TRIUMF 1987-88

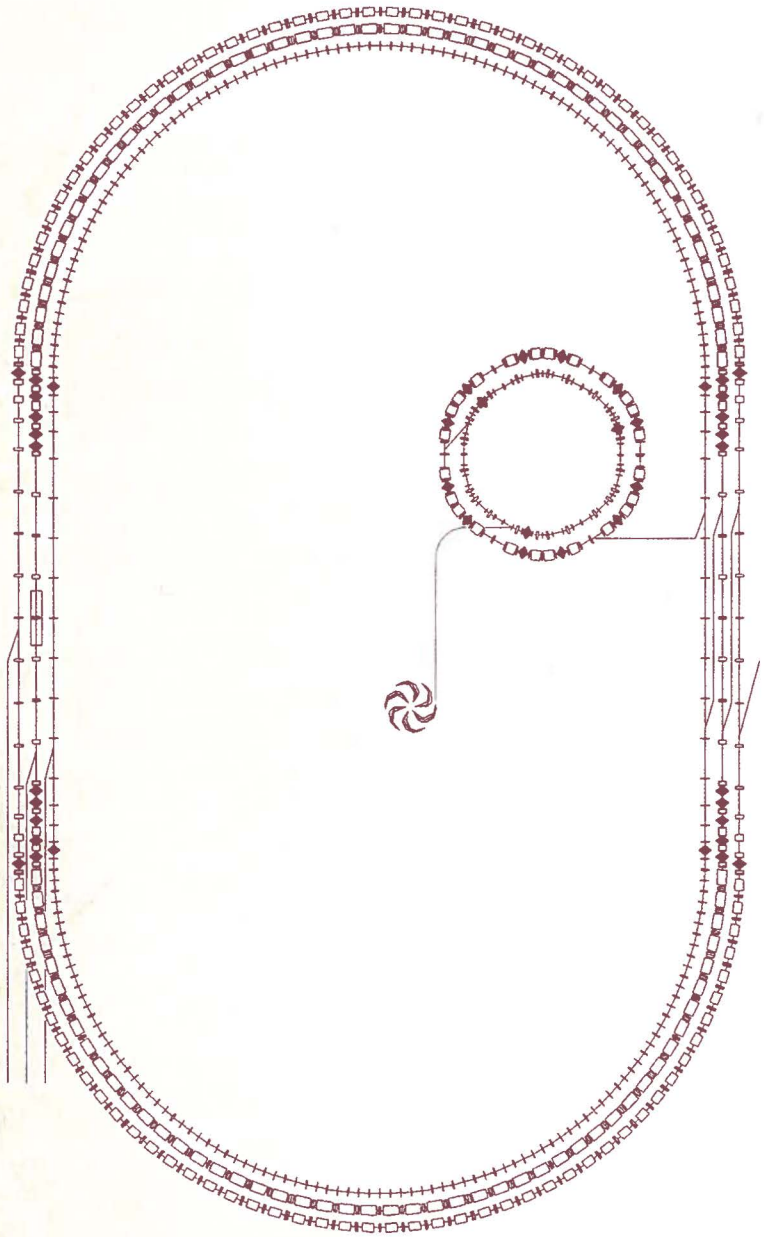
Annual Financial and Administrative Report

Including summaries of

Pure Research Activities

and

Practical Applications of Research



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Canada's national meson facility, managed as a joint venture by:

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

TRIUMF is operated under a contribution from the National Research Council of Canada

The Financial & Administrative Annual Report is prepared by the

TRIUMF Information Office

Editor: Michael La Brooy

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FRONT COVER

The proposed KAON Factory at TRIUMF was the focus of much attention in 1987-88. The drawing shows one of the possible layouts for this addition. The present cyclotron ("pinwheel" near the centre) provides the input for a small synchrotron (circle), which in turn feeds a large synchrotron in a "racetrack" design. The two synchrotrons combined will give each proton in TRIUMF's beam a sixtyfold boost in energy. (Actually, as shown in the drawing, each accelerator would first feed into a storage ring, which would, in turn, feed the next stage.) The small rectangular blocks are the magnets that guide and focus the proton beams.

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Dr. P. Kitching
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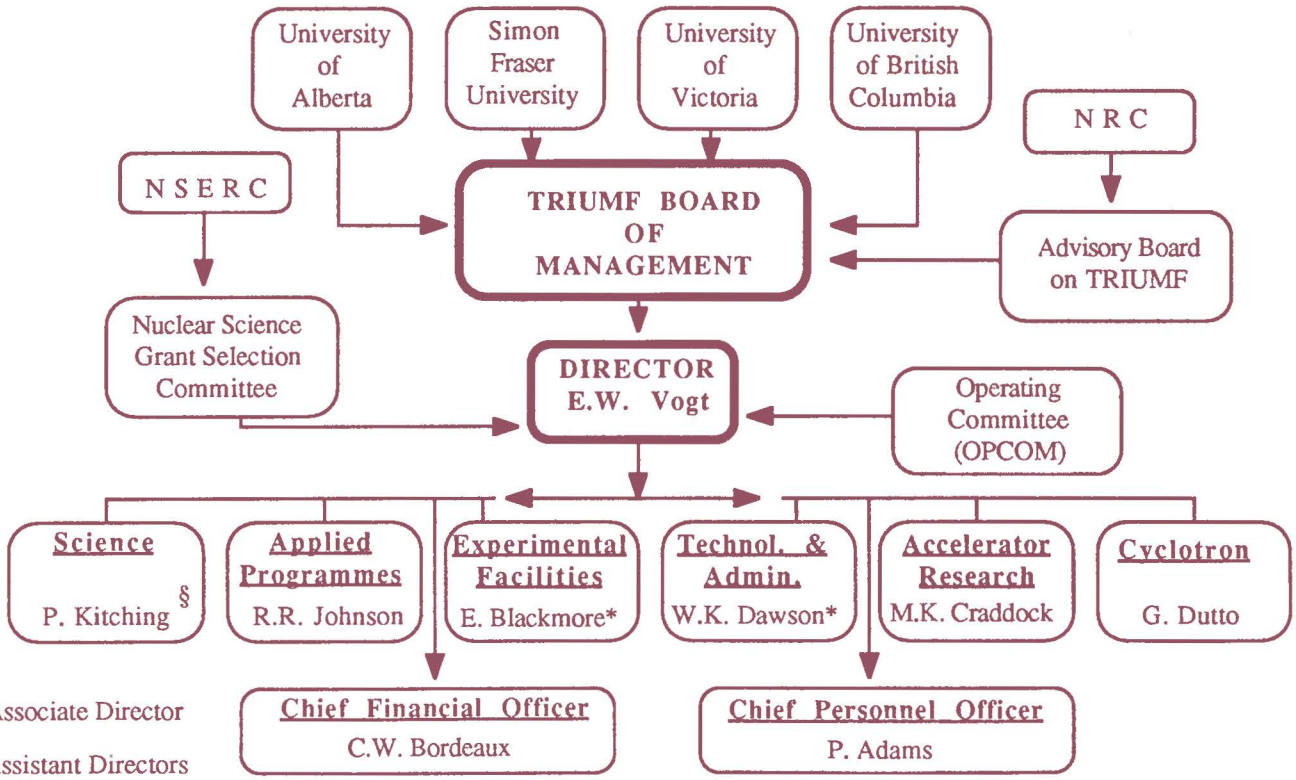

§ = Associate Director

* = Assistant Directors

Director's Report

As Canada's national facility for meson physics, TRIUMF pursues an experimental programme that involves scientific users from across the nation and from around the world. The best measure of the scientific momentum of the project is the number and quality of new scientific proposals received for the use of TRIUMF's pions, muons, protons and neutrons. By that measure TRIUMF is moving forward very strongly.

Only a small glimpse of TRIUMF's science, pure and applied, is given in these annual reports. This year's report focuses on the neutron portion of the programme, and the reader must look at other TRIUMF publications for the news about nuclear structure studies with pions, or about muons as probes of high-temperature superconductors, or many other areas of research. Each year, perhaps 60 important experiments at TRIUMF uncover new facts about this marvellous world we live in.

TRIUMF has enjoyed very strong support from the federal government in Ottawa — especially from the National Research Council, which funds its operation — from the provincial government in Victoria, and from the universities which manage it as a joint venture. With their support it is now rapidly moving toward its next phase, the KAON Factory, which promises to keep Canada at the forefront of subatomic physics for the next few decades.

An enterprise like TRIUMF thrives not only because of its science, but also because of the help given so freely to it by many individuals. Prime among these are the members of TRIUMF's Board of Management. It is with a great deal of sadness that we note the death, in 1988, of Gordin Kaplan, who was such a constructive and strong life force in his vision for the future of TRIUMF.

Erich Vogt

1988 TRIUMF Users' Group Executive Committee (TUEC)
Chairman: G. Smith
Associate Chairman: S.A. Page
Members: K. Hicks, W.D. Ramsay, G.M. Stinson
Liaison Officer: M. La Brooy

TRIUMF Users' Group

507 members from 138 institutions in 24 countries

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C. Oram
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D. Ottewell
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W. Rawnsley
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F.M. Rozon
T.J. Ruth
M. Salomon
P. Schmor
H.R. Schneider
M. Sevior
G. Smith
D.P. Spencer
I. Stancu
I.M. Thorson
A. Trudel
V.K. Verma
J.S. Vincent
E.W. Vogt
G.D. Wait
P. Walden
G. Waters
U. Wienands
R. Wittman
R. Woloshyn
J. Worden
S. Yen
M. Zach

University of Alberta

E.B. Cairns
J.M. Cameron
W.C. Choi
J.B. Elliott
P.W. Green
L.G. Greeniaus
E.A. Khaled
F.C. Khanna
E. Korkmaz
D.J. Mack
W.J. McDonald
K. Michaelian
G.A. Moss
E.A.K. Negm
G.C. Nielson
A.A. Noujaim
W.C. Olsen
J. Pasos
N. Rodning
G. Roy
H. Sherif
J. Soukup
G.M Stinson
J. Uegaki
J.S. Wesick
Y. Ye

B.C. Cancer Foundation

G.K.Y. Lam
L.D. Skarsgard
M.E.J. Young
(B.C. Cancer Control Agency)

University of Victoria

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A. Astbury
G.A. Beer
D. Britton
D.A. Bryman
E.T.H. Clifford
G.B. Friedmann
T.A. Hodges
R. Keeler
D.E. Lobb
G. Marshall
G.R. Mason
A. Olin
C.E. Picciotto
P.R. Poffenberger
P.A. Reeve
L.P. Robertson
M. Turcotte
C.S. Wu

Simon Fraser University

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S. Atkins
D. Boal
J. Brodovitch
J.M. D'Auria
O. Hausser
K.P. Jackson
R. Jeppesen
R.G. Korteling
B. Larson
P.W. Percival
B. Pointon
S. Sun-Mack
M. Vetterli
D. Webster

University of British Columbia

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D. Armstrong
E.G. Auld
D.A. Axen
M. Barnabas
J.H. Brewer
C.F. Cramer
F. Duncan
A. Feltham
D.G. Fleming
B. Forster
E. Grochowski
M. Hanna
D. Harshman
M.D. Hasinoff
G. Jones
N. Kaplan
J. Kempton
S. Kreitzman
A. Larabee
P.W. Martin
J. McAllister
C.A. McDowell
D.F. Measday
Y. Miyake
C.B.W. Ng
D. Noakes
R. Olszewski
B.D. Pate
M. Pavan
C. Ponting
I. Reid
J. Roy
D. Sample
M. Senba
V. Sossi
S. Stanislaus
R.P. Trelle
K. Venkataswaran
C. Virtue
D.C. Walker
C.E. Waltham
J.B. Warren
I. Weber
B.L. White
B. Yang
H.K. Yen

[Continued on page 5]

TRIUMF Users' Group—Other Institutions

Canada

AECL — J.K. Porter
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Carleton U. — A.L. Carter
Chalk River Nuclear Laboratories — M.S. De Jong, H.C. Lee, J.A. Sawicki
Cross Cancer Institute, Edmonton — J. Battista, J.W. Scrimger, R.C. Urtasun, S.R. Usiskin
U. of Manitoba —D. Bandyopadhyay, B.S. Bhakar, D.J. Birchall, N.E. Davison, C.A. Davis, W.R. Falk, K.M. Furutani, J. Jovanovich, R.H. McCamis, S.A. Page, W.D. Ramsay, A. Sakulovick, K.S. Sharma, J.P. Svenne, W.T.H. van Oers
McGill U. — J. Crawford, J. Lee, B. Margolis, S.K Mark, R. Moore, K. Oxorn
Universite de Montreal — P. Depommier, J. Lessard, R. Poutissou
National Research Council — M.S. Dixit, C.K. Hargrove, W.R. Jack
U. of New Brunswick — D.L. Livesey
Novatrack Analysts Limited — H. Blok, D.D. Burgess, H.L. Rosenauer
Queen's U. — G.T. Ewan, B.C. Robertson, M.J. Stott
U. of Regina — G.J. Lolos, E.L. Mathie, S.I.H. Naqvi, V. Pafilis, Z. Papandreou, D.M. Yeomans
U. of Saskatchewan — E.J Ansaldo, H.S. Caplan, R. Schubank, Y.M. Shin, N. Stevenson
Research Secretariat of B.C. — J.T. Sample
Universite de Sherbrooke — M. Krell, K.E. Newman
U. of Toronto — R. Azuma, C. Chan, T.E. Drake, L.R. Kilius, J.D. King
Vancouver General Hospital — R.T. Morrison
U. of W. Ontario — W.P. Alford, R. Helmer

Outside Canada

Australia
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U. of Melbourne — S.A. Long, K.J. Raywood, G.G. Shute, B.M. Spicer, G.N. Taylor
Flinders U. of South Australia — I.R. Afnan

Belgium
Universite Catholique de Louvain — J. Deutsch

Bulgaria
Sofia U. — I. Enchevich

China
Academia Sinica — X.-D. Jiang
Inst. Atom. Energy — Yong-Shun Wu
IHEP, Beijing — Chaoquing Chan, Z.H. Ding, N.S. Zhang, Y.P. Zhang

Finland
U. of Helsinki — J. Niskanen

France
CEN Saclay — L. Antonuk, P. Couvert, B. Mayer
Centre d'Etudes — R. Grynszpan
Bd Bequerel — F. Loyer

Germany
U. of Bonn — T. Anderl
DESY — J. Bailey
Karlsruhe — E.T. Boschitz
KFA Julich — S. Martin
Max-Planck Institut — C. Wiedner
Inst. f. Strahlen-und-Kernphysik, Bonn — J. Ernst
Tubingen U. — G. Wagner

Hungary
Central Research Institute for Physics, Budapest — D. Horvath

Israel
Hebrew U. — E. Friedman, A. Goldring
Soroka Med. Ctr. — M.R. Quastel
Tel-Aviv U. — J. Alster, D. Ashery, J.M. Eisenberg, M.A. Moinester, S. Ram, A. Stern, S.A. Wood, A.I. Yavin, A. Zidon

Italy
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INFN, Bari — N. Grion, V. Paticchio
Universita di Milano — A. Bracco

Japan
KEK — C. Yamaguchi
Kyoto U. — H. Sakaguchi
Meson Sci. Lab., Tokyo — R. Kadono
Osaka U. — T. Novo
Tohoku U. Sc — K. Sakamoto
U. of Tokyo — T. Azuma, K. Nagamine, T. Yamazaki
Tokyo Inst. of Technology — H. Miyatake, N. Nishida

Netherlands
NIKHEF — R. van Dantzig
Technische Hogeschool Delft — H. Postma
Technische Hogeschool Eindhoven — J.I.M. Botman

Nigeria
U. of Ife — B. Olaniyi

Poland
Warsaw U. — J. Miszczak

Saudi Arabia
U. of Petroleum & Minerals, Bahren — A.H. Hussein

Spain
Facultad de Fisica, Valencia — M. Vincente

Sri Lanka
P. Lumumba U. — K. Jayamana

Switzerland
Universitat Basel — G.R. Plattner
CERN — C. Amsler, G. Waters
PSI — W. Bertle, J. Domingo, H.J. Leisi, L. Rezzonico, S. van der Schaaf
Universitat Zurich — R. Engfer

Union of S. Africa
CSIR/NRIMS, Pretoria — J.M. Greben

United Kingdom
Bedford College, London — N.M. Stewart
JET Joint Undertaking, Abingdon — J. Kallne
U. of Liverpool — A.N. James
Queen Mary College, London — D.V. Bugg, W.R. Gibson
Rutherford — S. Cox
U. of Surrey — A.S. Clough, M.R. Harston, J.R.H. Smith

United States
Arizona State U. — T. Bowen, J. Comfort, P. Halverson, R.F. Marzke, J.R. Tinsley, T. Wu
AT&T Bell Labs — D. Harshman
Boston U. — E.K. McIntyre
Brookhaven National Laboratory — K.W. Jones, T.E. Ward

[Continued inside back cover]

Facilities

Although it may now be more difficult to make innovations than it was a few years ago, when the level of NRC funding was higher, some exciting changes were made, several facility contributions were made to and received from institutions abroad, and public interest in TRIUMF rose tremendously.

New M9 Beam Line

One of the most exciting changes here recently involves the M9 beam line in meson hall. For the past two years we have been moving toward modifying this beam line to accommodate a long superconducting magnet contributed by Japan. Superconducting magnets require to be cooled to very low (liquid helium) temperatures, and so a helium compressor was installed a year ago in a small building attached to the north side of meson hall. This year the helium connections were installed, and the magnet itself was delivered and was extensively tested. Final installation was well under way by the end of March. When completed later in 1988, this facility will provide an intense beam of negatively charged muons, and one of the first big experiments to be run will involve "radiative muon capture", in which the experimenters will look at the forces operating as such muons are captured by atomic nuclei in a target. Many preparations for this experiment were finished this year, and involved the construction of a large, new detector, and modifications to one of TRIUMF's old faithfuls — the large "Chicago" magnet.

TISOL

The TISOL facility, installed in proton hall during the previous year, had an important improvement early in 1988. Basically, TISOL (acronym for Test Isotope Separation On-Line) creates new, short-lived radioactive isotopes of many heavier elements by bombarding special targets in one of TRIUMF's proton beams. This process will produce several different isotopes simultaneously, but TISOL is designed to separate these, and can provide a pure beam of any single radioisotope of interest. However, because the output was physically close to the main proton hall beam lines, stray radiation reduced the sensitivity of the detection equipment. This has now been overcome by installing a short, new beam line to bend and steer TISOL's final beam into a well-shielded area. Experimenters could previously detect isotopes with half-lives as short as 100 milliseconds; they are now looking for those of 10 milliseconds.

Pion Therapy Beam Line

Another area that was taken apart and thoroughly overhauled was the M8 beam line, which carries a beam of negative pions from meson hall to the treatment room for pion therapy. As well, a new kind of collimator was installed at the end of the beam line, to give improved control of the beam as it enters the patient; and the old computer and its software (which controlled, amongst other things, the movement of the treatment couch) were replaced with up-to-date equipment possessing a much greater memory capacity.

Equipment Built for Use in Other Facilities

Recent years have brought increasing collaboration between large laboratories worldwide. This means that TRIUMF may receive equipment for new facilities being built here (e.g. the Japanese superconducting magnet already mentioned); or we may, on the other hand, contribute equipment to new facilities abroad. It also means that TRIUMF-based scientists, often involved in important experiments to be run in foreign laboratories, may contribute by tapping the wealth of expertise available here to fabricate experimental equipment, especially detectors, to be used elsewhere.

Late in 1987 TRIUMF sent West Germany part of Canada's contribution to their new "HERA" accelerator system being built in huge underground tunnels beneath the city of Hamburg: a set of 26 precision electromagnets for use in a connecting beam line. The magnets, worth about $1 million, were designed at TRIUMF, built by two Canadian firms according to our exacting specifications, and were then tested here before shipment.

Another big project during 1987 was TRIUMF's construction of approximately one third of a huge detector to be used at Stanford in an experiment to study the properties of Z particles. (These particles, one of the "carriers" of the weak nuclear force, were first discovered in a Nobel prize-winning experiment in Switzerland in 1984.) The cost of the 75 detector modules from TRIUMF was covered by a grant from NSERC, but building them was an exacting task that kept a team of technicians busy for months.

A third such project was the construction of a large detector — a cylindrical "drift chamber" — for an experiment being run at Brookhaven, N.Y., once again invoving a number of TRIUMF-based physicists.

TRIUMF's building programme essentially ended a year ago, so there were no significant extensions this year.

Public Tours of TRIUMF

Free public tours of our laboratory are normally offered twice daily for four months during the summer, and twice weekly at other times. In addition, special group tours (for students, clubs, etc.) can be pre-arranged.

Two years ago, during EXPO 86, the high tourist volume in Vancouver was reflected in a considerable increase in the number of persons touring our laboratory. In that year TRIUMF tours were taken by 2,117 persons, 705 of them being "general public" and 1,172 being students.

1987-88, however, brought us even more — 3,561 persons visited. This increase of 68% was due to a threefold jump in visits by the general public. It reflects the surge of interest in our facility following the publicity given to the KAON Factory proposal, and the national exposure (e.g. on W5 and Science Réalité) received by our applied programmes such as pion therapy for cancer.

Applied Programmes

TRIUMF's applied research is wide-ranging. Both the basic research carried out here and the equipment available are put to practical use in several areas: radioisotopes are made for medical imaging, as biological tracers, or as standards; mineral or biological materials are assayed by neutron activation analysis; an intense beam of pions is used to destroy cancer; a PET scanner creates images of living brains; new kinds of microcircuits and computer software are developed. During the past year, pion cancer therapy seems to have been in the spotlight, with much coverage both in print and the electronic media. We have therefore devoted more space below to developments in some other areas.

Positron Emission Tomography

Tomography is a recently developed imaging technique that creates special views of the interior of the body.

In a conventional X-ray picture, all the dense body structures traversed by the X-rays appear on the film, superimposed on each other. A tomograph, on the other hand, provides an image of what lies only in a single, narrow plane, a thin slice within the body. A positron emission tomograph (PET) relies on radiation emitted by structures or organs *within* a patient's body to form this kind of image. Such radiation is not normally present; to create it, a slightly radioactive substance is administered to the patient prior to the scan, and this material accumulates temporarily in the organ being examined. For PET scanners, positron-emitting radioisotopes are used.

A Window on the Brain

Some years ago TRIUMF scientists, utilizing their expertise in radiation detector technology, collaborated with the University of British Columbia to build the most sensitive and powerful of the three PET units available at that time in Canada — the PETT VI scanner. This tomograph is located in the hospital on the UBC campus, and is used for scanning brains. It is one of the most powerful imaging tools available for basic research on certain types of brain disorder.

Researchers at TRIUMF are vigorously pursuing several fronts in this area. One group works on improving the tomograph itself; another concentrates on ways of producing new kinds of suitably radioactive atoms; and a group of chemists finds ways of rapidly incorporating these atoms into pharmaceutical substances, ready for use in patients who need PET scans. This year, several scans were done in support of a novel surgical technique: patients with Parkinson's disease were treated by removing portions of tissue from their adrenal glands and implanting these in their brains, in the hope of stimulating the production of dopamine there. The operations were performed in the USA, and the patients were sent to Vancouver for PET scans to verify the success of the procedure.

Tomograph Development

Building on the experience gained in constructing the very successful PETT VI scanner, the TRIUMF tomograph development group has designed a new type of scanner, and has now begun testing a prototype. The innovative design is based on a patented, new kind of gamma-ray detector, developed over the past three years at TRIUMF.

This design leads to a machine which would be less costly than existing tomographs but which could, however, obtain the highest quality images, even when smaller doses of radiopharmaceutical were administered to the patient. Developing these features of the new instrument has been an important step in our quest to change the PET from being a rare medical research tool into an instrument routinely available for diagnosis in the nuclear medicine departments of all hospitals.

New Isotopes and Radiopharmaceuticals

Overlapping the quest for such tomograph improvements is the search for new radioisotopes, and for new radiopharmaceuticals — the chemical substances that incorporate those radioactive atoms and can carry them to the required part of the patient's body. Some of these materials, such as 6-fluorodopa and FDG (each carrying an atom of the positron-emitter, fluorine-18) are used with PET. Others are used in various other diagnostic techniques, and may include oxygen-15, carbon-11, or iodine-123 as the radioisotope. The Radiochemical Co., a subsidiary of Atomic Energy of Canada Ltd., occupies a laboratory at the TRIUMF site, and received awards last year (in the "Innovation" category of the annual Canada Awards for Business Excellence) for developing a way of producing ultra-pure iodine-123. This isotope has now become one of the firm's most profitable products. It can be incorporated into any one of several organic molecules, each specially tailored to transport the iodine into a specific bodily organ with minimal radiation hazard to the patient. Other new radiopharmaceuticals prepared at TRIUMF include SCH 23390, a ligand which labels certain receptor sites in the brain, and raclopride containing carbon-11, also used for studying brain receptor sites.

Pion Therapy

At least one milestone must be mentioned here: during the course of the year, this programme marked the fifth anniversary of its first human treatment by this method. Over 150 patients have now received pion therapy, but the treatment is still officially regarded as experimental. Although a formal statistical survey and report are not yet available, the results so far are clearly superior to those of alternative treatments for patients with glioblastoma brain tumours. TRIUMF is still one of only two places in the world where pion therapy is available, and we continue to receive many inquiries about it, both from Canada and abroad.

Pure Research at TRIUMF

TRIUMF's Neutron Beam—A Probe of Nuclear Structure

The Neutron in Nuclear Physics

Nuclear physics — the study of atomic nuclei — was born in 1911 as a result of the pioneering work of Lord Rutherford. In an historic experiment, he shone a narrow beam of fast-moving alpha particles (products of natural radioactivity) onto a series of thin foils made of various metals. Though most of the alpha particles passed straight through, a few were scattered in various directions. Studying their scatter patterns, Rutherford found he could mathematically describe the scattering process in terms of collisions between two very small positively charged objects. He concluded that these collisions, resembling those between tiny billiard balls, involved the alpha particles and *a very small part of each individual atom* in the metal targets — the central core, or the *nucleus* of each atom.

Rutherford's experiments correctly identified the nucleus as a very well localized concentration both of electric charge and of most of the atom's mass. But did the nucleus itself contain simpler components? Our basic understanding of its structure followed Chadwick's discovery of the *neutron* in 1932. This electrically neutral particle, unstable when isolated, is the more elusive of the two basic constituents of nearly all nuclei. The other one, the proton, also constitutes the entire nucleus of the lightest atom, hydrogen.

Today, any institution involved in nuclear research requires a substantial library to catalogue the wealth of detailed experimental information available on the nearly 300 naturally occurring nuclei and the many more which have been artificially produced as the result of nuclear reactions. A truly remarkable feature of this vast array of data is the extent to which it can be explained in terms of neutrons and protons and what we now know about the nature of the force acting between these nuclear constituents. A very significant simplifying feature is that the neutron and proton can be viewed as two versions of one particle, the nucleon, and are distinguished primarily by their electric charge.

Is it adequate to describe nuclei in terms of neutrons and protons? This has recently become an increasingly important question, following the clear evidence that the nucleons themselves are composite objects. Each nucleon consists of three charged quarks, bound together by uncharged gluons. Nuclear physicists pursue the goal — sometimes intriguing, always elusive — of identifying specific properties of nuclei that can be explained only in terms of their quark components.

The Force Between Two Nucleons

It is very important that we thoroughly understand the forces that act between just *two* nucleons. This can then become the natural starting point for a description of the structure of more complex nuclei. Experiments at TRIUMF have played a crucial role in our present understanding of two-nucleon interactions; in particular, they have provided precise information on the force that acts between a neutron and a proton. TRIUMF anticipated the need for this kind of experiment, and one its first initiatives was to provide a well-defined beam of neutrons, all having nearly the same energy (velocity). The past 12 years have seen many important experiments where this beam was directed onto different kinds of targets containing hydrogen, so that the individual neutrons in the beam could interact with the single protons in the hydrogen nuclei. Fundamental experiments of this nature are still a vital part of the TRIUMF programme.

For many investigations of the collisions of free nucleons, we need to know the energy of the neutron beam to within about 20 MeV (million electron volts). This is roughly 5-10% of the total kinetic energy of neutrons available at TRIUMF (200 to 500 MeV), and the original neutron beam here was designed to meet this requirement.

However, measuring much smaller energy changes is not so easy. Each atomic nucleus must obey the laws of quantum mechanics, and so can exist only in one of many well-defined "energy states". That is to say, it can change its energy content only by specific amounts — steps in a staircase, rather than a continuous slide. The differences between these "allowed" energies are around 1 MeV or less. Therefore, if we are to use neutrons to probe the detailed structure of the nucleus, we must produce a beam whose energy is known to within 1 MeV, or we must be able to measure the energy of neutrons emitted in nuclear reactions with similar precision. TRIUMF now has a unique facility, recently developed, to exploit the neutron in this way.

The (p,n) and (n,p) Reactions on Nuclei

What are the simplest possible ways that one allowed energy state of a nucleon can be converted into another? Answering this is an important objective in the study of any system having discrete energy levels. When a beam of protons strikes an experimental target, many reactions are possible. In some cases, an energetic proton striking a nucleus can result in the emission of a single energetic neutron. These processes are called (p,n) reactions to designate the incoming and outgoing particles, and investigating them has been very important for more than 25 years. This reaction can be used to transform the lowest energy state of the target nucleus into one of two very similar states in the new nucleus produced in the reaction. The transformation involves simply the conversion of one of the *neutrons* in the target nucleus to a *proton* in precisely the same spatial "orbit". Experiments such as these, identifying the simplest kinds of nuclear excitation in a wide range of nuclei, are amongst the highlights in the history of the field.

In general, the energy (velocity) of the incoming protons determines the probability that the (p,n) reaction alters the orbit of

only *one* of the target nucleons. Until the development of the facility at TRIUMF, experimenters everywhere were essentially limited to using protons at energies of 200 MeV or less. The study of (p,n) reactions at these energies had been very informative, and it was clear that important new information could be obtained by making measurements in the range of proton energies available at TRIUMF (200 to 500 MeV).

In addition to the prospect of making important contributions to an already active field, a rare opportunity arose for TRIUMF experimenters to initiate further studies: they would now be able to look at the very similar (n,p) reaction, where energetic incident neutrons are transformed into emerging protons. An important difference between these two reactions arises from the *relative numbers* of neutrons and protons in the target nucleus.

Some nuclear targets (such as carbon-12, the most abundant isotope of carbon) contain equal numbers of neutrons and protons. The very close similarity between the neutron and proton within a nucleus implies that studies of the (p,n) and (n,p) reactions for these targets should yield essentially identical results.

Dramatically different results, however, are expected for a nucleus such as lead-208, which consists of 126 neutrons and 82 protons. It is relatively easy for the (p,n) reaction to convert one of the "excess" neutrons into a proton, yielding a nucleus of bismuth-208. The (n,p) process here is not so easy. We have long known of an "exclusion principle" which states that two identical nucleons may not occupy the same orbit within the nucleus. The large neutron excess in lead means that many of the available neutron orbits are already occupied, and this strongly inhibits the transformation via the (n,p) reaction of one of lead's 82 protons into a neutron in a similar nuclear orbit.

These two examples illustrate the range of experiments possible if both (n,p) and (p,n) experiments can be performed on the same nuclear target. In the case of carbon-12, with equal numbers of neutrons and protons, subtle effects resulting from the differences between the neutron and proton can be investigated. For the structure of lead-208, however, the (n,p) reaction would provide very different information from that available from studies of the (p,n) reaction. Prior to recent developments at TRIUMF, there was no facility available anywhere for the study of the (n,p) reaction on nuclear targets at appropriate neutron energies.

(p,n) Studies at TRIUMF

Proton beams suitable for the study of (p,n) reactions are readily available in beam line 4B at TRIUMF. The challenge, as mentioned earlier, involved detecting the energy of the emitted neutrons to within about 1 MeV. We have accomplished this by a slightly devious route, making use of two facts. First, if energetic neutrons strike target material containing hydrogen, a small but useful fraction of the neutrons will be converted into *protons moving in the same direction, with the same energy*. Second, the energy of protons is relatively easy to measure: a magnetic field forces any moving, charged particles to travel in curved paths, and the degree of curvature depends on their energy. We therefore place the material containing the hydrogen in the path of the neutrons, positioned so that the energy of the emerging protons can be measured by bending their paths in a known magnetic field. This magnetic deflection is accurately measured in the medium resolution spectrometer (MRS) located in the proton hall.

The first experiment performed with this system involved studies of the (p,n) reaction on a target formed of the radioactive isotope carbon-14. This target was chosen because studies of how the (p,n) reaction places nucleons in two well-known states in the nitrogen-14 nucleus provide a critical testing ground of the way in which the reaction takes place with protons at the energies available at TRIUMF. This initial calibration of the probe has been followed by several useful investigations of other nuclei.

(n,p) Studies at TRIUMF

The (n,p) experiments at TRIUMF utilize essentially the same equipment as mentioned above. But how do we create the neutron beam? Studies of the (p,n) reaction show that if a proton beam strikes a primary target of lithium-7 atoms, a useful beam of neutrons will be produced. Most of the neutrons travelling in the same direction as the incident protons have an energy just slightly lower than that of the protons. This neutron beam can then be used to bombard a secondary target containing the nuclei of interest. Protons emitted as the result of (n,p) reactions in this target are detected in the MRS.

In the past 30 months, we have completed studies of the (n,p) reaction on many nuclei, ranging from deuterium (hydrogen-2) to uranium-238. For several targets with *equal* numbers of neutrons and protons, careful comparisons have been made of the corresponding (p,n) and (n,p) results. Already the precision of the (n,p) measurements rivals, and in some cases exceeds, that of the well-established (p,n) experiments. As expected, the (n,p) results for the heavier nuclei (containing many more neutrons than protons) are very different from those obtained with the (p,n) reaction. One observation is of particular importance: some sophisticated theories which seemed to account very well for previous (p,n) results fail conspicuously to account for the new (n,p) data. Much, therefore, remains to be done, both in terms of critical new experiments and further theoretical analysis.

In specific cases the results of the (n,p) experiments have relevance far beyond the field of nuclear physics. These are cases where estimates of the rates of certain nuclear reactions are crucial ingredients in the analysis of *other* experimental observations. Such applications are wide-ranging, from the smallest to the largest events in our universe. For instance, the results of neutron experiments are relevant in efforts to infer the mass and other properties of the elusive neutrino, and in ambitious attempts to account in detail for the processes involved in a supernova explosion.

Financial Review

The fiscal year 1987-88 was financially a stagnant one: the funds received from the National Research Council were at the same level as those for 1986-87 for operations, improvements and development, expansion of facilities and general support for experiments. The balance of funding was, when averaged out, also the same as in the previous year. As well, it was a time of uncertainty: we did not know what form the requisite upgrading of the facility would take in the coming years. Activities centred around maintaining as active a base as possible under these circumstances, so that future expansion can take place in whatever direction is selected.

The Medical Research Council of Canada continued to provide substantial support. Those funds are administered elsewhere and are therefore not reported here. The same holds true for funding by the Natural Sciences and Engineering Research Council of TRIUMF-based experiments administered elsewhere, as distinct from those administered at TRIUMF. Atomic Energy of Canada Limited is still the major commercial user of TRIUMF facilities. The flow of their funds through TRIUMF fluctuates because the great majority of their transactions are handled by their administration located on the TRIUMF site. Only those services required directly from TRIUMF are reported here.

The number of transactions handled on behalf of affiliated institutions has stabilized. The receipts consist of imprest funds and reimbursements of expenditures undertaken on behalf of these institutions, from Canada and abroad, for their TRIUMF projects. Expenditures in the Statement of Combined Funding and Expenditures are at acceptable levels. It is expected that the Federal Government will continue to support TRIUMF at a level sufficient to maintain the high international standing TRIUMF has achieved, and that this support will include the requisite upgrading of the facilities.

Source of Funds (millions of dollars)

	1987-88		1986-87
Source	Rec'd	%	%
National Research Council	$25.90	80.58	80.40
Natural Sciences and Engineering Research Council	3.04	9.46	8.31
Affiliated Institutions	1.69	5.26	5.48
Atomic Energy of Canada Ltd.	1.33	4.14	4.71
Province of British Columbia	—	—	.55
Miscellaneous	.18	.56	.55
	$32.14	100%	100%

Coopers & Lybrand

chartered accountants

a member firm of
Coopers & Lybrand (International)

AUDITORS' REPORT TO
THE BOARD OF MANAGEMENT
TRIUMF

We have examined the statement of financial position of TRIUMF as at March 31, 1988 and the statements of funding and expenditures for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests and other procedures as we considered necessary in the circumstances.

In our opinion, these financial statements present fairly the financial position of TRIUMF as at March 31, 1988 and its funding and expenditures for the year then ended in accordance with the accounting policies set out in note 2 to the financial statements, applied on a basis consistent with that of the preceding year.

Coopers & Lybrand

Vancouver, B.C.
June 3, 1988

[Editor's note: The following pages present *excerpts of the auditors' report* prepared by Coopers & Lybrand. Persons wishing to see the entire report should contact the TRIUMF Business Office.]

TRIUMF
STATEMENT OF COMBINED FUNDING AND EXPENDITURES
FOR THE YEAR ENDED MARCH 31, 1988

	1988	1987
	$	$
FUNDING		
National Research Council	25,900,000	26,095,459
Natural Sciences & Engineering Research Council	3,037,458	2,699,402
Atomic Energy of Canada Limited	1,332,119	1,529,850
Universities Council of British Columbia		182,751
Affiliated institutions	1,694,270	1,775,880
Investment income	180,801	171,321
	32,144,648	32,454,663
EXPENDITURES		
Building construction	18,835	479,518
Communications	304,622	287,042
Computer	1,410,500	2,213,794
Equipment	2,250,614	2,407,915
Lease payments — Atomic Energy of Canada Limited	578,508	650,284
Power	1,664,174	1,723,386
Salaries and benefits	19,238,755	18,562,793
Supplies and expenses	6,620,881	6,596,653
	32,086,889	32,921,385
EXCESS (DEFICIENCY)	57,759	(466,722)
LESS: DEFERRED FUNDING — NRC	216	154
SURPLUS (DEFICIT) FOR THE YEAR	57,543	(466,876)
SURPLUS — BEGINNING OF YEAR	887,729	1,354,605
SURPLUS — END OF YEAR	945,272	887,729

TRIUMF
STATEMENT OF FINANCIAL POSITION
AS AT MARCH 31, 1988

	1987 $	1986 $
ASSETS		
CASH AND TEMPORARY INVESTMENTS	1,428,446	1,852,163
ACCOUNTS RECEIVABLE	360,341	208,690
TOTAL ASSETS	1,788,787	2,060,853
LIABILITIES AND SURPLUS		
ACCOUNTS PAYABLE	251,922	470,056
DEFERRED FUNDING - NRC	216	154
DUE (FROM) TO UNIVERSITIES		
The University of Alberta	(2,245)	2,845
The University of Victoria	(12,512)	37,287
The University of British Columbia	598,641	635,741
Simon Fraser University	7,493	27,041
	591,377	702,914
SURPLUS (DEFICIT)		
Universities Council of British Columbia		853
Natural Sciences and Engineering Research Council	888,488	782,605
Affiliated institutions	162,506	96,121
Atomic Energy of Canada Limited	(272,520)	(59,222)
TRIUMF surplus	166,798	67,372
	945,272	887,729
TOTAL LIABILITIES AND SURPLUS	1,788,787	2,060,853

ENCUMBRANCES AND COMMITMENTS (note 3)

NATIONAL RESEARCH COUNCIL
STATEMENT OF FUNDING AND EXPENDITURES
FOR THE YEAR ENDED MARCH 31, 1988

	1988 $	1987 $
DEFERRED FUNDING - BEGINNING OF YEAR	154	2,613
FUNDING		
Cash contribution	25,899,846	26,092,846
TOTAL APPROVED CONTRIBUTION	25,900,000	26,095,459
EXPENDITURES BY ACTIVITY AREA		
Salaries	16,268,280	15,870,489
Power	1,664,174	1,723,386
Administrative and overhead	1,421,919	1,649,306
Cyclotron and facilities operation	2,577,707	2,557,293
Site services	441,196	465,198
Support services	1,772,096	1,592,556
Major projects	1,633,376	2,302,837
Minor projects and development	305,625	312,764
	26,084,373	26,473,829
Funds recovered — cost centres	184,589	378,524
TOTAL EXPENDITURES	25,899,784	26,095,305
DEFERRED FUNDING — END OF YEAR	216	154

EXPENDITURES BY OBJECT

Buildings	11,736	(211)
Communications	224,893	238,728
Computer	1,134,800	2,056,352
Equipment	1,888,754	1,946,618
Power	1,664,174	1,723,386
Salaries and benefits	16,339,027	15,943,828
Supplies and expenses	4,636,400	4,186,604
	25,899,784	26,095,305

TRIUMF
NOTES TO FINANCIAL STATEMENTS
FOR THE YEAR ENDED MARCH 31, 1988

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.

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 by TRIUMF, which are owned by the University of British Columbia.

These financial statements include the statements of fund transactions of TRIUMF. The sources and purposes of these funds are:

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

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

(c) Universities Council of British Columbia
Funding for buildings. All building projects to which funds were allocated have now been completed.

(d) Atomic Energy of Canada Limited
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) TRIUMF
Investment income for discretionary expenditures incurred by TRIUMF.

2. SIGNIFICANT ACCOUNTING POLICIES

As a non-profit organization, TRIUMF follows generally accepted accounting principles as referred to in the CICA Handbook except for:

- Capital Assets and Supplies
  Expenditures on capital assets and supplies are expensed as incurred.

- Operating and Capital Leases
  Lease payments are expensed when incurred.

TRIUMF
NOTES TO FINANCIAL STATEMENTS
FOR THE YEAR ENDED MARCH 31,1988

3. ENCUMBRANCES AND COMMITMENTS

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

	1988 $	1987 $
National Research Council	2,839,000	1,365,000
Natural Sciences and Engineering Research Council	206,000	311,000
Atomic Energy of Canada Limited	52,000	39,000
Affiliated institutions	73,000	55,000
	3,170,000	1,770,000

4. NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL — SURPLUS

	1988 $	1987 $
Funding unexpended	1,149,987	1,149,948
Grant accounts overexpended	(261,499)	(367,343)
Surplus — end of year	888,488	782,605
Number of grants awarded during year	49	47
Number of grants administered throughout year	96	78

5. AFFILIATED INSTITUTIONS — SURPLUS

The surplus funds at the fiscal year end are composed of:

	1988 $	1987 $
Funding received in advance	534,186	462,951
Funding receivable	(371,680)	(366,830)
Surplus — end of year	162,506	96,121

TRIUMF Users' Group — Other Institutions

(continued from page 5)

Brooklyn College, CUNY — A. Rosenthal
California Institute of Technology — K.H. Chang, A. Gonzales
California State U. — K. Aniol, M. Epstein, E.F. Gibson, D.J. Margaziotis
U. of California, Davis — F.P. Brady
U. of California, Irvine — W.P. Lee
U. of California, Los Angeles — B.M.K Nefkens, J.R. Richardson
Carnegie Mellon — P.D. Barnes
Central Washington U. — W.C. Sperry
U. of Cincinnati — S. Jha
U. of Colorado — J. Brack, X.Y. Chen, J.J. Kraushaar, D.A. Lind, R. Loveman, T. Masterson, R.A. Ristinen, J.R. Shepard, K. Vaziri, C.D. Zafiratos
Drexel U. — B.H. Wildenthal
U. of Florida — R. Piercy
Florida State U. — X. Aslanoglou, H.S. Plendl
General Physics Corporation — J. Clark
U. of Georgia — F.T. Baker
Hood College — J.M. Stadlbauer
U. Houston — C. Chu, P.J. Gareri Jr., W.W Mayes II, L.S. Pinsky, L. Tang
Idaho Nat. EL — A.J. Caffrey
Indiana U. — R.D. Bent, B. Blankleider, G.T. Emery, G. Huber, W.P. Jones, H.O. Meyer, M.E. Rickey, R. Sawafta, P. Schwandt, E.J. Stephenson, T. Ward
Johns Hopkins U. — Y.K. Lee
Kent State U. — B.D. Anderson, R. Madey, R. Pourang, P. Tandy, J.W. Watson
Kentucky U. — M.A. Pickar
Lawrence Berkeley Laboratory — C. Clawson, K.M. Crowe, R. Ferguson, G. Gidal, S. Kaplan, S. Ljungfelt, R.H. Pehl, V. Perez-Mendez, S. Rosenblum, H. Steiner, M.W. Strovink, R. Tripp
Lewis Reearch Center, NASA — J.W. Blue
Los Alamos National Laboratory — L.E. Agnew, H.L. Anderson, V.R. Cupps II, R.E.L. Green, R.C. Haight, C.Y. Huang, K. Jones, N.S.P. King, R.J. Macek, E.R. Siciliano
U. of Maryland — N.S. Chant
Massachusetts Institute of Technology — R.P. Redwine, G. van der Steenhoven, S.A. Wood
U. of Michigan — L. Antonuk, F.D. Becchetti
Michigan State U. — W. Benenson, L. Heilbronn, E. Kashy, D. Krofchek, D.J. Morrisey, A. Pradhan, G.D. Westfall
U. Missouri, Kansas City — J. Jean
National Science Foundation — H.B. Willard
U. of New Mexico — B. Bassalleck, B. Dieterle, G. Kyle
State U. of New York, Geneseo — J.R. Chen
Northwestern U. — B. Parker, R.E. Segel, K.K. Seth
Notre Dame U. — S.E. Darden, J.J. Kolata, R.E. Warner
Oak Ridge National Laboratory — F. Bertrand, B. Burks, C. Glover, D.J. Horen, J. Lisantti, T.P. Sjoreen
Ohio State U. — B.C. Clark, T.R. Donoghue
U. of Oregon — D.K. McDaniels
Oregon State U. — F. Farzanpay, P. Fuchs, K.S. Krane, R. Landau, A.W. Stetz, L.W. Swenson
U. of Redlands — R.F. Carlson
Rice U. — J.M. Clement, S.A. Dodds, T.L. Estle, G.S. Mutchler
Rutgers U. — C. Glashausser, A. Green
Stanford Linear Accelerator Center — R. Dubois
U. of Texas — M. Bachman, P.J. Riley
Texas A&M U. — R. Bryan
Utah State U. — V.G. Lind, R.E. McAdams, O.H. Otteson
U. of Virginia — D. Pocanic, C.E. Stronach
Virginia Polytechnic Institute and State U. — M. Blecher, K. Gotow, D. Jenkins, A. Serna, D.H. Wright
U. of Washington — I. Halpern, E.M. Henley, A.G. Williams
Western Wasington U. — A.S. Rupaal
Central Washington U. — W.C. Sperry
W. Kentucky U. — D. Humphrey
William and Mary Coll. — C.F. Perdrisat, M. Eckhause, W.J. Kossler, R.T. Siegel
Winona State U. — C.B.W. Ng
U. of Wyoming — T.M. Huber, R. Kunselman

(Unaffiliated) — J.S. Fraser, T.C. Sharma

USSR

Inst. Nuc. Rsrch. — V.N. Bolotov, S. Ju, V.D. Laptev, E.A. Monich

Yugoslavia

Inst. R. Boskivic, Zagreb — M. Furic