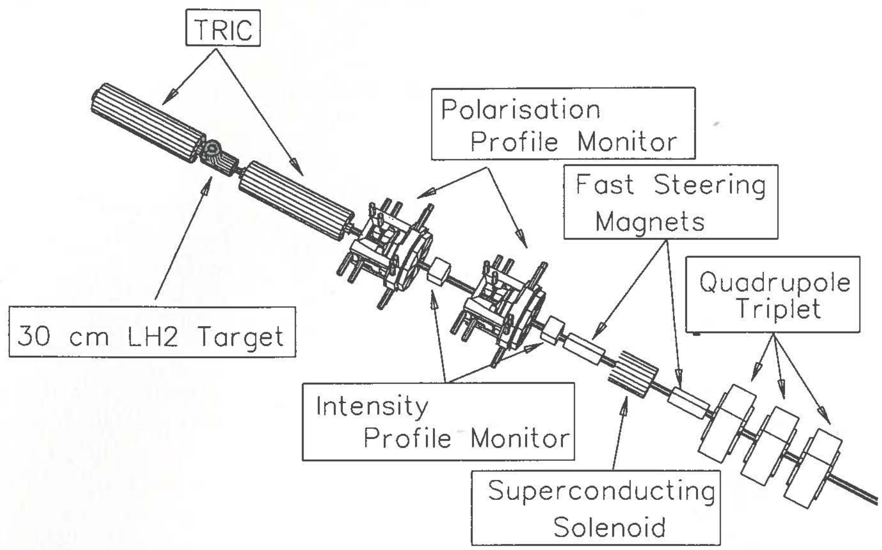
Spinning and Scattering

First, let us define some terms. A group of nucleons is polarized if they are all spinning the same way, with their axes parallel. All nucleons spin: when they collide, they behave much like spinning billiard balls and give the effects well known in the collisions of such balls. Since the direction of a nucleon's spin is defined by a rotation axis, the interaction of pairs of nucleons (or the "scattering" of one nucleon from another nucleon) will depend on their original spin directions. When one nucleon bounces off another without losing energy in the process, it is said to be "elastically scattered".

Charge Symmetry Breaking

Over the years TRIUMF researchers have carefully worked through a programme that required a series of precise measurements of how protons were scattered from other protons, or from neutrons; they have also examined in detail the spin dependence of this scattering process.

Layout of Parity Detection Apparatus



Recently these studies have focused particularly on the difference in the scattering of beams of neutrons, polarized with the spin axis pointing *up* (relative to the "billiard table"). The protons in the target were also held polarized, either in the same direction as the neutron beam or the opposite direction. This measured difference is expressed as a number called the "spin correlation parameter," A_{NN}. They also studied the difference in the number of polarized neutrons (with the direction of the spin axis perpendicular to the scattering plane) scattered at some angle, either to the left or to the right, from unpolarized protons in a target.

How are such polarized neutron beams created? TRIUMF's scientists have several clever tricks up their sleeves for experiments like these. In this case, they simply turn a beam of polarized protons into polarized neutrons by persuading the former to give up their positive charges! The polarized proton beam is aimed at a target of deuterium — an isotope of hydrogen whose nucleus contains one neutron plus one proton. When an accelerated proton strikes the neutron in a deuterium nucleus, the two particles can exchange identities! The proton can give up its positive charge to the neutron, and ends up bouncing off as a polarized neutron itself. TRIUMF's unequalled source of polarized H^- ions ultimately yields a powerful beam of polarized protons. Through the exchange mechanism just described, this is converted to the intense, high-quality, monoenergetic neutron beam needed for these experiments.

This capability makes TRIUMF a world-class facility for polarized neutron studies. The results of these experiments so far indicate a small but significant difference between the scattering of the polarized neutrons from protons, and polarized protons from neutrons. This demonstrates the reality of charge symmetry breaking. Further experiments are being prepared.

Parity Violation

Another effect that is investigated through polarized particles is called parity violation. Charge symmetry breaking, mentioned above, refers to a very small difference in the way that particles interact through the *strong* force. However, the forces of Nature are not mutually exclusive: two particles interacting via the *strong* force will feel the others also. At subatomic distances, though, the strength of the *weak* force is only one ten-millionth of the *strong* force. How can we study the behaviour of the *weak* force in the presence of the overwhelming *strong* force? We have to look for a unique signature of the *weak* force, and this is provided by the breaking of "mirror symmetry" — called parity violation in the language of the physicist.

To understand the concept of parity, we return once again to the billiard table. In nature we do not expect the laws of physics to depend on our choice of a coordinate system. For instance, if we observe two spinning billiard balls bouncing off each other, we would expect to see the same angular changes of direction, etc. if certain properties — such as the initial directions of travel — were reversed, as in a mirror image. This is "mirror symmetry".

However, *weak* force interactions may not follow this rule: certain properties of subatomic particles just cannot be reversed in a mirror! Because of this, the mirror-image interaction we try to create may not be exactly symmetrical with the original, so we may find that the "nucleon balls" bounce off each other in slightly different ways in the two situations. TRIUMF's parity violation experiment measures this effect.

This search too, therefore, depends on spin effects and the use of polarized particles. If mirror symmetry were present, polarized incident protons, with their spin axes pointing either along the direction of travel or in the opposite direction, should scatter from stationary protons (in the form of a liquid hydrogen target) in the same way. Without mirror symmetry, scattering would be different in the two situations. These scattering experiments are represented pictorially in Figure 1.

A unique TRIUMF experiment is being prepared to measure any relative difference in the scattering of such polarized protons from other protons. We can choose the beam energy so that the tiny effect to be measured (less than one ten-millionth of the gross effect) is sensitive to one particular aspect of the *weak* force. The quantity which will be measured is one of six similar quantities which represent the *weak* force between two strongly interacting nucleons. Clearly, measuring such a small effect demands the utmost of the experimenter. Many other effects can mimic the effect of interest. Therefore the main components of the experiment — the polarized proton beam, the liquid hydrogen target, and the detection apparatus which measures the beams — must all meet a set of very strict specifications. The properties of the incident proton beam must be continuously monitored, recorded, and adjusted where possible. We have developed unique monitoring and control apparatus, and a schematic view is shown below.

In the near future, experiments using this equipment will make important contributions to our understanding of the finer points of parity violation, and of *weak* force interactions generally.

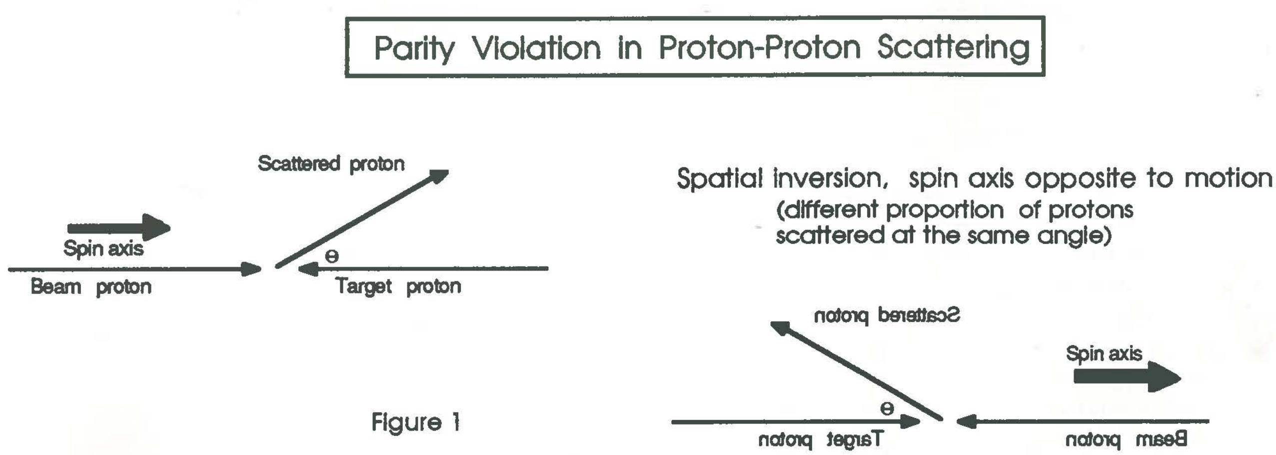


Figure 1

One of the significant events of the year was the arrival of a wonderful new PET scanner.

Pion Therapy

Clinical trials continue, comparing the effectiveness of pion therapy to the conventional gamma-ray therapy, in the treatment of brain and prostate tumours. BC Hydro donated a fast computer system to the centre. This will greatly help staff in the processing of treatment plans. Dr. George Goodman retired after many years of dedicated service as director of the facility.

TRIM

This programme (TRIUMF Radio Isotopes for Medicine) is developing several different radiopharmaceuticals containing iodine–123 (with many possible applications — creating images of tumours, of herpes infections in the eye, of diseased heart tissue, etc.) It also continues its work in manufacturing other isotopes, many of them distributed through Nordion International Inc.

PET Programme

Of the various instruments used for examining the brain, PET scanners are unique: they reveal *activity levels* in the various areas. Other methods, such as CT scanners, show only differences of *structure*, not function.

The original PET scanner built by TRIUMF scientists more than a decade ago has done sterling work for many years at the hospital on the campus of the University of British Columbia. One of only three operating in Canada during that time, it has contributed significantly to the reputation of the UBC hospital as a centre for the investigation of many brain disorders. Technology, however, marches on! In October 1991, a new $3 million machine, the only one of its kind in Canada and one of only three in the world, took its place alongside the older model.

The New System

The new PET scanner was built by the Computer Technology and Imaging Incorporation, a subsidiary of Siemens. Although all PET scanners operate in the same basic way, the new ECAT 953-B/31 machine has many distinct advantages. It permits a more accurate representation of brain activity by providing more images, and with finer resolution.

The older machine produced images at seven different depths within the brain, the "slices" being 14 mm apart. The new one provides images of *31 different slices*, with a 3.3 mm spacing. In addition, the images have higher resolution: the smallest unit of brain tissue represented by the new scanner is one fifth the volume of that from the old one. This generates a great deal more information for diagnoses. Besides yielding "sharper" images, the machine works fast, and the scan is completed more quickly and conveniently.

By the end of the year, the ECAT 953-B/31 had been well tested, and had exceeded all its specifications for resolution, uniformity, and stability.

Siemens donated part of the cost of this rare, new machine (the only other two in the world are in the Netherlands and in Britain). It was their contribution to a collaboration of TRIUMF scientists working on complex, new software that yields the highest-quality images from the scan data available. The new scanner accepts gamma rays emitted on many more planes than before; however, this means it will also receive more misleading or incorrect information, and in fact, approximately 80 percent of all the data collected must be discarded. In order to solve the problem of picking the acceptable data from all the signals received, special mathematical systems were created at TRIUMF.

An International Centre

These PET scanners are used essentially for basic research, to aid doctors around the world in their diagnosis of brain disorders. Mexico, UCLA, Sweden, Florida, Guam, and many other areas around the world have sent patients here to receive PET scans. The studies done with the scanner examine age-related changes in the brain; the effects of drug treatment on movement disorders; and effects of tissue surgically implanted in diseased areas in the brain. A recent study focuses on "pre-clinical" assessments: persons determined to be "at risk" are examined to learn if brain disease can be detected *before* symptoms appear.

Facility tours & visitors, 91–92

The number of visitors increased to 2978 (up 13%) this year, chiefly due to a considerable jump in the number of high school and university students taking tours (1384 came, up by 55% from the preceding year). In all, 353 separate groups visited, requiring 417 of TRIUMF's scientists and staff to act as guides. A model of the proposed KAON Factory drew much interest at an Open House on the University of Victoria, campus, and at displays elsewhere during the course of the year.

Despite the exceptionally tight financial situation at TRIUMF for most of this fiscal year, it was possible to complete or continue work on several facility improvements. Construction of the CHAOS detector, which was begun two years ago and was discussed in some detail in an earlier annual report, neared completion. The drift chambers for this unique detector were completed, as was a polarized target specially designed for it. Apart from CHAOS, a large, liquid hydrogen target was completed and used in experiments. Proton hall was modified extensively in preparation for the installation of the second-arm spectrometer (SASP), and the control system for liquid helium was upgraded. We present below some details of other important TRIUMF innovations.

1991–92 will be a memorable year for polarization experiments: not only was a new helium-3 polarized target completed, but the beam from the cyclotron achieved a world-beating level of polarization for an optically pumped source.

Helium-3 Polarized Target

Until a few years ago most physicists believed that the spin of the proton was made up of the spins of the point-like "quarks" inside the proton. This belief was strongly undermined by a recent experiment at CERN, in which polarized muons were scattered off quarks in a polarized proton target. The experiment indicated that the gluons (that bind the quarks together in composite particles like protons or neutrons) contribute in a major way to the proton's spin.

Because of this "spin crisis" of the proton, great interest is now focused on the neutron's spin structure. Unfortunately, although neutrons remain stable when bound in atomic nuclei, free neutrons cannot be readily studied: they decay, with a half-life of about 10 minutes. However, a good substitute exists for an isolated, polarized neutron: the stable nucleus of helium-3, since its spin is carried mainly by the odd neutron (the two proton spins cancel each other, being in opposite directions).

A group of physicists from Simon Fraser University and TRIUMF has developed a polarized helium-3 target which has set new performance standards. To polarize the helium, it uses two powerful lasers (10 watts total power) providing polarized infrared beams. The polarization of the photons in the laser beams is transferred to the electrons of rubidium (Rb) atoms inside a glass vessel. Next, these polarized Rb atoms collide with helium atoms, admitted as a gas at high pressure, and transfer their electron polarization to the helium. (For a further explanation of this kind of process, see "Polarizing Particles at TRIUMF" on page 21.) It takes an average of 100 million collisions with Rb before a helium atom becomes polarized. Minimizing the loss of polarization during the collisions of He atoms with the walls requires glass cells of extreme purity, and producing these is a major difficulty. In the best cells, the He polarization can be maintained for several days after the laser is switched off. This target contains helium-3 at higher pressures (up to 12 atmospheres) and in larger volumes (up to 35 mL) than previous models, and the peak polarization (60–70%) can be maintained over many weeks. An "adiabatic spin rotator" (ASR) allows one to point the target spin in any desired direction; and even reversing the polarization with the ASR is extremely efficient, with losses being less than one part in 10,000 per reversal. TRIUMF researchers have already performed several new, unique and interesting experiments with this target and our proton or pion beams. Several more are either being discussed or have already been approved at the world's three meson factories — LAMPF, PSI and TRIUMF.

A Complex Detector for Experiment 787

To probe deeply into the secrets of the Standard Model of particle physics, TRIUMF physicists are part of a collaboration at Brookhaven National Laboratory (BNL) in the U.S.A. that is attempting to observe the rarest particle decay reaction yet to be seen. The collaboration also includes physicists from BNL and Princeton U., and the KEK Laboratory with the U. of Tokyo in Japan.

The process—a positive kaon decaying to a pion and a neutrino-antineutrino pair ($K^+ \longrightarrow \pi^+ \nu\nu$) —is expected to be seen only once in every 10^{10} kaon decays. To observe it unambiguously, the Experiment 787 group has constructed a complex apparatus consisting of thousands of sensitive particle detector elements housed in a large magnet (see cover photo).
The TRIUMF group is not only making contributions to the design and construction of a new kaon beam and new electronics, detectors and software, but is presently constructing an innovative tracking chamber for measuring the decay products' trajectories in a magnetic field. (Knowing a particle's trajectory allows you to calculate its momentum.) To minimize any disturbance to trajectories, the gas-filled "drift chamber" contains very little material. It uses low-mass aluminum wires, and thin (1/40 mm) kapton cathode foils coated with a 0.0001 mm layer of copper, to separate gas regions and to obtain accurate coordinate measurements. Differential gas pressure inflates the foils, maintaining their shapes to the required tolerance. Under construction in TRIUMF's detector facility clean room, the 12-layer chamber system will, when completed, be transported to the experiment at BNL. The chamber contains 2000 individual detector elements and approximately 5000 hand-tensioned wires.

Meanwhile, a rare kaon decay experiment at BNL is searching for entirely new particles and interactions, hoping to open unexplored doors to fundamental knowledge about the structure of matter. These experiments are important to TRIUMF scientists because they are precursors of the kaon experiments that would be run at the future TRIUMF KAON Factory.

TRIUMF's New, Optically Pumped, Polarized Source

The original polarized beam at TRIUMF began with a Lamb-shift source, and produced both up- and down-polarized ions. However, it yielded only a low-intensity beam, whereas many experiments now require a much greater intensity. Higher intensity was, therefore, the main objective in designing the new system.

This new source uses the energy of laser beams to polarize the ions. Currently, only three other similar systems exist in the world. The Japanese built the first of this type in 1983, but being *pulsed*, that model emits ions in bunches. The TRIUMF team set out to design a source capable of producing a continuous stream of particles, which is a lot more difficult.
The new, optically pumped source is superior to the earlier one in several ways. Able to produce a current of five microamperes, it yields a

(continued on p. 11)

TRIUMF KAON Ventures Office

TRIUMF's fiscal year 1991–1992 was the first full year of operation of the TRIUMF-KAON Ventures Office (TKVO). Its mandate continues to be the vigorous pursuit of all financially and technically viable opportunities for commercialising the technologies which evolve from the research activities at the TRIUMF facility. The technology opportunities, and the resultant commercial potential, have exceeded the original forecasts for the TKVO, and are a direct reflection of the excellence of the scientific enquiry which occurs at TRIUMF.

Commercialising TRIUMF's technology requires that it be transferred to industry, with preference given to Canadian industry. Where no appropriate receptor company can be found in Canada, then the search becomes international. Five fundamental approaches are utilised by the TKVO in transferring technology from TRIUMF to industry:

1. *Consulting Services for Industry*

During 1991–92, TRIUMF provided consulting services to industry to a total value of about $650,000. The companies receiving these services ranged in size from small, "basement" operations to large enterprises with international interests.

2. *Staff Secondment*

Three TRIUMF staff were seconded to local companies during 1991–92 for extended periods, about one year each. This can be an effective two-way process for transferring technology, and appears to be gaining acceptance within both TRIUMF and industry.

3. *Start-up Companies*

Two TRIUMF staff have been working for some time on starting their own company to commercialise computer software that has been developed at TRIUMF. Although the process has yet to be completed, they have been linked with a local entrepreneur, and negotiations are proceeding. The coming year will clarify the future of this particular venture.

4. *Joint Ventures with Industry*

In recognition of the downside potential, TRIUMF and the TKVO have taken a very cautious approach to joint ventures with industry partners. At this time there are no joint ventures, although one potential collaboration is in the early stages of discussion.

5. *Licence Agreements with Industry*

During this year, TRIUMF signed three new licence agreements with commercial partners, and was actively negotiating five others. Royalty revenue for the year amounted to about $600,000 — a significant increase over the $150,000 received the previous year. The upward trend is projected to continue for the coming year. The approach taken by TRIUMF and the TKVO is to patent only those technologies that require patenting to protect their opportunity for commercial application. Thus, during the year, about forty technologies were presented to the TKVO, of which ten were subjected to formal TRIUMF review, and three were pursued for patenting.

To disseminate the information concerning the current twenty or thirty TRIUMF technologies that have commercial potential, TRIUMF and the TKVO have started a new programme of participation in trade shows across Canada. The early ventures have proved very successful, and it is anticipated that this programme will be enhanced with supporting brochures and documentation during the coming year.

A functional and efficient network of contacts and associates is essential for the effective transfer of technology from any facility like TRIUMF. Throughout the past year, the TKVO has maintained and enhanced its connections with both industry and other research institutions and their commercialisation offices.

In cooperation with the federal Department of External Affairs, TRIUMF has signed two letters of intent with similar research laboratories in Russia and Uzbekistan, and is discussing similar letters with representatives of facilities in other states of the former Soviet Union. The ultimate intent is to work jointly on projects with scientists from these facilities, and to assist them, where possible, in commercialising their technology in the western world.

While the past year has seen success in TRIUMF's transfer of technology into the commercial marketplace, the future looks even more promising. Projects currently in the negotiation stage should, for some years to come, result in a commendable performance in the commercialisation of TRIUMF technology. The key, however rests in the calibre of the science that is pursued at TRIUMF. With excellence in research, commercial technology will follow.

Facilities

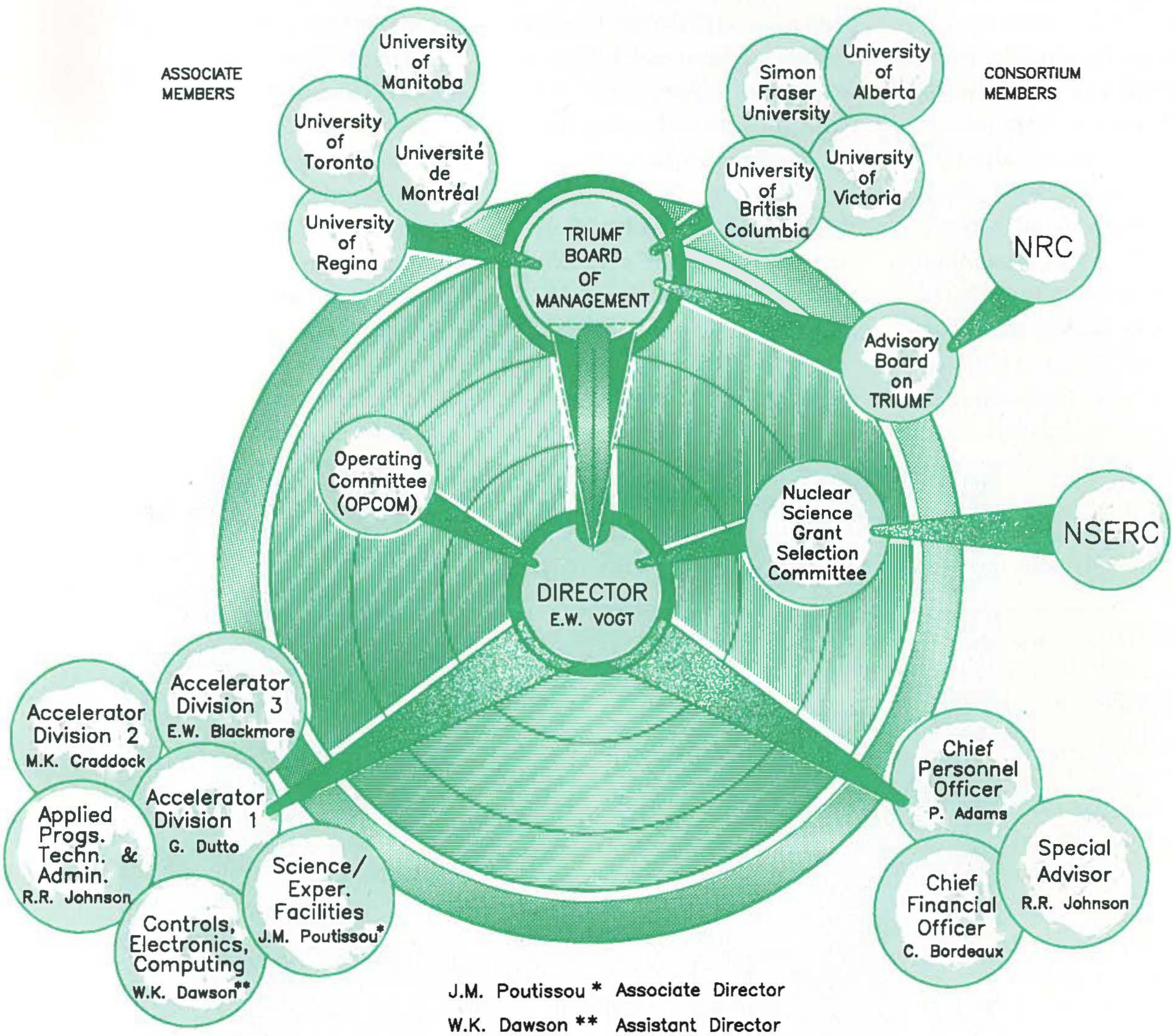
(continued from page 9)

Keerthi Jayamanna adjusts the controls on TRIUMF's record-setting, optically pumped, polarized proton source.

beam five times more intense than the older system. A beam with higher intensity generates more data and allows an experiment to be run in a shorter time. Also, there is little variance in properties among the accelerated ions of the optically pumped beam. This is important for certain experiments seeking very small effects (see the Pure Research section), as even minute changes in beam properties can affect the results.

Using laser technology has allowed TRIUMF this year to achieve a new world record for beam polarization with an optically pumped source (78%). With this innovation, experiments in future will provide data that are far more reliable.

Organization Chart



The previous year's crisis was carried forward into fiscal 1991–92, resulting in the continued cutback on development and an increased danger of major equipment failure due to inadequate maintenance. Some relief was provided through Industry, Science & Technology Canada (ISTC), via a $3.6 million grant channelled through the National Research Council. These additional funds allowed the cyclotron to operate till year-end, instead of the three-month operation that would have been the maximum possible with the NRC contribution of $24.855 million. The ISTC bailout also allowed TRIUMF to keep its staff intact, which permits normal TRIUMF activities to continue after the funding base has been restored. It also permits TRIUMF to maintain the cadre of scientists and engineers required to deal with any expansion, and thus does not jeopardize the negotiations under way between the Federal and B.C. Provincial governments on the future funding of TRIUMF.

Grants from the Natural Sciences and Engineering Council (NSERC) increased by $1 million over the previous year (in funds received directly by TRIUMF). The increase covers mainly equipment grants. NSERC also provides grants to others for use at TRIUMF. Those grants are administered elsewhere and are therefore not reported in TRIUMF's financial statements. The total value of NSERC grants related to experiments done at TRIUMF is not officially known to TRIUMF; it is expected to have remained around $4.2 million overall.

The Medical Research Council of Canada (MRC) also provides substantial support to scientists performing experiments at TRIUMF. All such MRC grants are administered elsewhere and therefore are not reported in this review.

NORDION International Inc. is still the major commercial user of TRIUMF facilities. It produces radiopharmaceuticals and is experiencing ever-increasing sales, now exceeding $10 million annually from its TRIUMF site.

EBCO Industries Ltd. uses TRIUMF's services in the construction of small cyclotrons for the production of medical isotopes. Both NORDION and EBCO have technology transfer licences from TRIUMF which produced $562,264 in royalty funds in 1991–92, a substantial increase over the $150,000 of the previous fiscal year.

It was an extremely difficult year financially, in spite of some increased funding. The funding base has deteriorated to the point where TRIUMF now cannot operate on a year-round basis without extra funding. Such extra funding is not assured, and this adds to the problem. It is expected that negotiations between the Federal and the B.C. governments will result in solutions to the current crisis, and will allow long-range planning to be restored as well.

C.W. Bordeaux
Chief Financial Officer

SOURCE OF FUNDS	*1991–92*		*1990–91*	
	$ million	*%*	*$ million*	*%*
National Research Council	28.5	72.7	26.5	72.6
NSERC	4.0	10.2	2.9	8.0
Prov. Project Defn. Study Extension	–	0.0	0.9	2.6
NORDION International Inc.	2.3	5.9	2.0	5.5
Affiliated Institutions	3.3	8.4	2.9	7.9
EBCO Industries Ltd.	0.3	0.8	0.7	1.9
Royalty Fund	0.6	1.5	0.2	0.4
Investment & Other Income	0.2	0.5	0.4	1.1
	39.2	100%	36.5	100%

From the Auditor

Coopers & Lybrand | chartered accountants | a member firm of Coopers & Lybrand (International)

AUDITORS' REPORT TO
THE BOARD OF MANAGEMENT
TRIUMF

We have audited the statement of financial position of TRIUMF as at March 31, 1991 and the statements of funding and expenditures and changes in fund balances for the year then ended. These financial statements are the responsibility of TRIUMF's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with generally accepted auditing standards. Those standards require that we plan and perform an audit to obtain reasonable assurance whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation.

In our opinion, these financial statements present fairly, in all material respects, the financial position of TRIUMF as at March 31, 1991 and its results of operations and changes in fund balances for the year then ended in accordance with generally accepted accounting principles.

Coopers & Lybrand

Vancouver, B.C.
June 5, 1991

NOTE: The excerpts from the Auditor's Report in the following pages are prepared by the TRIUMF Information Office, which takes responsibility for any inadvertent errors or deviations. Copies of the entire Auditor's Report to the TRIUMF Board of Management are available from the TRIUMF Business Office. [Editor]

TRIUMF

STATEMENT OF COMBINED FUNDING AND EXPENDITURES AND CHANGES IN FUND BALANCES

For the Year Ended March 31, 1992

FUNDING	1992	1991
National Research Council	$ 28,455,000	$ 26,510,000
Natural Sci. & Eng. Research Council	3,992,669	2,925,064
Prov. Project Def. Study Extension	–	942,000
NORDION International Inc.	2,283,567	1,992,500
Affiliated institutions	3,301,509	2,904,804
EBCO Industries Ltd.	367,017	686,328
Royalty Fund	562,264	150,000
General Fund	266,794	407,624
	39,228,820	36,518,320

EXPENDITURES		
Communications	270,609	320,340
Computer	1,704,287	1,756,426
Equipment	2,331,407	1,706,602
Power	1,951,294	1,909,320
Salaries and benefits	24,526,551	23,282,269
Supplies and expenses	7,533,005	8,783,824
	38,317,153	37,758,781
Excess (Deficiency) of Funding over Expenditures for the Year	911,667	(1,240,461)
Fund Balances — Beginning of Year	1,768,706	3,009,167
Fund Balances — End of Year	$ 2,680,373	$ 1,768,706

TRIUMF

STATEMENT OF FINANCIAL POSITION

As at March 31, 1992

	1992	1991
ASSETS		
Cash & Temporary Investments	$ 3,363,172	$ 2,290,234
Funding Receivable (note 3)	942,889	730,792
Total Assets	$ 4,306,061	$ 3,021,026
LIABILITIES AND FUND BALANCES		
Accounts Payable	$ 808,314	$ 494,567
Deferred Funding	124,352	–
Due to (from) Joint Venturers		
The University of Alberta	(8,255)	32,527
The University of Victoria	6,389	(26,952)
The University of British Columbia	688,486	751,609
Simon Fraser University	6,402	569
	693,022	757,753
Fund Balances		
Natural Sciences & Engineering Research Council (note 5)	1,098,471	904,191
Prov. Project Definition Study Extension	–	(318,893)
NORDION International Inc.	12,351	100,000
Affiliated Institutions (note 6)	(297,992)	(138,183)
EBCO Industries Ltd.	15,735	1,013
Royalty Fund	523,485	95,368
General Fund	801,222	956,202
Intramural Accounts	527,101	169,008
	2,680,373	1,768,706
Total Liabilities & Fund Balances	$ 4,306,061	$ 3,021,026

Encumbrances and Commitments (note 4)

TRIUMF

STATEMENT OF FUNDING AND EXPENDITURES

NATIONAL RESEARCH COUNCIL

For the Year Ended March 31, 1992

	1992	1991
Deferred Funding — Beginning of Year	$ Nil	$ 15
FUNDING		
Contributions	28,455,000	26,509,985
Total Approved Contribution	28,455,000	26,510,000
EXPENDITURES BY ACTIVITY AREA		
Salaries	20,904,823	19,973,830
Power	1,951,294	1,909,320
Administrative and overhead	1,821,403	1,693,122
Cyclotron and facilities operation	2,373,084	2,427,609
Site services	366,124	570,323
Support services	938,527	1,172,299
Major projects	373,028	260,450
Minor projects and development	418,857	438,152
	29,147,140	28,445,105
Funds recovered — salaries and cost centres	(692,140)	(1,206,576)
	28,455,000	27,238,529
Contribution from other funds	–	(728,529)
Total Expenditures	28,455,000	26,510,000
Deferred Funding — End of Year	$ Nil	$ Nil
EXPENDITURES BY OBJECT		
Communications	$ 234,348	$ 273,076
Computer	1,030,735	1,175,197
Equipment	1,018,735	844,180
Power	1,951,294	1,909,320
Salaries and benefits	20,920,073	19,975,787
Supplies and expenses	3,713,907	3,860,089
Salary expenditure recovered	(414,092)	(799,120)
Contributions from other funds	–	(728,529)
	$ 28,455,000	$ 26,510,000

TRIUMF

STATEMENT OF FUNDING AND EXPENDITURES AND CHANGES IN FUND BALANCE

PROVINCIAL PROJECT DEFINITION STUDY EXTENSION

For the Year Ended March 31, 1992

	1992	1991
FUNDING		
Contributions	$ –	$ 942,000
EXPENDITURES		
Communications	–	6,469
Computer	–	64,318
Equipment	–	143,857
Salaries & benefits	–	473,067
Supplies & services	–	518,429
	Nil	1,206,140
Contribution from General Fund	318,893	–
Excess (Deficiency) of Funding over Expenditures for the Year	318,893	(264,140)
Fund Balance — Beginning of Year	(318,893)	(54,753)
Fund Balance — End of Year	$ Nil	$ (318,893)

TRIUMF

NOTES TO FINANCIAL STATEMENTS

For the Year Ended March 31, 1992

1. **Joint Venture Operations**

TRIUMF is a joint venture established by the University of Alberta, the University of Victoria, Simon Fraser University and the University of British Columbia, having as its goal the establishment and continuance of a national facility for research in intermediate energy science under a contribution from the National Research Council of Canada. As a registered charity, TRIUMF is not subject to income tax.

Each university owns an undivided 25% interest in all the assets, and is responsible for 25% of all liabilities and obligations of TRIUMF, except for the land and buildings occupied rent-free by TRIUMF, which are owned by the University of British Columbia.

These financial statements include only the statements of fund transactions of TRIUMF and do not include the assets, liabilities, revenues and expenditures of the individual joint venturers. The sources of funding include grants and contributions from the NRC, NSERC and governments; advances and reimbursements from other sources; and investment income. The sources and purposes of these funds are:

(a) National Research Council (NRC)
Funding of operations, improvements and development; expansion of facilities (buildings excluded); and general support for experiments.

(b) Natural Sciences and Engineering Research Council (NSERC)
Funding to grantees for experiments related to TRIUMF activities. These funds are administered by TRIUMF on behalf of the grantees.

(c) Provincial Project Definition Study Extension
Funding provided by the provincial government to continue to research and define the financial and scientific requirements of the proposed KAON Factory.

(d) NORDION International Inc.
Advances and reimbursements for expenditures undertaken on its TRIUMF project.

(e) Affiliated Institutions
Advances and reimbursements for expenditures undertaken on behalf of various institutions, from Canada and abroad, for their TRIUMF projects.

(f) EBCO Industries Ltd.
Advances and reimbursements for expenditures undertaken on the 30 MeV cyclotron project.

(g) Royalty Fund
Royalties from technology transfer agreements.

(h) General Fund
Investment income for discretionary expenditures incurred by TRIUMF.

(i) Intramural Accounts
Net recoveries for internal projects and services. The recoveries of expenditures are charged to the appropriate TRIUMF funding source by Intramural Accounts.

2. **Significant Accounting Policies**

TRIUMF follows generally accepted accounting principles for non-profit organizations as referred to in the CICA Handbook. Expenditures on capital assets and supplies are expensed as incurred.

Royalty Income

TRIUMF records royalty income when notification and verification of sales are received.

3. **Funding Receivable**

	1992	1991
Natural Sciences and Engineering Research Council	$ 423,395	$ 450,596
Provincial Project Definition Study Extension	–	242,000
NORDION International Inc.	305,976	236,280
Affiliated Institutions	103,758	(294,322)
EBCO Industries Ltd.	109,760	96,238
	$ 942,889	$ 730,792
Funding received from affiliated institutions comprises —		
Funding receivable	$ 597,428	$ 328,174
Less: Funding received in advance	(493,670)	(622,496)
	$ 103,758	$ (294, 322)

4. **Encumbrances and Commitments**

In addition to the accounts payable reflected on the statement of financial position, outstanding encumbrances and commitments, representing the estimated costs of unfilled purchase orders and contracts placed at the fiscal year end, comprise:

	1992	1991
National Research Council	$ 445,000	$ 230,000
Natural Sciences and Engineering Research Council	249,000	129,000
Provincial Project Definition Study Extension	–	60,000
NORDION International Inc.	53,000	35,000
Affiliated Institutions	38,000	80,000
EBCO Industries Ltd.	–	1,000
Royalty Fund	20,000	1,000
General Fund	85,000	170,000
Intramural Accounts	4,000	–
	$ 894,000	$ 706,000

5. **Natural Sciences and Engineering Research Council — Fund Balance**

	1992	1991
Funding unexpended	$ 1,536,834	$ 1,319,046
Grant accounts overexpended	(438,363)	(414,855)
Fund balance — end of year	$ 1,098,471	$ 904,191
Number of grants awarded during year	48	47
Number of grants administered throughout year	110	120

6. **Affiliated Institutions — Fund Balance**

	1992	1991
The fund balance at the fiscal year end comprises:		
Funding received in advance	$ 131,495	$ 294,135
Expenditures recoverable	(429,487)	(432,318)
Fund balance — end of year	$ (297,992)	$ (138,183)

7. **Pension Plans**

The employees of TRIUMF are members of the pension plan administered by the university that sponsors their employment. TRIUMF records the pension expense as cash contributions to the plan based on a prescribed percentage of employee earnings. The pension expense for the year was $1,368,432 (1991 — $1,288,163).

Synchronized Subatomic Spinning

Polarizing Particles at TRIUMF

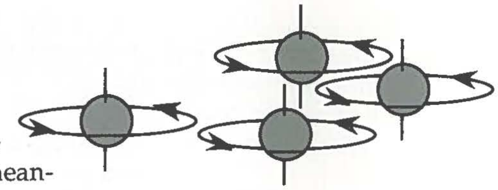
The basic constituents of the subatomic world possess a characteristic property called "spin". The spin of a particle may be thought of as the angular speed with which the particle rotates around its own axis. If the particle is charged, a magnetic dipole field is associated with the spin, as though a tiny bar magnet were inserted along the axis. A particle's spin can have either of two possible orientations, referred to as "up" or "down". In a random group of particles, there are usually equal numbers of each. If, however, an assembly of particles has all the spins oriented in the same direction, it is said to be 100% "polarized".

Many of our experiments require either the incoming beam of particles, or the material in the target (often hydrogen or helium isotopes), or both, to be polarized. In recent years TRIUMF has developed new ways of achieving a high degree of polarization in beams or targets. Beam polarization uses an "optically pumped" source, laser light, and rubidium atoms. (See the "Facilities" section, p. 9–10, concerning the world record polarization — for an optically pumped source — achieved in TRIUMF's proton beam.)

Polarizing Rubidium

In a suitable cell, polarized laser light of a specific wavelength irradiates the vapour of rubidium (Rb)—a heavy, metallic element. The Rb atoms become polarized as their outermost electrons absorb the energy of this light. Rb has relatively large, slow-moving atoms. Colliding infrequently with the sides of the cell, they maintain their polarization a long time.

At this point, the objective is to create a uniform spin among all outermost electrons of the Rb atoms. Electron spins may be either *up* or *down* at ground state. To produce atoms with all outer electrons spinning *up*, for example, the exact frequency of light that will be absorbed by the *down*-spinning electrons must be applied. All these *down* electrons will then be excited to a higher energy level, but can quickly drop to the ground state again. As they do so, some will keep their *down* spin and some will switch to *up*, thus reducing the total number of electrons spinning *down*. As the frequency which excites the *down*-spinning electrons continues to be applied, more and more Rb atoms will have outer electrons with the spin *up*; so the polarized source is said to be "optically-pumped." (A different frequency—or colour—of light would be applied to excite and "pump" electrons spinning *up* at ground state if a polarized beam with *down*-spinning electrons were desired.)



Nearby, in the meantime, hydrogen gas fills a plasma chamber. Microwave power breaks up the atoms and molecules into a random collection of protons and electrons.

Transferring the Polarization

The protons from the plasma chamber are now channelled as a beam into the rubidium cell. As the protons pass through, each may pick up a polarized electron from a Rb atom, thus forming an electron-polarized, neutral, hydrogen atom. These atoms then pass through a region where the magnetic field reverses, causing the polarization of each electron, in effect, to be transferred to the proton. The hydrogen atoms are now proton-polarized: their protons are all spinning in the same direction.

Now the polarized H atoms pass through a chamber of sodium vapour, becoming ionized as each picks up one more electron from a sodium atom. The proton-polarized hydrogen ions are finally injected into the cyclotron. They retain their polarization while being accelerated.

Polarized helium targets are created by transferring polarization from rubidium to He, instead of H atoms, using a comparable process.

1992 TUEC
(TRIUMF Users' Executive Committee)
Chairman: A. Olin
Associate Chairman: W.T.H. van Oers
Members: D. Armstrong, J. Brewer, P. Kitching
Liaison Officer: M. La Brooy

TRIUMF Users' Group

(as of March 1992)

308 Members — 104 Institutions — 26 Countries

TRIUMF

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J. Brack
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G. Waters
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S. Yen
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TRIUMF Users' Group—Other Institutions

Canada

B.C. Cancer Inst.— G.K.Y. Lam, L.D. Skarsgard
Calgary U. — C.Y. Kim
Cancer Agency — M.K. Dimitrov
Carleton U. — M. Dixit, R. Hemingway
Chalk River Nuclear Laboratories — I.S. Towner
EBCO Industries — J.T. Sample
Kwantlen Coll. — J.B. Pearson
McGill U. — J. Crawford
Queen's U. — B.C. Robertson
U. of Saskatchewan — E.J Ansaldo, C. Rangacharyulu
Vancouver General Hospital — S.A. Jackson
U. of W. Ontario — W.P. Alford

Outside Canada

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U. of Melbourne — S.A. Long, B.M. Spicer
Belgium
Université Catholique de Louvain — J. Deutsch
Bulgaria
Sofia U. — I. Enchevich
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Peking U. — Y. Ye
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NPIC — J. Zofka
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KFA Jülich — S. Martin, B. Pearce
Max Planck Institut — C. Wiedner
Tubingen U. — G. Wagner
(Unaffiliated) — W. Schott
Greece
INS — X. Aslanoglou
Hungary
Budapest Research Inst. for Physics — D. Horvath
India
K. Venkateswaran
Israel
Hebrew U. — E. Friedman, M. Paul
Soreq Nucl. Resrch. Ctr. — A. Altman
Tel-Aviv U. — J.M. Eisenberg
Italy
Inst. di Fisica, Trieste — N. Grion, R. Rui
Japan
KEK — S. Kanda, K. Nakai
Kyoto U. — A. Okihana
Osaka U. — N. Matsuoka
U. of Tokyo — K. Kojima, T. Nagae, K. Nagamine, M-H. Tanaka, T. Yamazaki, Y. Yamazaki
Korea
Yonsei U. — J.M. Lee
Netherlands
Utrecht U. — Z. Papandreou
Poland
Warsaw U. — A. Sliwinski
Russia
INR, Dubna — P. Nomokonov
INR, Moscow — A.S. Belov, V.N. Bolotov, R. Djilkibaev, V. Gaidach, N. Ilinsky, V.D. Laptev, E.A. Monich, P.N. Ostroumov, A. Pashenkov, V.G. Polushkin, P. Reinhardt-Nikulin, J.V. Senichev, S. Serezhnikov, E. Shaposhnikova, N.A. Titov, S. Yesin, A. Zelenski
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Spain
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Sri Lanka
P. Lumumba U. — K. Jayamanna
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U. Fribourg — L. Schellenberg
PSI — R. Abela, B. Blankleider, F.S.N. Gygax, E. Morenzoni, A. van der Schaaf, H.C. Walter
Universitat Zurich — R. Engfer
Union of S. Africa
Nat. Accelerator Centre — D.M. Whittal
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United Kingdom
Leicester U. — E.D. Davis
United States
Argonne N.L. — M. Barnabas
Arizona State U. — J. Comfort, R.F. Marzke
Boston U. — J. Miller
Bowdoin Coll. — G.T. Emery
California State U. — E.F. Gibson,
U. of California, Los Angeles — B.M.K. Nefkens, J.R. Richardson
Carnegie Mellon — P.D. Barnes

TRIUMF Users' Group—Other Institutions

CEBAF — D.J. Mack

Centenary Coll. — J. Lisantti

U. of Colorado — X.Y. Chen, S. Holbraten, J.J. Kraushaar, R.A. Ristinen

Florida State U. — H.S. Plendl

U. Illinois — P.T. Debevec

Indiana U. — R.D. Bent, J.M. Cameron, W.P. Jones

Johns Hopkins U. — Y.K. Lee

Kent State U. — R. Madey

Kentucky U. — M. Kovash, M.A. Pickar

Lawrence Berkeley Laboratory — D.S. Armstrong, J. Batchelder, D.M. Moltz, T. Ognibene

LLNL — S. Han, L.S. Pan

Los Alamos National Laboratory — L.E. Agnew, W.D. Cook, R.E.L. Green, R.C. Haight

U. of Maryland — N.S. Chant, D. Leinweber

MIT — R.P. Redwine

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U. of New Mexico — B. Bassalleck, B. Dieterle

Oak Ridge National Laboratory — D.J. Horen

Ohio U. — J. Rapaport

Ohio State U. — K.K. Gan, H. Kagan, R.L. Malchow, F.H. Morrow

Pacific Northwest Labs — P.L. Reder

Pennsylvania U. — H.T. Fortune, P. Hui

Rice U. — S.A. Dodds, T.L. Estle

Rutgers U. — C. Glashausser, S.K. Kim

SSC Lab — A. Fry, D.P. Gurd

Stanford Linear Accelerator Center — S. Kuhn

Stanford U. — W. Cummings, S. Hanna

Temple U. — C.J. Martoff

Texas A&M U. — R.A. Bryan

Texas Tech. U. — D. Lamp

U. of Virginia — E. Frlez

Virginia State U. — D. Noakes

Virginia Polytechnic Institute and State U. — M. Blecher, K. Gotow, D. Jenkins

U. of Washington — V. Cook, C. Gossett, G.A. Miller

William and Mary Coll. — M. Eckhause, R. Pourang

(Unaffiliated) — M. Halka

Uzbekistan

INR, Uzbek — G. Iljar, A. Melis

Yugoslavia

Boris Kidrich Inst. — L. Milinkovic

U of Zagreb — M. Furic

[Note: Because of ongoing political changes in Eastern Europe, the affiliations and countries of Users' Group members from that area may now be different from those shown. — Editor]

ULTRA THIN CHAMBER