Canadian
Fusion Fuels
Technology
Project

Annual Report 1988-89

The CANADIAN FUSION FUELS TECHNOLOGY PROJECT, founded in 1982, is a key fusion centre in Canada's National Fusion Program (NFP).

CFFTP is funded jointly by the Government of Canada, the Province of Ontario and Ontario Hydro.

- Government of Canada participation is via Atomic Energy of Canada Ltd., which operates NFP with funds supplied by Energy, Mines and Resources Canada, —Panel on Energy, Research and Development.
- The Province of Ontario participates through the Premier's Council Technology fund, operated by the Ontario Ministry of Industry, Trade and Technology and supported by the Ontario Ministry of Energy.
- Ontario Hydro is the administrator of the Project and supplies key CFFTP staff.

CFFTP's mission is to extend Canada's fusion capabilities, by developing and applying specific fusion technologies. CFFTP technology programs concentrate on:

- Fusion fuel cycle research and development
- Site, reactor, and system design and engineering
- Safety and environmental aspects of fusion

One of CFFTP's goals is to contribute to world fusion projects to aid the global effort in fusion development.

Another specific CFFTP goal is development of technologies and engineered systems for the next-step fusion reactors being designed now. Last year, Canada became a contributor to the International Thermonuclear Experimental Reactor (ITER) through a special fusion partnership with the European Community.

In Canada, CFFTP manages and supports programs in research and development, engineering design, and transfer of technology to industry. Outside Canada, CFFTP has working partnerships with a number of fusion projects in Europe, the United States, and in Japan.

Electrical utilities will continue to need a mix of energy options in the future, as they have done in the past. Changes in world conditions, and in the availability of traditional energy sources require that utilities and governments further explore and evaluate the newer ways and means of energy production. Exploration of the fusion option is an important part of energy planning for the future.

CFFTP and Ontario Hydro view the partnerships with fusion programs in other countries, such as Canada's participation in ITER, as essential to successful development of fusion energy.

Ontario Hydro's commitment to electrical power research spans more than seven decades. We are dedicated to making domestic and foreign power systems more secure, cost-effective and environmentally safe. Our participation in CFFTP, and our role as CFFTP project manager are part of that commitment.

Robert Franklin
Chairman and President
Ontario Hydro

It gives me much pleasure to present this annual report on CFFTP's seventh year of operation. The year was one of great interest and activity, and of satisfying accomplishment.

We welcome the renewed support of the Province of Ontario as a funding partner in CFFTP. Their participation, through the Premier's Council Technology Fund, will help CFFTP to operate more effectively in joint international tasks. In particular, the funds will permit more rapid technology transfer to industry by allowing CFFTP to award more fusion design contracts for work pertinent to next step machines, like ITER and NET, to Canadian engineering companies.

Additional federal funding has been requested from the Department of Regional Industrial Expansion to match the Provincial funds. These funds will help prepare industry and the Canadian program to cooperate in the international programs that will emerge in the 1990's.

During the last year we further extended our work in fusion plant design and fusion reactor system integration, while continuing work in traditional CFFTP areas of tritium and fuel system research and design, remote handling and safety. The newer work added to the widening international recognition of the technology capabilities of CFFTP and its partner R&D organizations.

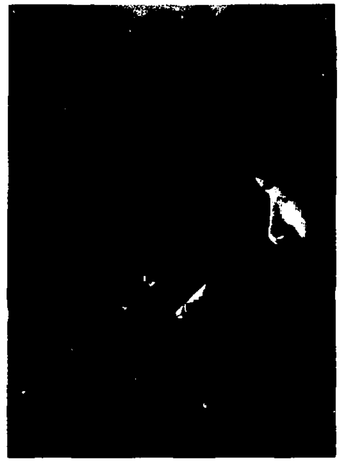
Application abroad of our fusion technologies has increased dramatically; we are supplying complete, engineered fusion systems to senior world fusion laboratories. Recently, CFFTP was awarded the task of designing the reactor exhaust and fuel cleanup systems for the Next European Torus (NET) project in Europe.

The acceptance of Canadian participation in the R&D and design work for ITER, the International Thermonuclear Experimental Reactor, has been most gratifying. The multi-national ITER collaboration is a world flagship program to design an energy-producing prototype fusion reactor. A special Canada- European Community agreement establishes the protocol for our involvement in ITER through the European Community.

The total value of work performed for 1988/89 was $10 million. This was comprised of $6 million of base partner funding, with the balance made up of in-kind contributions by subcontractor and client funds.

We completed delivery of accelerator tritium control systems to King Fahd University, Saudi Arabia, and were awarded contracts to deliver complete engineered tritium systems to University of Rochester Laboratory for Laser Energetics, USA, and to the Kernforschungszentrum Karlsruhe Tritium Laboratory, Federal Republic of Germany.

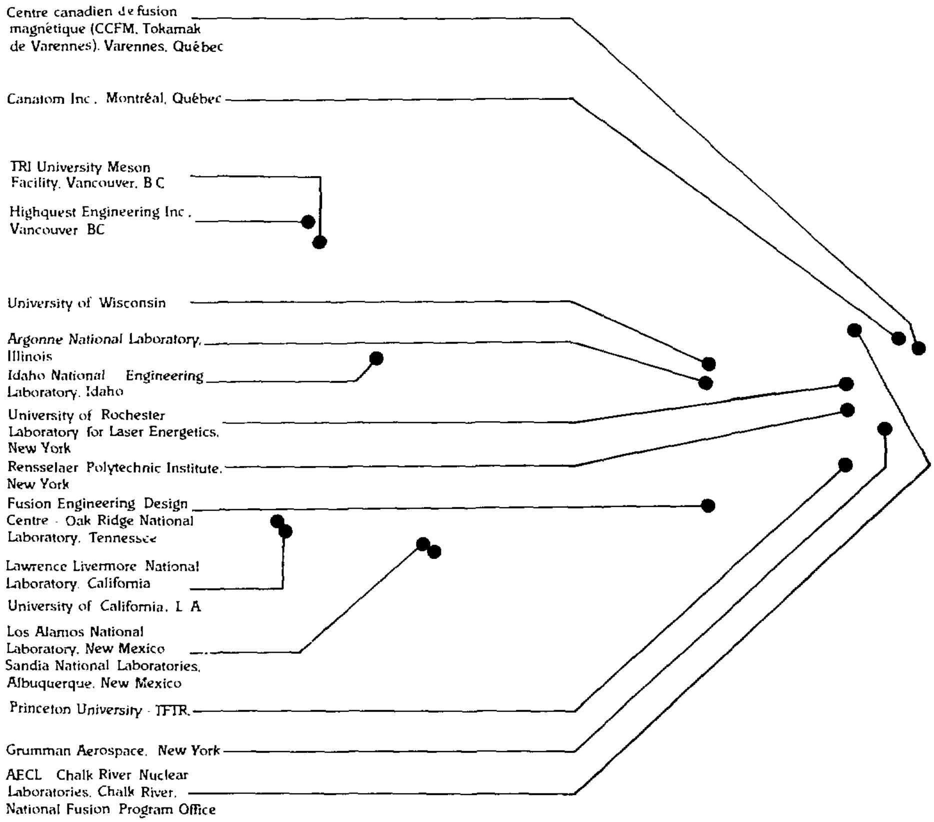
The scale and reach of CFFTP activities have never been greater than today. The capabilities we have developed, and continue to develop, rest on active partnerships with industry, universities, governments and utilities. Through these partnerships, fusion engineering capabilities of international calibre are being transferred to Canada's science and engineering infrastructure at an increasing pace.



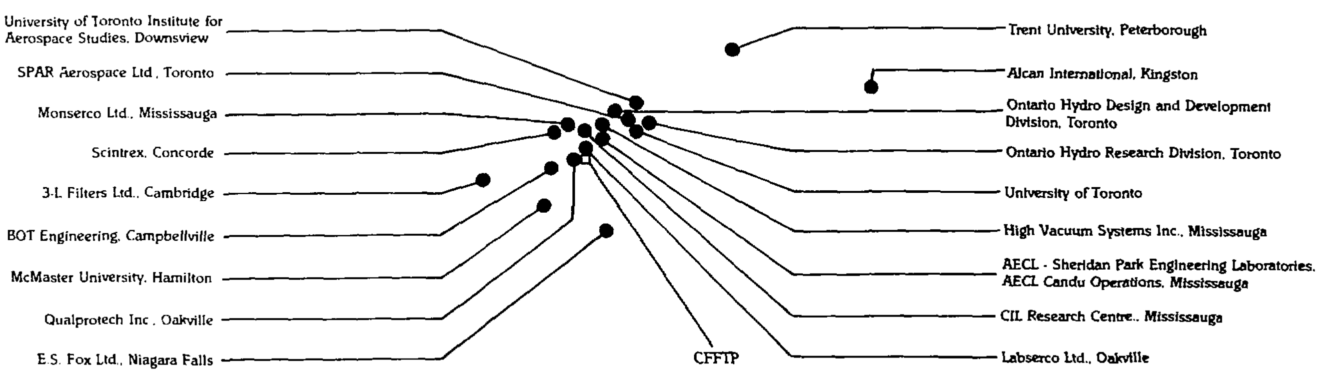
I would like to extend greetings to our friends and collaborators around the world, and to all Canadians participating in CFFTP's programs. CFFTP will continue in the coming years to contribute as much as possible to the world effort in fusion. The staff of CFFTP look forward to sharing continued friendship with our colleagues in Canada and abroad in advancing toward our common goal.

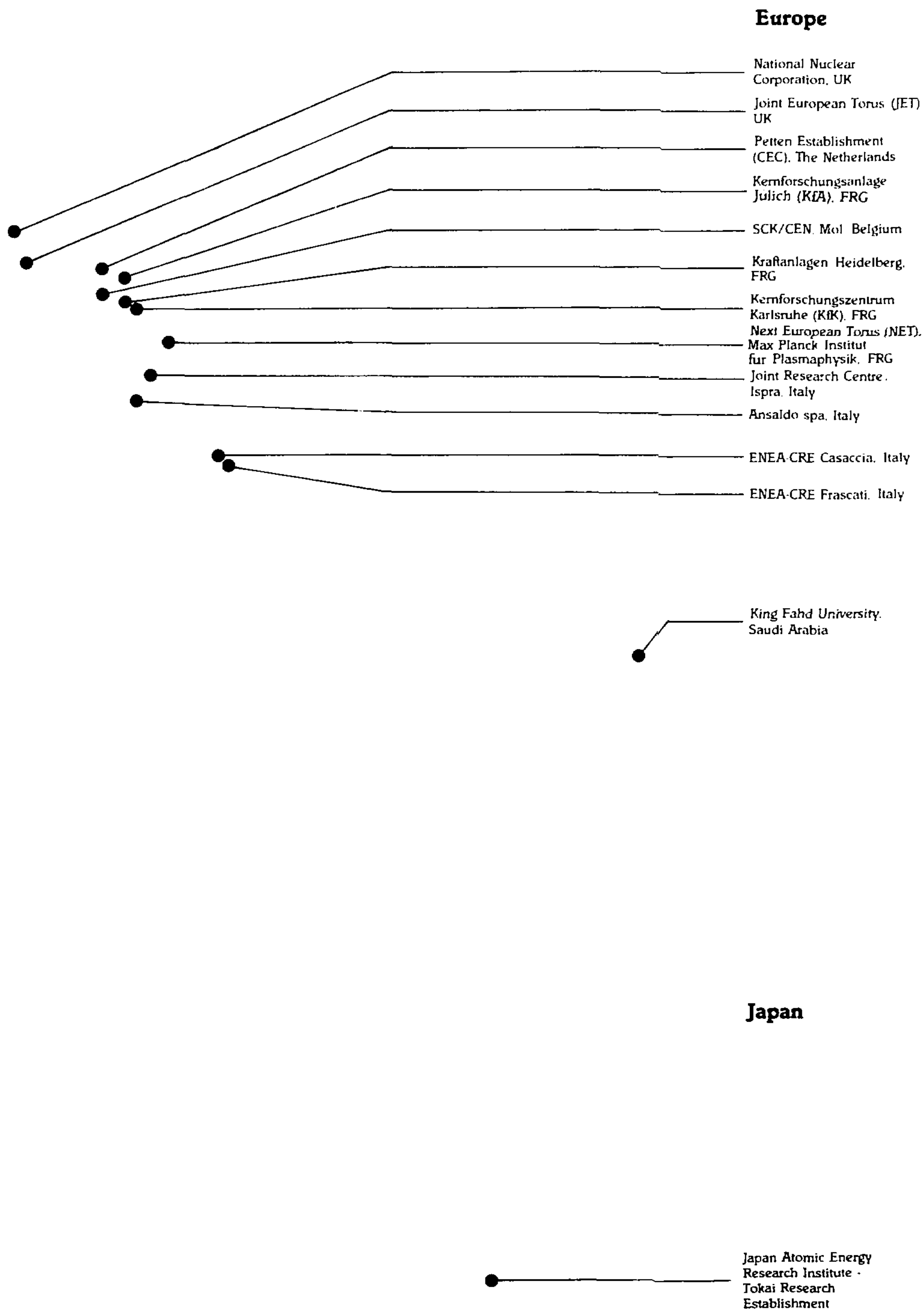
Donald P. Dautovich
Program Manager

North America



Southern Ontario




Europe
National Nuclear Corporation, UK
Joint European Torus (JET) UK
Petten Establishment (CEC), The Netherlands
Kernforschungsanlage Julich (KfA), FRG
SCK/CEN, Mol Belgium
Kraftanlagen Heidelberg, FRG
Kernforschungszentrum Karlsruhe (KfK), FRG
Next European Torus (NET), Max Planck Institut fur Plasmaphysik, FRG
Joint Research Centre, Ispra, Italy
Ansaldo spa, Italy
ENEA-CRE Casaccia, Italy
ENEA-CRE Frascati, Italy
King Fahd University, Saudi Arabia
Japan
Japan Atomic Energy Research Institute - Tokai Research Establishment

Fusion is a natural source of energy; it is the energy source that heats stars. At the core of every visible star, the fusion process is continually generating vast amounts of energy that heat the entire star to incandescence. Fusion in the sun provides the sunlight energy that maintains life on earth.

Fusion simply means the joining together of atoms to produce a heavier atom. At temperatures of tens of millions of degrees, atoms of certain elements such as hydrogen can be made to join, or fuse, together. When they do so they release energy, as they fuse with each other to create an atom of a different, heavier element such as helium.

The energy released by one fusion reaction is tiny. However, if fusion reactions are made to happen continuously in great numbers, the small individual energy parcels add together so that very large amounts of energy can be obtained for long periods.

The Goal of Fusion Research

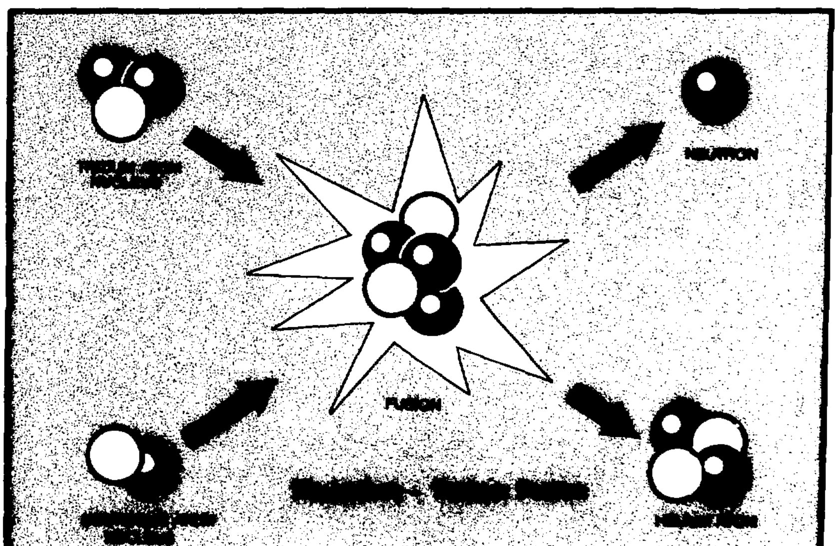
The goal of the world's fusion programs is to harness the fusion process in practical power plants, to generate usable energy in the form of heat or electricity.

This goal has not been an easy one to reach. Generating usable energy from fusion is possibly the most difficult technical challenge ever undertaken by humanity. We need to create star-like conditions in a man-made machine, to 'ignite' and sustain the fusion reaction so that we can extract the energy generated.

Although we are becoming confident that fusion can be a practical energy source, we still need improved knowledge in physics and in fusion plant engineering. In physics, for example, we still need to understand more about how the hot fuel gas, or plasma, behaves at fusion temperatures, so that maintaining energy-generating fusion reactions becomes routine. In engineering, we need to design sophisticated structures and find new heat resistant materials to build a durable, cost effective fusion plant.

Prototype fusion power reactors, called *next step* machines are being designed now. The best-known next step machines are the multi-national ITER project and the European Community's Next European Torus, both headquartered in West Germany. Construction of a demonstration fusion reactor could well begin in about five years, with demonstration of fusion power generation about ten years later.

Deuterium-Tritium Fusion Reaction. At temperatures over 100 million degrees, nuclei of deuterium and tritium atoms have enough energy to breach natural repulsion barriers and fuse together.



Abundant Fuels

The most likely fuel for the first fusion plants is a gas mixture containing two forms of hydrogen called deuterium and tritium. Deuterium is very plentiful; it is more abundant than all but eleven of the elements. Tritium, however, occurs naturally only in trace quantities; tritium for use as fusion fuel would be made in the fusion energy plant from the element lithium.

As a fusion fuel, a deuterium-tritium gas mixture is very rich in energy; just one gram of deuterium-tritium (D-T) mixture, fused completely, will release the same energy as 70 *million* grams (ten thousand litres) of gasoline.

Lithium is found widely on every continent in various mineral forms. It is readily mined and can be easily converted to the chemical forms needed for processing into tritium in the fusion plant. There is enough lithium on earth for at least 10,000 years of electricity generation at global levels of energy use.

Deuterium is found as a component of all natural hydrogen, at one part in 7,000. Since water is made up of hydrogen and oxygen, deuterium can be extracted as so-called heavy water from either fresh water or salt water, anywhere in the world. Pure deuterium, a gas, can then easily be made from the heavy water by electrolysis.

Success in harnessing fusion would thus give mankind a virtually unlimited supply of energy. Considered as fusion fuels, lithium and deuterium are practically inexhaustible.

How Fusion Occurs

Fusion occurs in stars because the immense pressures and temperatures at a star's core combine to force hydrogen atoms close enough together for them to fuse. A powerful natural repulsive force called the coulomb force manifests itself when atomic nuclei approach each other closely. At temperatures below several *million* degrees, this repulsion prevents atoms approaching close enough to initiate fusion. This is why fusion is not normally seen outside a star's interior.

Temperatures above 100 million degrees give atoms of the lighter elements (hydrogen and helium, for example) enough energy of motion to push through the coulomb barrier and fuse together, when the fuel is dense and there is proper confinement of the energetic atoms.

At these temperatures, the fuel materials cease to be gases as we normally understand the term. The atoms are stripped of their orbiting electrons, and become a 'plasma', a mobile mixture of positively charged atomic nuclei and free electrons. Plasmas have some entirely unique characteristics, and there is still much to learn about their behaviour at fusion temperatures. Understanding plasma behaviour is one of the greater challenges of fusion research.

A mixture of deuterium (D) and tritium (T) gases is favoured as the fuel for the first generation of fusion power plants, because the D-T fusion reaction requires the lowest ignition temperature - the 100 million degrees mentioned previously - at the fuel densities we can practically achieve. This is the lowest ignition temperature for any fusion fuel combination we know.

Even at the right temperature, sustained fusion cannot take place unless the energetic fuel atoms are confined together long enough for fusion reactions to occur *en masse*.

A combination of confinement time (τ) and plasma density (n), called the Lawson criterion, represents a key parameter in judging the success of a fusion experiment. For self-sustaining fusion to occur in the fuel mix, both the Lawson criterion and the minimum ignition temperature must be exceeded at the same time. Progress made in various experimental machines toward achieving this three-part condition, sometimes called the 'fusion parameter' and written $n\tau T$, is seen in the chart on the opposite page (in this case, T means plasma temperature).

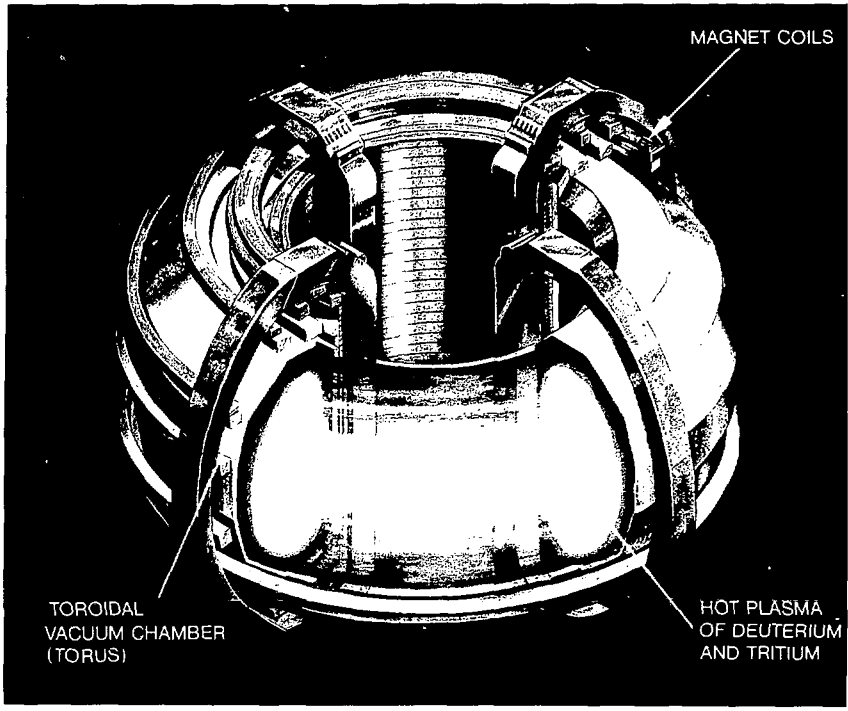
The Technology

Making Fusion a Reality

Two main technology approaches are being made to designing a fusion power reactor. They are called *Magnetic Confinement Fusion* and *Inertial Confinement Fusion.*

Magnetic fusion plant designs heat a large volume of fuel gas - tens of cubic metres - at low densities (near vacuum) with confinement times of a few seconds. Inertial confinement reactor designs very rapidly heat and compress a small pellet of frozen D-T fuel - about one millimetre diameter - to very high density with confinement times in the region of a few billionths of a second. Either approach, fully engineered could create the necessary mix of temperature, fuel density and confinement time needed to ignite a fusion 'burn'.

In any practical fusion device the heated fuel gas cannot be permitted to touch anything solid, like a metal wall, since contact would cool the plasma below the fusion ignition point.



A tokamak has a vacuum vessel containing the plasma, surrounded by magnet coils to create the magnetic fields.

The Tokamak

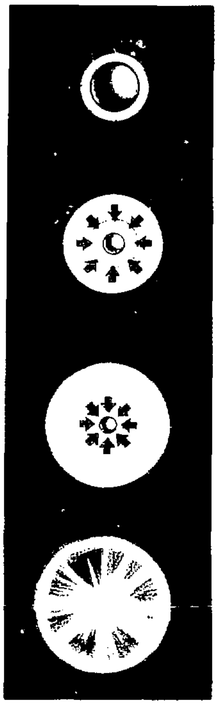
Around the world the most-studied, most advanced, fusion reactor design is a magnetic fusion device called a tokamak. A tokamak heats the fuel gases while containing them in a 'magnetic bottle' shaped like a 'dough-nut' or torus and composed of strong magnetic fields. The magnetic fields are generated by powerful electromagnets arranged around the torus, with the plasma circulating inside. The plasma is heated to fusion temperatures by a current flowing through the middle of the plasma ring (much as electric current heats a stove element), aided by auxiliary heating methods such as injection of high powered microwaves.

The largest tokamaks operating now are the Joint European Torus (JET) at Culham Laboratories (UK), the Tokamak

Fusion Test Reactor in Princeton (USA), the JT-60 tokamak near Tokyo (Japan), and the T-15 tokamak in the USSR. Canada operates an advanced, medium-sized research tokamak at Centre canadien de fusion magnétique (CCFM), near Montréal, Québec.

Inertial Confinement Fusion

In this approach, very high power laser beams simultaneously heat the pellet to fusion temperatures and compress it to many times the density of lead. Under these temperature and density conditions, fusion is ignited in the centre of the pellet and then spreads, burning it up in a few billionths of a second. After each pellet burns, exhaust gases are removed and another pellet is fired into the reaction chamber - similar in concept to the pulses of power obtained in gasoline piston engines. As of 1988, inertial confinement fusion experiments had achieved conditions similar to those of magnetic fusion.



SURFACE HEATING
Lasers rapidly heat the fusion target, forming a plasma envelope.

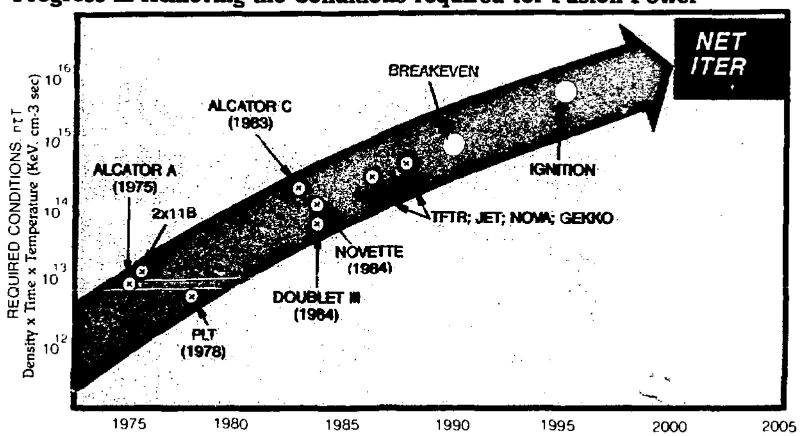
COMPRESSION
Fuel is compressed by thermal heat from blowoff of the surface material.

IGNITION
With the final driver pulse, the fuel core ignites at over 100 million °K.

BURN
Thermonuclear burn spreads rapidly through the fuel, yielding many times the energy input.

Sequence of steps during an inertial confinement fusion implosion.

Progress in Achieving the Conditions required for Fusion Power



Fusion research is believed to be on the edge of achieving breakeven - a scientific milestone where fusion energy produced in a device equals the energy put in to start it. Several major machines are expected to demonstrate breakeven within the next few years, indicating that we can make the fusion process work. Today, the emphasis is on optimizing the physics and developing practical fusion technology that will produce economical and environmentally acceptable power.

Four world powers are collaborating to design and build a prototype fusion reactor called ITER. The European Community, the USA, Japan and the USSR operate the world's four largest programs in fusion development. As a result of a 1985 agreement between President Reagan and General Secretary Gorbachev, these four powers began collaboration on the ITER project in 1987. Canada is also now a contributor to ITER, through the European Community.

The aim of ITER is simple; to demonstrate the feasibility of fusion power by designing and building a fully engineered, power-generating fusion test reactor.

ITER is a project of global importance. It is the most extensive world fusion collaboration ever undertaken. As well as being a signal of superpower cooperation, the decision to collaborate on ITER indicates the significance attached by world powers to the need for developing fusion energy technology. There is also an economic motivation for sharing the development of ITER. If it is built, the capital cost of ITER and its site is expected to be in the region of $4-5 billion.

As part of Canada's involvement in ITER, CFFTP is contributing design manpower and technology research and development to this project. ITER technical work is done in Garching, Federal Republic of Germany by a 40 member design team equally representing the four major partners in the collaboration.

Canada is enabled to contribute through a special Canada-European Community agreement on ITER, under the Canada-EC Bilateral collaboration agreement in fusion.

The Basic ITER Design

A design concept for ITER was finished during a joint 1988 work session at Garching, and refined at another joint work session in February and March this year.

ITER will be a tokamak, expected to generate 1,000 megawatts of fusion power for periods of up to two weeks. ITER will consume a similar amount of power for its operational requirements, such as electrical power for the magnet coils, for plasma heating and for operation of the plant auxiliary systems. Every essential technology needed for a practical fusion plant is included in ITER's design.

At full power, the reactor's fuel injection requirement will be in the order of 400 grams of mixed D-T fuel per hour.

Ohmic heating of the fusion plasma will be supplemented by about 200 megawatts of neutral beam and radio frequency heating. Plasma currents will be as much as 25 million amps. Superconducting magnet coils will provide the magnetic fields for the confinement and ohmic heating of the plasma. The tritium breeder blanket will generate almost as much tritium as the reactor consumes as fuel; the fuel systems will process tritium generated in the breeder blanket and feed it to the fusion chamber.

The reactor fusion chamber, or vessel, will be a torus about 10 metres high, with an outer diameter of 19 metres. In-vessel components are to be fully replaceable by remote handling methods. With its magnets, support structures and additional equipment, the reactor will stand about 20 metres high with an outer diameter of 25 metres.

Autumn 1988 ITER design team members relax in Munich ITER Management Committee Chairman Ken Tomabechi (JAERI, Japan) is at centre. Bob Stasko (CFFTP) stands left At right is Paul Dinner (CFFTP), attached to NET representing NET for the European Community Paul leads the ITER Tritium Systems team NET workers John Blevins (CFFTP) and Clive Holloway (SPAR Aerospace) confer in background

Detailed design work on ITER started in June this year, once more at Garching. This will be finished in November 1990, at which point the decision on whether to go ahead and build ITER can be made. A host country for building ITER has not yet been chosen.

ITER R&D and Design

Robert Stasko of CFFTP has spent several months at Garching, assisting in the ITER conceptual design effort. Other Canadians have attended meetings of design specialists to review design concepts for breeder blankets, the fuel cycle, remote handling methods and other topics.

Canada has also contributed a preliminary design for the Isotope Separation System, a portion of ITER's fuel handling systems. The ISS is a complex cryogenic distillation system responsible for separating out tritium from the reactor's tritiated waste streams, including the fusion plasma chamber exhaust stream. The plasma exhaust stream contains large amounts of unburnt tritium fuel. Tritium will be recycled to ITER's Fuel Storage and Preparation System. The design has been accepted as the European reference design for ITER's Isotope Separation system. The ISS was designed by Ontario Hydro with CFFTP funding. Design refinement will continue until late 1990.

Technical Issues

Some of the important ITER design issues are:

Divertor and first wall technology. Divertors touch the plasma to control plasma shape and position in the machine, so they receive the highest heat loads and are subject to severe erosion. Engineering and materials developments are needed.

Magnet coil reliability. Superconducting coils on the ITER scale have not yet been built. Reliability must be assured.

Mechnical forces on the structure. The design must be modular to allow replacement of fusion chamber sections, yet withstand large transient forces caused by the magnetic effects of sudden changes in the plasma current.

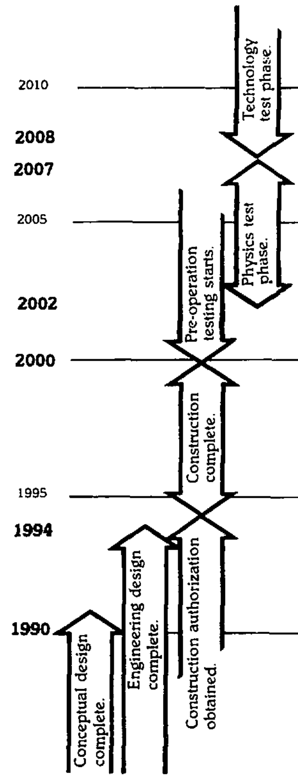
Tritium inventory. Using existing materials such as graphite to line the fusion chamber, tritium could build up to kilogram quantities in the liner material and adjacent structures. These levels must be minimized to assure low tritium inventories.

Future R&D Contributions

CFFTP shares Canada's commitment to the ITER Collaboration, and will continue its contributions to the project. Future research and development contributions from CFFTP are expected to be in these areas:

Tritium breeder blanket systems
Fuel processing systems
Remote handling
First wall materials
Safety systems
Plant systems and layout
Waste management

Provisional ITER Milestones



The arid summer of 1988 drew the world's attention to continued global warming, exaggerated by the aptly named Greenhouse effect. Droughts and extreme temperatures underscored the worldwide need for energy sources such as fusion, that do not burn fossil fuels and produce carbon dioxide, one of the largest contributors to the greenhouse effect. Necessarily, the importance of fusion as an energy option was highlighted. As part of its mandate, CFFTP places strong emphasis on developing the benign environmental potential inherent in the fusion energy concept.

The Safety and Facilities Engineering group is responsible for CFFTP's safety and environment programs. This field of study touches almost all aspects of fusion reactor technology, and includes fundamental work in safety philosophy and engineered safety systems. The study of environmental tritium behaviour provides a window on the extent of the department's activities, and CFFTP's commitment to this subject.

Tritium and the Environment.

Tritium behaves differently in a winter environment than it does in summer. Microorganisms in soil steadily convert tritium from its elemental form to its oxide, or water, form in summer, but do not do so in winter when the microorganisms are less active. This interesting finding was suspected strongly for some time, and is now confirmed after a long and extensive international collaboration, in which CFFTP took part.

Canada and five other countries took part in the Canadian Environmental Tritium Experiment, performed in 1987 to study dispersion behaviour of tritium in the environment. Analysis of data from this experiment and others was completed in 1988/89, and used to validate a Canadian tritium dispersal code called ETMOD - Environmental Tritium Model.

Since tritium is to be used in quantity as a fusion fuel, it is important to know how tritium would behave if ever there should be a significant tritium release from a plant, however improbable the event. How much of the tritium, for example, is converted from the elemental gas form to the oxide, or water form, which is absorbed by humans much more readily? How much would drift away, and how much would lodge in soil or vegetation? How would it behave there? These and other questions have been researched for some years by CFFTP and others. With the assistance of many other groups, CFFTP helped develop the ETMOD computer code to help predict environmental tritium behaviour and biological impacts of tritium releases. A systematic field experiment was performed to prove out ETMOD and other codes, and verify the tritium behaviourial data used in the models.

The experiment was conducted in Ontario at the Chalk River Nuclear Laboratories. A harmless quantity of tritium gas was released over an open field, and its movement measured by the six national teams with their own instruments. Soil and air measurements

The personal tritium dosimeter from BOT Engineering. Worn on the belt, it monitors tritium in air and calculates the wearer's exposure to tritium. Sound signals alert wearer at preset exposure level.

were taken over a period of several months, and samples taken back to a number of the countries for analysis.

Canada and the other nations met in Cadarache, France in October 1988 to pool results after more than a year of analysis, and compare them with data from other experiments. Three of the common conclusions reached were:

- Direct conversion of elemental tritium (HT) to the oxide form (HTO) in the atmosphere is very slow.
- HT to HTO conversion is primarily done by microbes in surface soil, after HT is deposited on the ground.
- After an HT release, HTO vapour emitted slowly from the ground persists in the atmosphere around the release site for weeks after the release.

The ETMOD code can now be used with increased confidence to predict the environmental behaviour of a postulated tritium release from a fusion plant, or from an experimental tritium laboratory. CFFTP anticipates using it in site safety assessments for NET and ITER.

Such assessments are an important part of the design of fusion plants. If the environmental and radiological effects are known for a defined tritium release, we can determine plant parameters which will maintain the environmental and safety effects of a postulated tritium release within socially acceptable bounds.

Computer-Aided Design station. Designs can be exchanged electronically with other fusion projects. Systems, reactors or complete sites can be designed.

SAFE Operations and R&D

The SAFE activity areas:

Environment and Public Safety
- Environmental tritium behaviour.
- Accident and routine emission analysis.
- Plant and system safety analysis.
- Safety philosophy development.
- Radioactive waste management methods.
- Containment and confinement in plant design.

System Safety
- Develop fusion-relevant nuclear safety standards in reactor design.
- Licensing studies.
- Tritium inventory analysis.
- Reactor radiation level analysis.

Occupational Safety
- Personal tritium dosimetry development
- Biological behaviour of tritium.
- Control of surface and air contamination.
- Air detritiation systems R&D
- Maintenance and operations methodology.

This department was created in late 1987 as a separate CFFTP group, dedicated to safety research and to embedding high safety and environmental standards in the design and operation of future fusion power plants and present day experimental laboratories.

Highlights of the SAFE Program

Plant design and layout

This was one of the department's chief activity areas in 1988/89. The application of nuclear plant design and operations experience from the CANDU has influenced work on fusion reactor designs at several centres. In 1988/89, SAFE staff contributed to fusion plant designs at NET, ITER, and FEDC (Oak Ridge, Tennessee).

An original concept from CFFTP is the use of large flexible bags for containing radioactive contamination on fusion reactor parts being removed for maintenance. Entire sections of the reactor could be wrapped and transported in this way inside the reactor building. Using such 'flexible casks' instead of more traditional heavy shielded transport casks, designers could reduce the size and cost of reactor building structures, while maintaining high levels of worker safety. The material of the 'flexible cask' would need to be durable, easily decontaminated and resistant to radiation damage. Last year, CFFTP earmarked funds for a research program to find and test such a material.

CFFTP contributions at other fusion centres have helped designers to be more aware of the impact of fusion reactor design changes on the buildings, structures and the overall site. For example, by applying Canadian nuclear experience to ITER, CFFTP staff showed that one suggested change to reactor design could add 20 metres to the height of the ITER reactor building.

Dosimetry Research

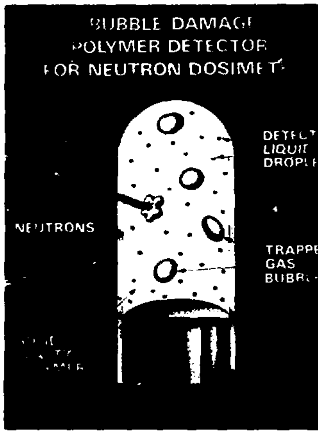
This long standing program has yielded an interesting instrument in the difficult field of tritium-in-air measurements. BOT Engineering (Campbellville, Ontario) has produced a working prototype of a small personal tritium dosimeter that can be worn on the belt. The instrument has shown good tritium detection performance, and alerts the wearer to increased tritium levels. A pilot manufacturing run has been ordered for field trials. The Department of Regional Industrial Expansion cofunded the BOT project with CFFTP.

Development of fixed tritium-in-air monitoring instruments for tritium laboratories and facility continues. Labserco (Oakville, Ontario) completed the work on a prototype of a modular, low-cost tritium-in-air area monitor.

CFFTP has actively supported deployment of the small passive neutron bubble dosimeter developed by Bubble Technologies Inc. (Chalk River).

Other SAFE Activities

A Darlington TRF Tritium Experience Manual was commissioned and is in preparation. This documentation of commissioning and operating experience from the world's largest civilian tritium processing plant should be a valuable repository of information for tritium system designers.

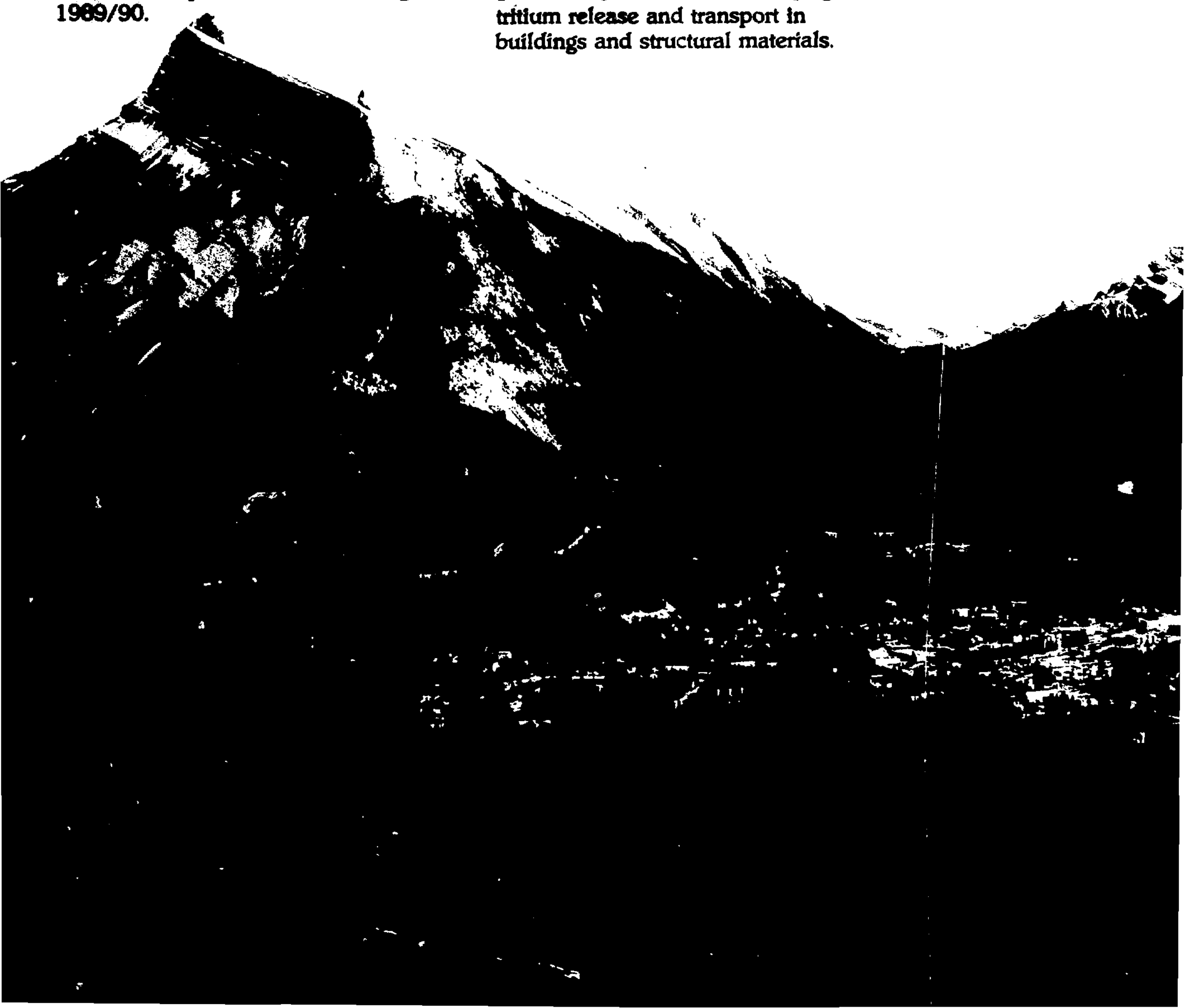


Passive neutron radiation detector by Bubble Technology Industries Inc. Neutron flux is calculated by counting bubbles created by neutrons passing through sensitive medium.

Research into toxicity of uranium tritide aerosols began at University of Toronto. The Advanced Dryer Systems program at CRNL continued, addressing the general need for high-efficiency removal of tritiated water vapour from laboratory atmospheres.

McMaster University produced several processes and materials, including aluminum oxide layers, as candidate tritium barriers for fusion reactor surfaces. They will be tested during 1989/90.

CFFTP is now participating in an initiative by the International Energy Agency to study the *Environmental, Safety and Economic Aspects of Fusion Energy*. Canada, Japan, the European Community and the USA are cooperating in the study on an initial program of eight proposed technical tasks. CFFTP is helping to organize preliminary work in a proposed task focusing on tritium safety and environmental effects, and is particularly interested in studying tritium release and transport in buildings and structural materials.



Technology capability is the product of research, engineering design and development, and technology transfer to industry. 1988/89 saw more application of CFFTP fusion technology in world fusion laboratories than last year. We believe this indicates that CFFTP's fusion technology development areas continue to be relevant to the needs of the fusion research community, and that transfer of CFFTP's technologies to Canadian industry is progressing well.

In 1988/89, CFFTP had working relationships with 16 Canadian companies and 6 companies abroad. Active R&D links were maintained with three universities in Canada, nine European fusion sites, eleven US fusion sites and with the Tokai research establishment in Japan.

CFFTP has the goal of developing technology for tritium-burning next-step fusion reactors. In the nearer term, applying our current fusion technology in today's fusion and tritium laboratories is advancing CFFTP towards this goal. Our current fusion technologies were founded on indigenous Canadian technology capabilities, and on the fusion research and development work of previous years. Today's CFFTP research programs extend our current knowledge and experience, creating the foundations of knowledge for tomorrow's capability.

Technology capability can be demonstrated by its applications. A system being supplied to the Karlsruhe Tritium Laboratory, Federal Republic of Germany, exemplifies some of the fusion capabilities developed by CFFTP and its partners.

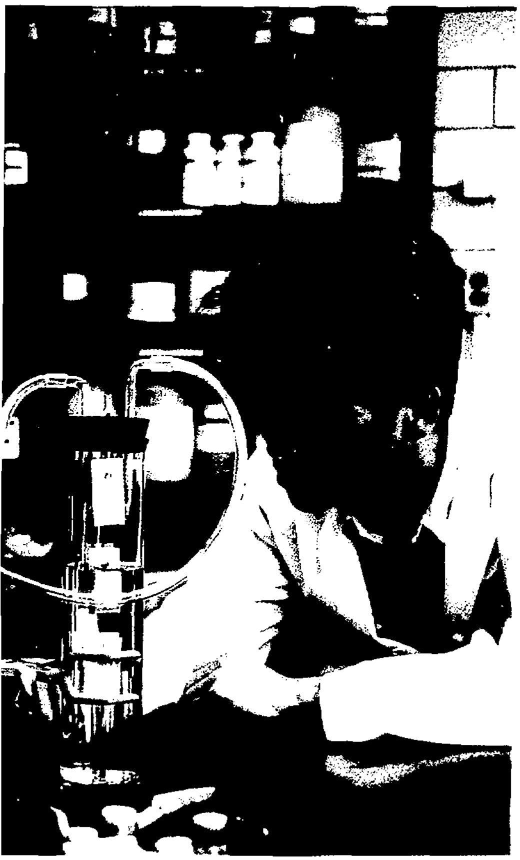
Karlsruhe Tritium Laboratory

Kernforschungszentrum Karlsruhe (KfK) contracted with CFFTP in October 1988 for the supply of a Gas Chromatography Isotope Separation System (GC-ISS) for the KfK Tritium Laboratory. Five Canadian companies and three West German companies have joined with CFFTP to design and manufacture the complete system. The GC-ISS system is the culmination of a long research program at Ontario Hydro Research Division (OHRD), supported by CFFTP and Ontario Hydro.

The KfK GC-ISS is a fully engineered system, designed and built in Canada to German nuclear and engineering standards. Delivery is scheduled for March 1990. It is designed to process tritium gas mixtures. Fusion reactor exhausts are expected to contain mixtures of tritium (T), deuterium (D) and ordinary hydrogen (H). The KfK GC-ISS system will process such a gas mix (H,D,T), separating it out into purified streams of the individual gas components.

KfK is a key fusion site in the European Community's fusion program. The KfK Tritium Laboratory will use the GC-ISS system for research into fusion reactor fuelling systems and tritium handling technology.

The heart of GC-ISS is a cryogenic gas chromatograph column, where physical separation of the hydrogen isotopes takes place. Programmed temperature



Corrosion tests on stainless steel coupons at University of Toronto Chemical Engineering Department.

control speeds up gas processing and separation, compared with other chromatograph designs. GC technology was transferred to Labserco, Inc. (Oakville, Ont.). In association with OHRD, Labserco demonstrated in 1988 a working prototype of the system required by KfK . Labserco is building the GC isotope separator, as well as designing the complete process system, which includes uranium beds for absorbing and storing gas mixtures and the separated isotopes. The uranium beds are being fabricated by AECL-Sheridan Park. Zirconium-iron scavenger beds are being manufactured by E.S. Fox Ltd. (Niagara Falls, Ont.), to whom getter bed technology was transferred starting in 1986.

The M. Braun company (FRG) is expected to build the gloveboxes which form an outer containment boundary around the complete GC-ISS system. Kraftanlagen AG Heidelberg will build some of the pressure vessels and piping systems. Design reviews and equipment inspections will be done by the American subsidiary of TüV Baden. Monserco Ltd. (Mississauga, Ont.) will perform a safety assessment of the system. Ontario Hydro's Nuclear Engineering Department will participate in a number of project activities.

Technology Research

The main research areas in technology development:

Fuel and Systems Engineering
- Laser isotope separation for H,D,T.
- Cryogenic distillation separation for H,D,T.
- Reactor exhaust gas processing;
  - Pressure-swing adsorption
  - cryogenic pumping
- Alternative storage/getter beds, such as zirconium/cobalt, for absorbing H,D,T.

Breeder Blanket and First Wall
- Aqueous lithium salt blanket research: chemistry, metals corrosion, lithium salt radiolysis.
- Solid breeder ceramics: fabrication, radiation testing, tritium production, thermal/mechanical testing.
- First wall materials: erosion theory and testing; tritium retention and mobility tests at low and high temperatures, new materials fabrication.

There were 73 technology R&D contracts active in 1988/89, including 26 contracts for safety and environment R&D. Research findings are contributed to fusion work in other countries, and form the basis for building industrial fusion technology in Canada. Here are some points of interest from work in 1988/89.

Materials Research

This is one of CFFTP's key research directions. 1988/89 produced some very interesting results. Here are some of the highlights.

Ceramic Tritium Breeders

A 'blanket' of lithium ceramic surrounding a fusion reactor chamber is a promising way of generating the 200 - 300 kg per year of tritium fuel that a 1,000 megawatt fusion power plant might need. Research into ceramic breeder materials is an important CFFTP activity.

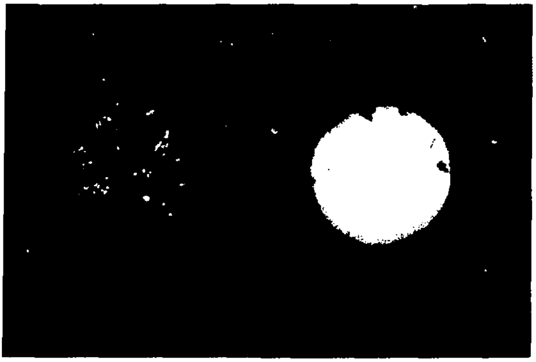
One attractive design for a ceramic breeder blanket is based on surrounding the fusion plasma chamber with small (about 1 millimetre diameter) spheres of lithium breeder ceramic. For a large fusion power reactor, such a blanket could require perhaps 500 tonnes - or more than 300 billion - of the spheres. Mass production of these 'microspheres' is therefore very important, yet production of microspheres with suitable mechanical and thermal properties is not an easy matter. Processes designed at AECL Chalk River, have now produced high yields of durable lithium aluminate microspheres with a one micrometer grain size, able to survive the severe thermal shocks they would see in breeder service. These pilot-scale production processes can be scaled up to the mass production rates needed.

Work on making lithium zirconate spheres has now begun, in expectation that zirconate will release the newly generated tritium more readily than lithium aluminate ceramic.

Tritium breeding tests

Irradiation testing of lithium ceramics at Chalk River continued in 1988/89. Using the NRU high flux reactor at Chalk River, the CRITIC test facility completed a 21 month high temperature irradiation program on a 100 gram lithium oxide sample. This is the most severe in-reactor test ever conducted of lithium ceramic for fusion; about 2,000 Curies in total of tritium were produced and released by this one sample at temperatures between

Dr. Antonio Moauro (left) of ENEA-Casaccia at AECL-Chalk River, learning about CREATE tritium analysis system from Joan Miller (Group Leader, Tritium Technology) and colleagues.



Tritium implanted in pseudo-monocrystalline graphite with accelerator for diffusivity measurements. Images made with tritium camera in UTIAS Tritium Laboratory. Spot size = 1 cm.

400°C to 850°C. About 1% of the lithium was converted to tritium. The test yielded new data on tritium release rates and mechanisms, and proved the design of CRITIC as an advanced breeder test facility.

This work directly contributed to Canada's ability to participate in the international BEATRIX II breeder irradiation program, now under way at Hanford, Washington. AECL Chalk River have supplied to Hanford a tritium recovery system and tritium instrumentation. Canadian ceramic samples will be irradiated in Hanford's FFTF (Fast Flux Test Facility) reactor starting in 1990.

Another Chalk River ceramic test facility called CREATE was used to evaluate ceramic samples from ENEA-Casaccia (Italy) after they were irradiated in NRU. AECL Chalk River supplied a duplicate of the CREATE rig to Casaccia's fusion ceramic group.

Plasma-facing Materials

Behaviour of materials facing the plasma inside a fusion reactor must be understood so that durable, erosion resistant plasma-facing materials can be developed.

The Tritium Laboratory at University of Toronto Institute of Aerospace Studies (UTIAS) is now complete and operating. This ultra-high vacuum laboratory is one of the few in the world equipped for direct testing of materials erosion under tritium bombardment, and for researching tritium retention, mobility and outgassing behaviour in first wall materials. Samples can be heated to 2000°C. High temperature tritium retention and mobility tests have begun on graphites. First results with tritium indicate that retention and erosion with low energy tritium atoms is similar to that of hydrogen. An upper bound has been established for diffusivity of tritium in 'pseudo-monocrystalline' graphite.

Also at UTIAS, a dual beam particle accelerator for advanced erosion tests is under construction with CFFTP support. With this machine, materials will be bombarded simultaneously by controlled fluxes of energetic hydrogen and impurity atoms believed to dominate the plasma edge region where plasma-materials contact occurs.

Aqueous Lithium Salt Blanket

Coolant chemistry is a critical issue for the aqueous lithium salt blanket (ALSB), considered to be a real breeding blanket option for ITER. CFFTP has a strong interest in ALSB design. Radiolytic decomposition of aqueous salts is being measured at AECL Chalk River. CIL research laboratory (Mississauga), a new research partner, is performing corrosion tests on type 316 stainless steels and other alloys in an aqueous salt environment.

Fundamental work in tritium-materials behaviour and work in applied systems research are important in developing designs for advanced fuel systems and systems for processing fusion reactor exhaust gases.

H, D, T Isotope Separation Research

Laser isotope separation of H,D,T has been a long CFFTP program, seeking a possible alternative to chemical/ thermal separation methods. The CFFTP-supported research at Ontario Hydro Research Division (OHRD) resulted last year in promising laser and gas irradiation cell designs for a viable laser isotope separation (LIS) system. Earlier problems in laser-gas interaction physics have been solved. With the recent advances, LIS may have potential to become commercially competitive. A concept for a pilot-scale LIS system has been developed, and a proposal for constructing the system is being evaluated.

Also at OHRD, a self-contained cryogenic H,D,T separation column was installed and tested successfully last year. This program began in 1987/88. Operating with hydrogen and deuterium only, the cryogenic column showed that separation processing with a very low tritium inventory is possible. The column is being modified to further reduce inventories, and to equip it for processing elemental tritium. Cryogenic distillation with tritium could begin this year. Progress is good, and it is considered that such a system would be useful in world tritium and fusion laboratories.

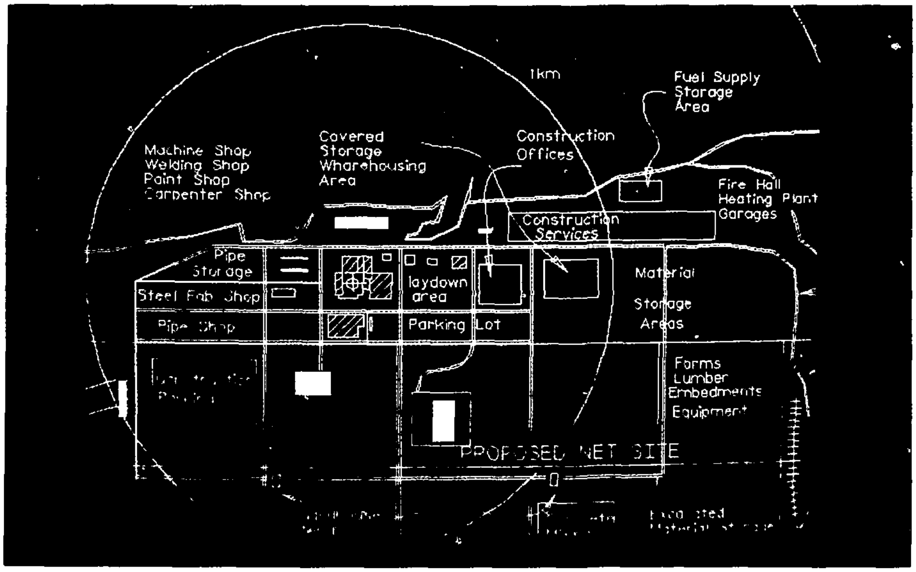
Fusion Reactor Plasma Exhaust Purification

It is expected that more than 90% of the D-T fuel injected into a fusion reactor will be exhausted unburnt. Research in processing of fusion reactor exhaust streams to recover unburnt D-T fuel, and to remove contaminants and radioactive species, is therefore an important topic.

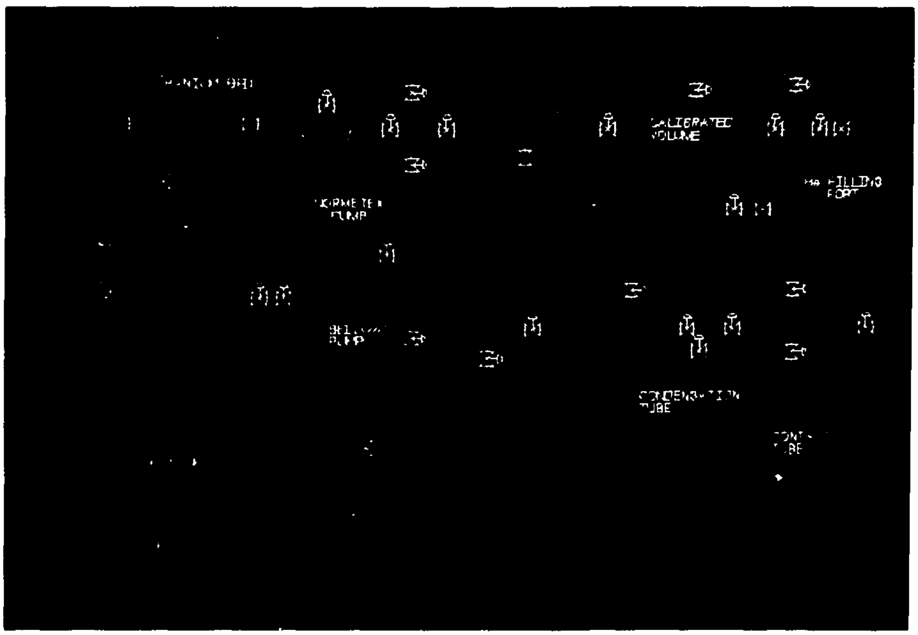
Plasma exhaust purification by cryogenic gas condensation is being examined at AECL Chalk River. The process has potential as a method of removing impurities such as hydrocarbons and oxides of carbon from plasma exhaust streams of fusion reactors. The functional objective of a cryo-condensation system would be production of a purified tritium/ deuterium/hydrogen (H,D,T) gas mixture from the complex exhaust gas mix, suitable for isotopic separation so that purified streams of D, T, and D-T molecules could be recycled to the fuelling system.

An all-metal, tritium-compatible vacuum cryostat and specialized gas analysis system have been built at Chalk River for the work. The operating principle is to pass an exhaust stream over cryogenically cooled surfaces to condense gases other than helium. As the loaded condensing surface is warmed under program control, the gases might separate sufficiently during regeneration to produce H,D,T mixes pure enough (a few parts per million of gases other than helium and H,D,T) for input to an isotopic separation process.

A copper condensing surface is used as a reference cryosurface, although the cryostat can test other cryosurfaces. Data obtained should help assess the feasibility of larger-scale cryogenic exhaust gas separation. Tritium experiments are next-stage work.



Site layout for Next European Torus. CAD system image, courtesy of Max-Planck-Institut für Plasmaphysik.



Process diagram for tritium microballoon fill station, University of Rochester.

Thermally coupled pressure-swing adsorption techniques are also being studied for applications in plasma exhaust processing and breeding blanket purge gas recovery. Highquest Engineering Inc., a Vancouver company, is performing experiments in this field for CFFTP. The technique has potential for continuous operation, easy scalability to high gas throughput, and relatively low cost.

CFFTP considers its Staff Attachments Program very important to effective cooperation with fusion centres abroad. Staff have now been attached at ten fusion sites outside Canada.

CFFTP's continuing liaison with two of Europe's fusion centres - the Joint European Torus (JET) and the Next European Torus (NET) - illustrate the scope of the Attachments Program.

King Fahd University, Saudi Arabia. Ken Torr (left) of Monserco Ltd. with Rafat Nassar (right), Tritium Systems Leader, and colleagues. Ken led commissioning of tritium control systems supplied through CFFTP.

Joint European Torus Culham Laboratories, UK.

Charles Gordon (Ontario Hydro) completed a four year stay in JET's Tritium Safety Group. He was responsible for JET's compliance with safety and regulatory requirements during the forthcoming tritium phase of JET operations, when deuterium-tritium fuel mixtures will be heated in the torus. Paul Ballantyne (AECL-Chalk River) joined JET as Charles' successor in this work, which includes design reviews and safety analyses.

Alan Dombra (AECL Chalk River) was attached at JET for several months. He participated in design, engineering and process analysis of tritium systems. Alan contributed to design and specification of the Exhaust Detritiation system.

Ernie Groskopfs (Ontario Hydro) concluded his eighteen-month attachment at JET in August 1988. He assisted in design and engineering of several tritium systems including the isotope storage system, tritium transfer systems and impurity processing systems.

Martin Galley (AECL) joined JET in August 1988. He is attached with the Active Gas Handling group to assist with design, procurement and commissioning. He developed a process control algorithm for the exhaust impurity processing system.

Dominic Wong of Ontario Hydro also joined JET in August 1988, to work on design and engineering of tritium handling systems, including the product storage system, exhaust detritiation system and various tritium piping systems.

Spencer Pitcher (Research Fellow) completed a two-year attachment in March 1989. He worked in JET's experimental program, assisting with investigations of plasma-wall interactions, and development of plasma edge diagnostics.

Alan Rolfe (SPAR Aerospace) is in the fifth year of his attachment. Dr. Rolfe is Remote Handling Applications Group Leader in JET's Fusion Technology Division.

Attachments at Next European Torus (NET)

SPAR Aerospace, Wardrop Engineering, Qualprotech Inc., CFFTP and Ontario Hydro have attached staff to NET.

Hank Brunnader (CFFTP) returned to Canada at the end of 1988, after a year and a half at NET performing systems reliability analyses and helping to integrate individual reactor systems into a complete NET design. John Blevins (CFFTP) spent four months at NET, with responsibility for the first complete layout of the NET reactor building and site. Their work aided completion of an integrated design for the NET fusion reactor, supporting plant, buildings and the site.

Jeff Stringer (Wardrop Engineering) has joined Clive Holloway (SPAR Aerospace) at NET to work on comprehensive strategies for the remote handling of NET in-vessel components. Clive has been attached at NET since 1986; Jeff joined him in January 1988.

Paul Gierszewski visited NET for two months to assist with tritium breeder blanket design.

Paul Dinner of CFFTP continued through 1988/89 in his position of Leader-Tritium Systems at NET. Mr. Dinner has now been attached at NET for five years. Dave Murdoch of Qualprotech Inc., Oakville, Ont., joined the NET tritium systems team.

Other staff attachments of particular note were in Japan and the USA.

Ronald Matsugu (CFFTP) was the first person to be attached by CFFTP at a Japanese fusion centre. In 1988 he spent three months at the Tokai Research Establishment, near Tokyo, of the Japan Atomic Energy Research Institute. He assisted with commissioning of the Tritium Process Laboratory, which is capable of handling up to 100 grams of tritium.

Art Kempe (AECL Sheridan Park) began an attachment to Princeton Plasma Physics Laboratory in February this year. He is appointed as Project Engineering Manager for the Compact Ignition Tokamak project.

Sandra Brereton (CFFTP) continued her attachment at Idaho National Engineering Laboratory, working with the U.S. Fusion Safety Program. Dr. Brereton has focused on safety philosophy and analyses for the US Compact Ignition Torus and for ITER.

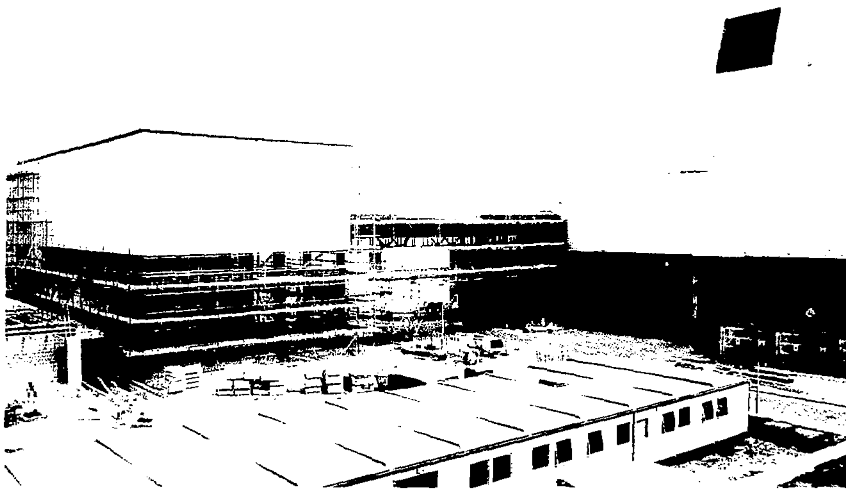
Robert Sissingh has been on attachment at the Tokamak Fusion Test Reactor (TFTR) at Princeton University since 1986, most recently as Tritium Systems Branch Head. He has been responsible for design and construction modifications to the TFTR Tritium Systems, and their commissioning.

Players in the Tritium Tennis Tournament, held on the eve of the Third Tritium Technology Conference, *Toronto, May 1988. The USA emerged victorious, to win the* International Tritium Cup.

CFFTP helped to host the Third Tritium Technology Conference, in cooperation with the Canadian Nuclear Society, the American Nuclear Society, the European Nuclear Society and the Nuclear Society of Japan. More than 160 papers were presented at the Conference, by authors from 11 countries. This series of tritium conferences, originated by American tritium workers, is regarded as representing the world's leading authorities on tritium.

CFFTP involvement in fusion projects outside Canada is providing staff of CFFTP and its partners with a broad base of fusion design experience, and a valuable overview of world fusion reactor design practice. Involvement in the design exercises and the engineering and manufacturing efforts of other projects, and the opportunity to share experience with other designers, is significantly enhancing the skills of Canadian fusion system designers.

CFFTP has already been active in the NET, JET, MARS, TFTR, MINIMARS, TITAN, TIBER and FINESSE projects, and has done design work for Frascati and Casaccia in Italy, and for the Fusion Engineering Design Centre (Oak Ridge, Tenn.) and the University of Rochester in the United States.



Active Gas Handling Building at JET. Tritium systems in the building will recover tritium and deuterium from torus exhaust for recycling to fuel systems.

Tritium and Fuel Cycle Designs

Useful experience was gained in supplying tritium control systems to King Fahd University in Saudi Arabia for their tritiated-target deuteron accelerator. This system was shipped and installed last year, and is performing to design specification.

The University of Rochester last year awarded CFFTP the task of designing and manufacturing a tritium fill station for microballoon targets used in its inertial confinement experiments at the Laboratory for Laser Energetics. The project affords the opportunity for specific experience in design and manufacture of high pressure inertial confinement fusion systems. Delivery of the microballoon fill station was scheduled for the summer of 1989.

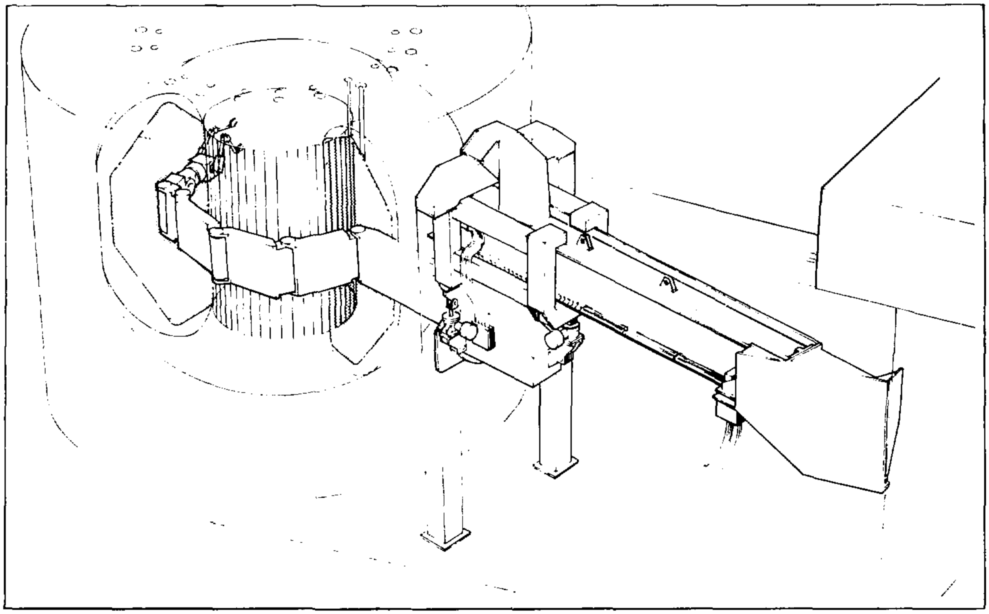
Design of the ITER Isotope Separation System has been, and will continue to be, invaluable experience in designing systems for full scale fusion power reactors having complete tritium breeding-recycling fuel systems.

The award of the task to design the NET reactor exhaust and fuel cleanup systems, in February this year, is an opportunity to apply results of the tritium and fuel cycle research programs.

Remote Handling

In remote fusion reactor maintenance schemes, internal reactor parts weighing as much as one tonne or more must be carried and positioned very accurately by any feasible remote maintenance manipulator.

The Remote Manipulator Systems Division of SPAR Aerospace (Weston, Ontario) has completed an active computer model of a robot maintenance system for the inside of the NET torus. The model is in effect a computerized design of the



Remote maintenance manipulator concept for Compact Ignition Tokamak. Courtesy of SPAR Aerospace.

maintenance robot called the In Vessel Handling Unit (IVHU); it responds to commands to transport and position imaginary loads inside the NET vessel. After testing and modifying the model, the IVHU could be physically designed and built.

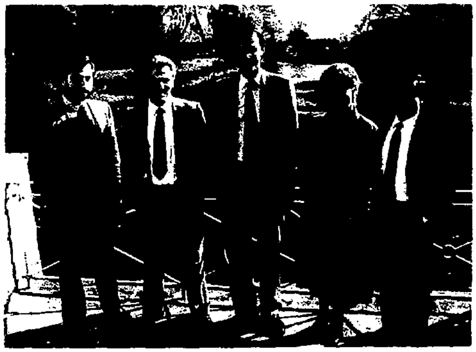
Improved Design Tools

Two computer design tools have significantly added to CFFTP's system and reactor design capabilities.

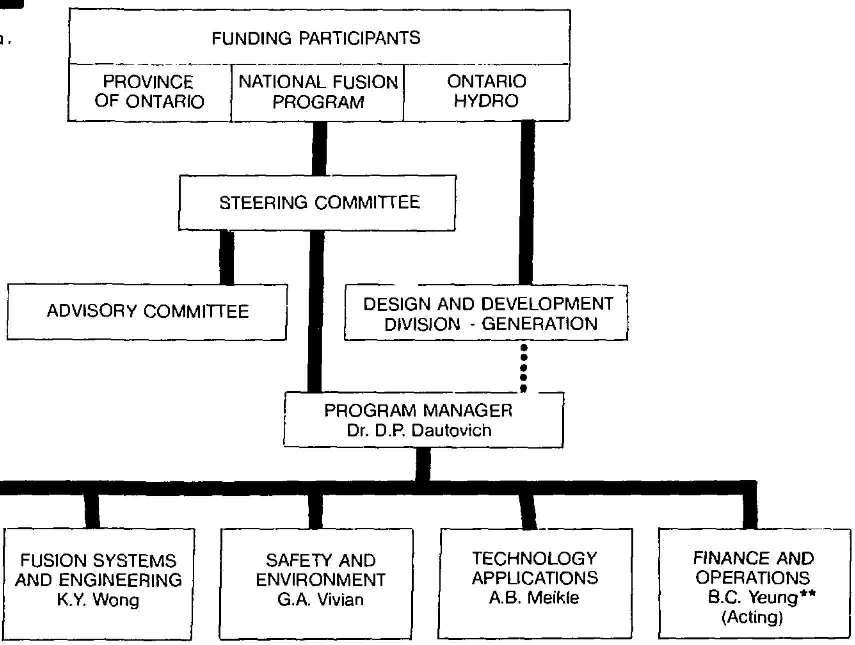
A fusion process system simulation code called FLOSHEET is being routinely used for developing and optimizing process designs, plant commissioning and troubleshooting. FLOSHEET can perform detailed mass and energy balances on various process units in the overall fusion fuel cycle. Notably, it was used to optimize design of an Isotope Separation System suitable for ITER, a system that will process large quantities of tritium. Without FLOSHEET, it is doubtful whether the system could have been optimized to have such a low tritium inventory. The modular code runs on microcomputers.

CFFTP has acquired advanced CAD (Computer Aided Design) system capability for its reactor design and system integration work. The software is compatible with software used in Europe and the USA, so that design files can be exchanged with CFFTP's partner fusion design centres abroad. Some of the illustrations in this report were produced by the system.

For the future, CFFTP will expand its contributions to ITER and continue its contributions to the many international projects in which it is privileged to be involved. In so doing, the staff and partners of CFFTP look forward to enlarging their experience and capabilities in the field of reactor and fusion systems design.



(Left to Right) R.R. Stasko, A.B. Meikle, D.P. Dautovich, K. Brubacher-Hett, K.Y. Wong.



ITER, NET Design and Engineering
Provides fusion design, engineering and coordinates R & D for ITER, NET and equivalent next step machine and facilities

Fusion Systems and Engineering:
Develops fusion-fuels related technologies (processes, hardware, materials) and engineering designs for fusion reactor systems, and maintains awareness of developments in fusion concepts and physics.

Safety and Environment
Develops skills and technologies related to the reliable and safe operations of fusion facilities.

Technology Applications:
Focuses on robotics and the application of technology and its transfer to industry and international fusion facilities

Finance and Operations
Provides day-to-day financial management, coordinates longer term planning and policy making, and provides administrative support services to develop and execute the communications program.

* *Established in April 1989 to focus CFFTP's ITER NET activities*

** *BC. Young succeeded K. Brubacher-Hett as Acting Manager, Finance & Operations effective April 1989*

Steering Committee

Front Row (Left Right)

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Project Officer
Premier s Council
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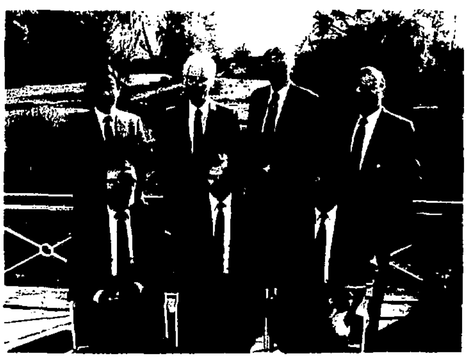
Toronto, Ontario

*—Official Members

Advisory Committee



Front Row (Left Right)

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Dr. R. Morrison – Chairman
Director General, Uranium and
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Dr. J. Darvas (absent from photo)
substitute **Dr. J. Nihoul** attended
meeting on his behalf
Division Head, Fusion Technology
Commission of the European Comm
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Financial Review

for the 1988/89 fiscal year ended March 31, 1989

Economic Impact

(1988/89 vs 1987/88)

The total economic impact, which includes the sum of partner funding, client funding, and subcontractor in-kind contributions for fiscal year 1988/89 reached $10.0 M, an increase of $2.7 M or 37% higher than the previous year.

The 1988/89 partner funding for the Project was $6.0 M. Client funding on some CFFTP contracts amounting to $2.7 M was awarded from international fusion research projects. This is an increase of $0.9 M or more than 50% from the 1987/88 fiscal year.

The 1988/89 subcontractor in-kind contribution was $1.2 M, an increase of about $0.3 M over the previous year. These contributions are provided on specific contracts, usually in the form of discounted billings, uncharged time or costs related to the contracts. Subcontractor in-kind contributions is an indicator of subcontractor interest in and support for the Project's technical activities.

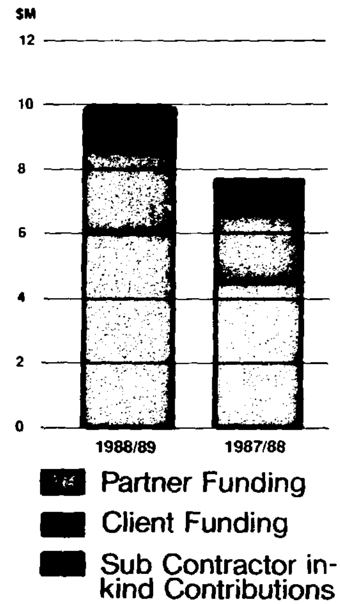


Figure 1

Distribution by Sector

(1988/89 vs 1987/88)

CFFTP works in conjunction with key Canadian resource sectors as shown in Figure 2. This distribution by sector shows contract and related expenditures which totalled $8.7 M in1988/89. Subcontractor in-kind contributions is not included in Figure 2 since it is contributed by the subcontractors themselves and, as such, does not represent an inflow to them. Also shown in this figure is a comparison with the 1987/88 sector distribution. The greatest rates of growth are in the Industry and University sectors which combined increased from $1.6 M in 1987/88 to $2.9 M in 1988/89, or more than 80%. Contracts awarded to AECL also increased by 42% to $1.7 M. The breakdown of the 1988/89 sector awards is as follows:

Sector	**$M**
Industry	2.3
Universites	0.6
AECL	1.7
Ontario Hydro	1.9
CFFTP	2.2
Total	**8.7**

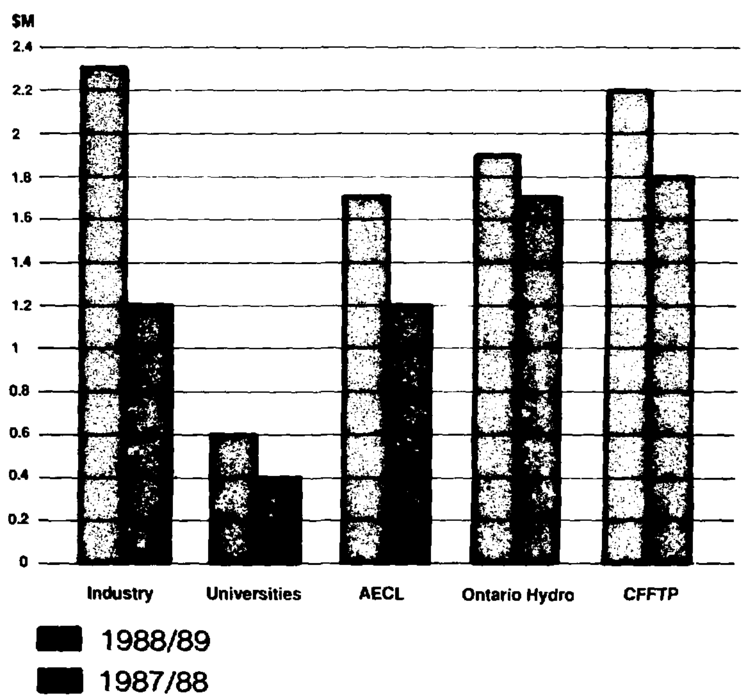


Figure 2

Communications Highlights

Distribution of the "Understanding Fusion Energy" educational resource kit was completed. More than 1100 of these kits which deal with the basic science and technical aspects of fusion energy were distributed to educational facilities across Canada. The resource kit "An Investment in the Future" which addresses the environmental aspects of fusion is currently in distribution with over 500 distributed in this fiscal year.

CFFTP's newsletter CFFTP Journal, now published in-house, took on a more technical aspect this year, to better reflect the information needs of the international fusion community. CFFTP Journal provides information on R&D directions, international liaisons and CFFTP project initiatives. Distribution is aimed at the fusion industry, governments, national and international agencies, and other interested parties in Canada and abroad. CFFTP has contributed to a number of publications on fusion energy and submitted a synopsis of capabilities for the CNA publication "Fusion Energy - What Canada Can Do".

CFFTP co-chaired and helped to host the "Third Topical Meeting on Tritium Technology in Fission, Fusion and Isotopic Applications". This important international meeting was held in Toronto.

Further developments for the Communications program include ongoing public speaking engagements, production of information material such as pamphlets and display boards, and stronger communications links with international partners.

Management's Responsibility for the Financial Report

The accompanying financial statements of CFFTP are the responsibility of the management of the Project. They have been prepared in accordance with the requirements laid down in the Second Term Agreement between Ontario Hydro and Atomic Energy of Canada Limited, and between Ontario Hydro and the Ontario Ministry of Industry, Trade and Technology. All costs incurred in the year have been accurately recorded in the accounts as they apply to particular projects, or allocated to all projects in a systematic and rational manner. We are satisfied that the financial statements have been properly prepared within reasonable limits of materiality.

The operations of CFFTP are controlled by the Ontario Hydro Management System. As member of management of the Project, we believe that the Project and Ontario Hydro have systems of internal control adequate to permit the preparation of accurate statements in accordance with generally accepted accounting principles and those specified in the Second Term Agreement.

The financial statements have been examined by Clarkson Gordon, independent external auditors, in order to ensure that the statements present fairly the costs of the Project. The scope of their examination and opinion are outlined in the auditor's report.

D.P. Dautovich
Program Manager

B.C. Yeung
Acting Manager Finance and Operations

Financial Review

Financial Statements

Statement of Net Project Expenditures

For the Year Ended March 31, 1989
(with comparative figures for the year ended March 31, 1988)

Expenditures (note 2(b))	**1989**	**1988**
Fusion Systems and Engineering:		
Blanket and First Wall Systems	$1,544,046	$1,116,230
Fusion Fuels Systems	1,015,945	770,348
Alternate Concepts	14,120	-
Safety and Facilities Engineering:		
Safety and Environment	775,622	610,952
Risk Reliability and Maintenance	376,898	525,912
Technology Applications:		
Services	1,808,826	1,224,225
Remote Handling	561,135	604,871
Technology Transfer	99,864	66,327
Business Opportunities	1,032,050	-
Finance and Operations:		
Finance	375,238	331,334
Operations	1,145,437	1,026,118
Total expenditures for the year	**8,749,181**	**6,276,317**
Client Funding (note 2(c))		
Fusion Systems and Engineering:		
Blanket and First Wall Systems	297,745	176,502
Fusion Fuels Systems	141,020	68,141
Alternate Concepts	34	-
Safety and Facilities Engineering:		
Safety and Environment	198,459	87,738
Risk, Reliability and Maintenance	78,863	198,131
Technology Applications:		
Services	1,068,136	837,438
Remote Handling	269,263	334,478
Technology Transfer	172	470
Business Opportunities	609,585	-
Finance and Operations:		
Finance	71,000	100,000
Total client funding for the year	**2,734,277**	**1,802,898**
Net project expenditures for the year	**$6,014,904**	**$4,473,419**

(See accompanying notes to financial statements)

Statement of Accumulated Net Expenditures and Contributions by Participants

	Expenditures	Contributions	Net excess expenditures
Accumulated, as at March 31, 1988			
Atomic Energy of Canada Ltd.	$ 2,236,709	$ 2,200,000	$ 36,709
Province of Ontario	-	-	-
Ontario Hydro	2,236,710	2,200,000	36,710
Total	**4,473,419**	**4,400,000**	**73,419**
Current year amounts			
Atomic Energy of Canada Ltd.	2,295,277	2,200,000	95,277
Province of Ontario	1,424,350	1,490,800	(66,450)
Ontario Hydro	2,295,277	2,200,000	95,277
Total	**6,014,904**	**5,890,800**	**124,104**
Accumulated, as at March 31, 1989			
Atomic Energy of Canada Ltd.	4,531,986	4,400,000	131,986
Province of Ontario	1,424,350	1,490,800	(66,450)
Ontario Hydro	4,531,987	4,400,000	131,987
Total	**$10,488,323**	**$10,290,800**	**$197,523**

(See accompanying notes to financial statements)

Auditors' Report

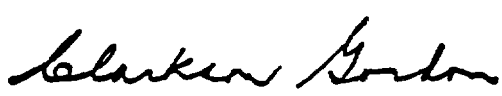
To Atomic Energy of Canada Limited,
the Ministry of Industry, Trade
and Technology (Province of Ontario)
and Ontario Hydro:

Re: The Canadian Fusion Fuels
Technology Project
(Second Term Agreements)

We have examined the statements of net project expenditures and accumulated net expenditures and contributions by participants of The Canadian Fusion Fuels Technology Project (Second Term Agreements) for the year ended March 31, 1989. 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 net expenditures of the Project and accumulated net expenditures and contributions by participants for the year ended March 31, 1989 in accordance with the provisions of the Second Term Agreements of The Canadian Fusion Fuels Technology Project and significant interpretations thereof as described in the notes to the financial statements applied on a basis consistent with that of the preceding year.

Toronto, Canada
June 9, 1989.



Chartered Accountants
A Member of Arthur Young International

Financial Review

Notes to Financial Statements

March 31, 1989

1. Purpose of the Project
The Canadian Fusion Fuels Technology Project (the "Project") was formed under a Comprehensive Agreement in 1983 (the First Term Agreement) to develop expertise in tritium-related technology and robotics for the development of fusion powered systems. The First Term Agreement terminated on March 31, 1987. A Second Term Agreement which covers the period from April 1, 1987 to March 31, 1992 was signed during 1987 by Ontario Hydro and Atomic Energy of Canada Limited ("AECL") (each of which areed to fund 50% of the net project expenditures for this period).

During 1989, the Province of Ontario (represented by the Ministry of Industry, Trade and Technology) and Ontario Hydro signed an additional Second Term Agreement which covers the period September 1, 1988 to March 31, 1993. The agreement reflects a commitment by the Province to match the contributions of the other parties up to a prescribed limit. Ontario Hydro and AECL are each committed to provide the Project with $11 million under the Second Term Agreement. The Province of Ontario is committed to provide to a maximum of $9.4 million under its agreement with Ontario Hydro.

Ontario Hydro is responsible for the management of the Project and, in this regard, is authorized to enter into agreements with outside parties to provide the necessary engineering and administrative services to fulfill the mandate of the Project.

2. Basis of accounting
The following significant accounting policies have been approved by the Project's Steering Committee for purposes of accounting for the Second Term Agreements:

(a) Contributions by participants are recorded by Ontario Hydro on behalf of the Project as they are due, according to the terms of the operating Agreements.

(b) Expenditures are recorded using the accrual basis of accounting. Costs include shared branch and divisional expenses, following Ontario Hydro's standard accounting practices and procedures, with the exception of the application of the standard corporate overhead charge, which has been waived for this Project.

(c) Client funding represents expenditure reimbursements and revenue.

The Project has entered into engineering contracts with other parties whereby reimbursements are received for a portion of certain expenditures incurred by the Project. Reimbursements under these contracts are recognized on the accrual basis, where there is reasonable expectation of future receipt.

Business Opportunities funding represents revenue arising from the Project's activities and is recorded on an accrual basis, where there is reasonable expectation of future receipt.

(d) Any interest earned on funds advanced by the participants to Ontario Hydro in excess of net Project expenditures is not credited to the Project, nor is interest charged on funds provided by Ontario Hydro for expenditures in excess of advances.

3. Related party transactions
The Project subcontracted certain work to both AECL and Ontario Hydro during the year as follows:

	1989	**1988**
Payments to AECL	$1,696,172	$1,236,628
Payments to Ontario Hydro	$1,929,485	$1,750,662

4. Payments to Industry and Universities

	1989	**1988**
Payments to Industry for subcontract work	$2,257,286	$1,158,007
Payments to Universities for subcontract work	$ 638,542	$ 355,445

5. Comparative figures
Certain of the 1988 comparative figures have been restated to conform with the presentation adopted in 1989.

Information about CFFTP programs is distributed freely, to encourage industrial participation, to explain the role and mission of CFFTP in the modern energy economy, and to circulate the results of its technology programs to other fusion sites. All the publications and technical reports described here are free on request. CFFTP staff also publish and present numerous scientific and engineering papers. Write, telephone or send a FAX to the CFFTP Information Centre with your requirements.

CFFTP Journal

This is CFFTP's technical newsletter. It reports on CFFTP work, to inform the fusion community and stakeholders in fusion development. It will interest research institutions, fusion projects, industry, government agencies, utilities and universities.

Each issue reports on our research programs, design project events, contracts awarded to and by CFFTP, industrial collaboration and CFFTP collaboration with other fusion centres and national fusion programs.

CFFTP Annual Report on Activities

Yearly review of CFFTP activities, accomplishments and financial results, along with a summary of future plans. Sections include: Year in review, What is fusion?, ITER, Safety and the Environment, Technology capabilities, Financial summary, CFFTP attachments and a summary of CFFTP reports and publications.

Fusion Services & Equipment Supply

A brochure which briefly outlines the design, construction and commissioning services provided by CFFTP. Also described are the research and equipment development services.

A teaching resource for secondary school and community college teachers which introduce the topic of energy from fusion. Each teaching resource consists of a filmstrip, audio cassette and teachers' guide.

Understanding Fusion Energy

Science courses. Designed to develop a clear understanding of the physics/chemistry of fusion, outlines of the objectives of world fusion programs.

An Investment in the Future

Geography/environmental science courses. Discusses energy alternatives, introduces principles of fusion to the non-scientist, encourages discussion of Canada's research and development challenge

These are available free, in English or French, through a 1-hour workshop focusing on program content and classroom implementation.

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Glossary of Acronyms and Abbreviations

AECL	Atomic Energy of Canada Limited
ALSB	Aqueous Lithium Salt Blanket
BEATRIX	Breeder Experimental Matrix
CAD	Computer Aided Design/Drafting
CCFM	Centre canadien de fusion magnétique
CFFTP	Canadian Fusion Fuels Technology Project
CNA	Canadian Nuclear Association
CREATE	Chalk River Experiment to Assess Tritium Emission
CRITIC	Chalk River In-reactor Tritium Instrumental Capsule
CRNL	Chalk River Nuclear Laboratory
ENEA	Energia Nucleare Energie Alternative
ETMOD	Environmental Tritium Model
FEDC	Fusion Engineering Design Centre, Oak Ridge
FINESSE	Fusion integrated Nuclear Experiments Strategy Study Effort
FFTF	Fast Flux Test Facility
FRG	Federal Republic of Germany
GC	Gas Chromatography
GC-ISS	Gas Chromatography-Isotope Separation System
ISS	Isotope Separation System
ITER	International Thermonuclear Experimental Reactor
IVHU	In-Vessel Handling Unit
JAERI	Japan Atomic Energy Research Institute
JET	Joint European Torus
KfK	Kernforschungszentrum Karlsruhe
LIS	Laser Isotope Separation
MARS	Mirror Advanced Reactor Study
MINIMARS	Mini-Mirror Advanced Reactor Study
NET	Next European Torus
NFP	National Fusion Program
NRU	Nuclear Reactor Universal
OHRD	Ontario Hydro Research Division
ORNL	Oak Ridge National Laboratory
R&D	Research & Development
SAFE	Safety and Facilities Engineering
TIBER	Tokamak Ignition/Burn Experimental Reactor (USA)
TITAN	TITAN reversed-field pinch fusion reactor design (USA)
TRF	Tritium Removal Facility
TFTR	Tokamak Fusion Test Reactor
UK	United Kingdom
USA	United States of America
USSR	Union of Soviet Socialist Republics
UTIAS	University of Toronto Institute for Aerospace Studies

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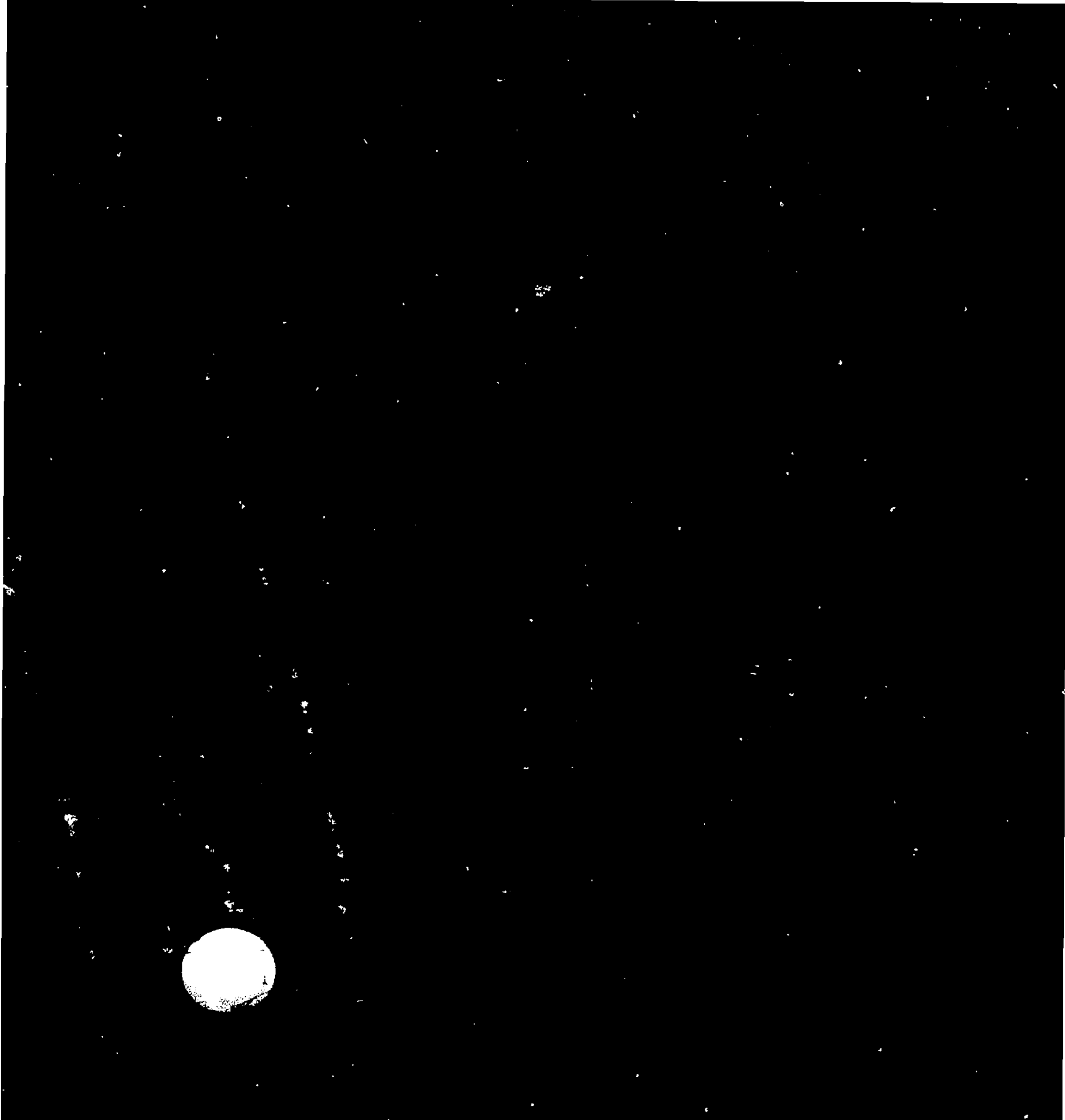
Design: David Blackshaw
Author/Editor: Macphee Technical Corporation
Co-ordination: Sonja Morgan, CFFTP
Printing: PRO-ART Graphics Inc.



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