Canadian Fusion Fuels
Technology Project

CFFTP

CANADIAN CAPABILITIES IN FUSION FUELS TECHNOLOGY AND REMOTE HANDLING

CFFTP-G-87002,
OCTOBER 1987

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1.0 THE CANADIAN FUSION FUELS TECHNOLOGY PROJECT

The Canadian Fusion Fuels Technology Project (CFFTP) has been established to develop and apply advanced technology for fusion power development. CFFTP is funded by the Government of Canada, the Province of Ontario, and by Ontario Hydro and focusses on the technology required to produce and manage the tritium and deuterium fuels to be used in fusion power reactors.

Technology and engineering services are provided by CFFTP to international fusion and fusion related projects. The work includes systems studies, systems and facilities design, and commissioning. Health and safety activities are a part of many of the projects. In some cases, CFFTP selects staff to work directly at the project site.

CFFTP selects and supports research and development programs which expand our expertise in fusion fuels management. Our programs focus and extend existing Canadian technology on the special problems of this field. We apply this expertise in fusion laboratories as part of Canada's contribution to international fusion power development.

Development and use of fusion fuels builds on Canada's expertise gained during its 30-year nuclear power program. This program has produced the CANDU heavy water nuclear power reactor and provided Canada with a large resource base in nuclear engineering. Together with other technologies, in particular the remote handling technology developed for the aerospace industry, this resource base provides the foundation for the CFFTP project.

CFFTP has organized its activities within three responsibility areas:

1. Systems development and engineering

   Concepts, materials, processes and hardware are developed for systems needed on fusion devices. The systems of interest are those that directly impact the fusion core and are divided into two categories. Blanket and first wall systems include the blanket, blanket tritium recovery and first wall systems. Reactor exhaust and fuel processing systems include the vacuum, fuel cleanup, isotope separation, fuelling and fuel storage systems.

2. Maintenance and operations

   Concepts, methods, data, hardware and materials are developed for the reliable and safe operation of fusion facilities, to conduct safety assessments and to apply safety technology to the design of fusion facilities. The two major program areas are safety technology and safety analysis and design.

(a) Safety technology addresses effluent cleanup, radioactive waste management, tritium control aspects such as diffusion, absorption and outgassing in materials and surfaces, permeation barriers, surface protective coatings and personal protective clothing, radiological monitoring instrumentation, and dosimetric and environmental aspects of tritium.

(b) Safety analysis and design activities include the development and application of analytical tools for conducting tritium facility and fusion device safety assessments. Safety criteria are being developed for application in the design/operation of fusion facilities.

3. Technology Applications

Technology Applications activities are designed as follows:

(a) To apply developments in fusion fuels and related systems to specific projects, e.g., tritium laboratories, fusion power systems, neutron accelerators, tritium fill stations.

(b) To provide Canadian services, e.g., project management, design, design reviews, safety assessments, supply, construction, installation, commissioning and attachment of specialist personnel to external projects.

(c) To offer training courses to the international tritium community.

(d) To utilize and adapt Canadian developments in remote handling equipment to fusion applications.

The theme of tritium runs through all areas of technological development and application, since tritium will be an important fusion reactor fuel for the foreseeable future. Tritium management expertise is widely available in Canada, because tritium is a byproduct of the routine operation of CANDU reactors.

Tritium produced in the heavy water systems of CANDU reactors raised concerns that led to many activities related to tritium management. Tritium management technology was developed and health and environmental effects investigated in detail. These activities were carried out primarily by Atomic Energy of Canada Limited. (AECL) and Ontario Hydro, who represent two of the important resources being utilized by CFFTP in the application of Canadian technology to national and international fusion programs.

Canadian experience in remote handling is based on technology developed for fission reactor, aerospace and industrial applications. The applicability of this experience to fusion device requirements has been established through the results of work done by a CFFTP industrial team (SPAR Aerospace, CAE Electronics, and Canadian General Electric), participating in the TFTR, JET and NET projects.

CFFTP publishes technical reports on its programs. These reports are available from the CFFTP Information Centre. This report summarizes Canadian tritium technology and remote handling experience and capabilities that are applicable to fusion.

2.0 CANADIAN TRITIUM LABORATORIES

The tritium handling facilities of Ontario Hydro, AECL/Chalk River Nuclear Laboratories (CRNL) and Canadian universities, that are utilized and available for fusion fuel technology research and development, are described below.

2.1 CRNL Tritium Laboratories

The tritium handling facility at CRNL was designed and constructed to handle several grams of T_2. The primary purpose of the laboratory is to develop methods for the immobilization and packaging of elemental tritium recovered from CANDU reactors. Under contract to CFFTP, CRNL has evaluated a small scale fusion fuel purification system in the tritium laboratory.

Technology was developed and knowledge and experience gained in the preparation and evaluation of metal hydrides which were candidates for use as a tritium storage bed. During tritium operation, the facility's equipment (e.g., glove box, glove box atmosphere cleanup system, pumping and valving systems) was evaluated along with other facets of tritium laboratory operation such as tritium monitoring philosophy and monitoring, operating procedures, and health and safety requirements. CFFTP has also utilized CRNL facilities and personnel to provide hands-on training with tritium as a part of CFFTP's Tritium Safe Handling Course.

2.2 Ontario Hydro Tritium Laboratory

The tritium laboratory at Ontario Hydro is designed to handle gram quantities of T_2. Its main purpose is to support commissioning and operation of Ontario Hydro's heavy water tritium extraction facility which is scheduled to be in service during 1988.

The laboratory has been using trace quantities of tritium to conduct developmental work on uranium beds. As a 200 m^2 laboratory, it is licensed to handle several thousand curies of tritium. The development of a gas chromatograph unit for hydrogen isotope separation has been completed. Other work includes laser separation of hydrogen isotopes for the heavy water production and the removal of tritium from light water effluents.

2.3 University Tritium Laboratories

The McMaster University tritium laboratory, licensed to handle small quantities of tritium, is used mainly for materials-oriented R&D programs. The programs are designed to support CFFTP and CANDU reactor programs. A program of specific interest to the fusion community is an investigation into the effects of temperature and radiation on tritium permeation in metals.

The University of Toronto Institute for Aerospace Studies tritium laboratory is licensed to handle small quantities of tritium. The laboratory will be used to investigate hydrogen and impurity interaction with carbon at the first wall.

3.0 TRITIUM STORAGE BEDS AND SHIPPING CONTAINERS

Shipping containers have been developed by CRNL and Ontario Hydro to contain and transport up to 0.5 MCi of immobilized tritium. The Ontario Hydro container has been tested at CRNL and is licensed as a Type B container.

CRNL has completed an extensive program which has demonstrated techniques for the immobilization of tritium as metal hydrides and has characterized their properties.

Uranium beds for shipping and in-process storage have been built in several sizes at CRNL, Ontario Hydro Research Division (OHRD) and by E.S. Fox, a Canadian manufacturer. A storage container utilizing titanium sponge, capable of containing 0.5 MCi of tritium, has been built, tested and licensed. A number of these containers will be used for the long-term storage of the large inventory of tritium extracted by the Darlington Tritium Recovery Facility.

4.0 TRITIUM EXTRACTION PLANTS

4.1 Darlington Tritium Removal Facility

The Darlington Tritium Removal Facility (TRF) has been built and is currently being commissioned at Ontario Hydro's Darlington Nuclear Generating Station Site. Once in service, it will extract 99.9 per cent pure elemental tritium from heavy water at a rate of 2 kg/a using the vapour phase catalytic exchange (VPCE) process followed by cryogenic distillation. Reactor water is vaporized and superheated before being brought into contact with deuterium gas. After contact in a bed of catalyst, the mixture is cooled to condense the water to allow separation of the tritium enriched gas and depleted vapour.

The Darlington TRF comprises four modular packages containing:

1. Tritium extraction subsystems.
2. Tritium cleanup subsystems.
3. Concentrated tritium handling/storage subsystems.
4. Building and services.

Ontario Hydro planned and developed the facility concept and is involved in all phases of the design, licensing, construction and commissioning of the facility. The detailed design of the tritium extraction and cleanup subsystems was carried out by contractors under Ontario Hydro supervision. The VPCE and cryogenic distillation systems were designed and supplied by Sulzer Canada Limited.

Scheduled to be in service during late 1987, the plant will be operated with full engineering support, including computerized process simulation, tritiated waste conditioning, disposal, and environmental monitoring.

4.2 CRNL Tritium Extraction Facility

CRNL is constructing a tritium extraction plant to extract tritium from 5 Ci/L heavy water at a rate of 70 g/a using a liquid phase catalytic exchange (LPCE) process. In the LPCE process, reactor water trickles down a column packed with a wet-proofed catalyst and exchanges its tritium with an ascending stream of deuterium gas. The CRNL facility will be the first industrial scale plant to demonstrate the wet-proofed catalyst which was developed at CRNL. The plant will produce 99.9 per cent pure tritium.

With the exception of the cryogenic distillation column, which was designed and supplied by Sulzer Canada Limited, the plant was designed and manufactured at CRNL. The tritium gas handling facility was designed and constructed at CRNL.

4.3 NRX Reactor Tritium Production Loop

A He-3 loop was designed and installed by CRNL personnel in the NRX reactor at CRNL. Primarily to study neutron flux control using He-3, it provides a source of high concentration tritium gas for use in the tritium laboratory. Maximum oxide concentrations of tritium in the loop are similar to those encountered in the fusion fuel cycle, and the magnitude of radiological hazards and the pathways are comparable.

The neutron flux reaching fuel elements in the experimental loop is controlled by H-3 circulating in a stainless steel coil located in an annular space around the fuel. The (n,p) reaction on He-3 produces H-1 and H-3. The hydrogen is removed to sustain flux control characteristics. This is accomplished by cycling the gases over hot copper oxide to oxidize the hydrogen catalytically so that it can be collected on a molecular sieve.

5.0 TRITIUM EQUIPMENT

Tritium monitors and equipment developed in support of the CANDU reactor and fusion programs are described below, and a listing of Canadian suppliers of tritium equipment is given in Appendix A.

5.1 Monitors

The radiation monitoring and tritium control requirements imposed by CANDU reactor operation have lead to the development of a number of tritium monitors. Monitor designs have been developed by AECL and Ontario Hydro to meet a wide range of health physics and process monitoring needs, including a monitor which discriminates between tritium in elemental and oxide forms and compensates for interfering radioisotopes.

5.2 Instrumentation and Control

The central and local control and data logging systems required by the tritium extraction systems (Section 4.0), were designed by the respective owners and supplied by Canadian manufacturers. The systems provide for manual, semiautomatic and fully automatic control as appropriate. Both hard-wired control logic and software programmed digital control are employed.

5.3 Uranium Beds

CRNL and Ontario Hydro have acquired uranium bed design, construction and testing experience. They have investigated the performance of uranium beds for applications such as processing (i.e. purification) and storage of tritium and tritium compounds. Other activities include:

1. Systematic studies of U-bed performance under typical hydrogen loading/unloading conditions expected in tritium handling systems.

2. Experimental testing and evaluation of a 6 kg U-bed designed and built by Los Alamos Nuclear Laboratory (LANL) for use in the tritium system test assembly (TSTA).

3. Design of a 3 kg U-bed which optimizes hydrogen loading rates.

4. Design of a loop for transferring tritium from storage containers to uranium transportation containers and for refurbishing spent storage transportation containers.

5. Construction of a 3 kg prototypical U-bed for service in the tritium immobilization loop.

6. Construction of U-beds for a prototypical transfer loop to carry out a systematic study of hydrogen transfer and container recycling.

In cooperation with CFFTP and technical support from CRNL and Ontario Hydro, a Canadian Manufacturer, E.S. Fox, has been qualified to build U-beds.

5.4 Glove Boxes

Glove boxes for a variety of tritium service applications have been designed and manufactured by CRNL and Canadian industries. The designs range from air atmosphere glove boxes required to enclose low concentration maintenance wastes to inert gas atmosphere glove boxes, equipped with hydrogen removal systems, to enclose tritium processing systems containing up to 0.5 MCi of tritium.

5.5 Driers

High integrity vapour recovery systems are used in CANDU reactors to collect tritiated D_2O which has escaped from various reactor systems. Regenerable desiccant bed driers are used to collect the tritiated D_2O from within the confinement areas.

Analysis and testing of vapour recovery systems by Ontario Hydro and CRNL have shown that driers having detritiation factors of greater than 10 000 can now be produced. Current air detritiation systems oxidize elemental tritium for removal in molecular sieve driers. Appendix A lists several Canadian suppliers of driers.

5.6 Pumps and Blowers

Ultra low leakage tritium compatible pumps and blowers are available from NOVA Magnetics Ltd. or through CFFTP. With leakages as low as 10^{-11} cc/s they can be used in such applications as tritium storage, process and purification systems. Further information is provided in CFFTP Product Bulletin "Tritium Compatible Pumps and Blowers."

5.7 Protective Clothing

Disposable and reusable radiation suit systems for use in tritiated atmospheres are available through CFFTP. The protection factor for new suits has been determined to be approximately 1200:1; the effect of wear on the protection factor is currently being investigated. The suit systems incorporate a cooling vest, breathing air supply and communications equipment.

6.0 HEALTH PHYSICS

CFFTP, through its resource organizations, AECL and Ontario Hydro, is able to supply health physics support and services to the fusion community. AECL and Ontario Hydro experience includes health physics research and development, nuclear plant design review and operational health physics with CANDU pressurized heavy water reactors. Research and development activities include development of tritium monitors, dosimeters and dosimetry methodology, protective clothing, and environmental tritium assessment and control.

Plant design reviews are conducted on all CANDU nuclear plants at each design stage, and all radioactive systems are subject to radiation safety reviews. These include reviews and modifications to comply with ALARA* criteria, as well as reviews designed to ensure the absence of any potentially acute hazards.

Operational health physics programs manage tritium hazards at 14 operating CANDU reactors with tritium inventories which are predicted to reach more than 6 million curies per reactor. Extensive field knowledge and experience is available for:

1. Tritium contamination control.

2. Tritium exposure control.

3. Tritium monitoring.

4. Control of airborne releases and liquid effluents.

5. Waste management.

The Canadian nuclear industry uses a system safety approach for management of radioactive hazards. Elements of the management oversight and risk tree (MORT) system approach are employed (developed for the US Department of Energy), as well as incorporating more modern system safety methods. The behaviour of tritium within the human body has been extensively studied at CRNL, along with the effect of tritium quality factor. The dosimetry for tritium in the body and in various organs is presently under study.

The measurement and movement of tritium in the region of the CRNL plant site at Chalk River, Ontario, and the NPD reactor at Rolphton, Ontario has been monitored through water and air measurements. This includes the pickup and retention of tritium by vegetation. A recovery system for tritium from the air is being developed at present.

An Ontario Hydro tritium dispersion code (OHTDC) has been specifically developed for fusion facility and tritium laboratory application to analyze chronic and accidental releases of tritium. A version of this code is already in use at Princeton Plasma Physics Laboratory (PPPL).

7.0 TRITIUM TECHNOLOGY ENGINEERING SERVICES

CFFTP is able to offer engineering services for tritium applications in the following areas:

1. Conceptual, preliminary and detail design.

2. Failure and consequences analysis.

3. Seismic analysis.

* ALARA - as low as reasonably achievable.

4. Environmental assessment.

5. Licensing.

6. Construction supervision.

7. Commissioning.

8. Technical support to operating plants.

For the above services, CFFTP draws on the resources of Ontario Hydro, AECL and Canadian Nuclear Industrial Manufacturers. A high degree of competence has been achieved in all of the noted disciplines through the design, construction and operation of the CANDU power and the handling facilities and tritium extraction plants described in Sections 1.0, 2.0, 3.0 and 4.0. Appendix B lists some recent projects underway or completed on behalf of offshore clients using the expertise described.

Some of the experience upon which this competence is based is described in the following sections.

7.1 Conceptual and Detail Design

Since the introduction of CANDU nuclear power plants in Ontario (1962), the importance of tritium management has been recognized throughout nuclear design, construction, commissioning, and operation. As a result, equipment and systems have been developed that far exceed previous standards of leak-tightness. Procedures and equipment have also been developed which reduce operator exposure during the operation and maintenance of plants and during the management of tritiated waste.

Based on operating experience and measured leak rates, an established data base of component leakage performance is constantly being expanded. Design guidelines, with the objective of minimizing leakage, are documented and refined with the design of each successive station. Data on permeation of tritium through various materials is constantly being evaluated and updated.

High integrity systems to confine tritium, which has escaped as tritiated water vapour, have been designed and are operational at all nuclear stations. Regenerable desiccant bed driers are used to collect tritium and D_2O from within confinement areas. Recovery technology is highly developed and performs efficiently.

Systems which monitor tritium levels throughout each power station have been developed and are operational. These systems also monitor the quantity of tritium released into the environment via ventilation exhaust systems. Releases have been kept below 1 per cent of regulatory limits.

Tritium leakage and emission rates associated with all station systems are constantly evaluated and updated. Computer-based environmental pathway models are used to evaluate public doses associated with chronic tritium emissions from nuclear sites. Accident analyses are performed for all systems and facilities containing potentially hazardous quantities of tritium.

In addition to the foregoing experience which is largely related to the CANDU plants, the tritium production and handling facilities described in Sections 2.0 and 4.0 have been largely designed and constructed in Canada.

7.2 Failure and Consequence Analysis

The Canadian nuclear industry has many years of experience in the assessment of the radiological consequences of tritium emissions. The group has expertise in the modelling of equipment releases of tritium, dispersion, and environmental pathway analysis and the assessment of hydrogen fire and explosion hazards.

The aforementioned expertise is being applied to elemental tritium releases and has been used on a variety of safety assessments. These comprise the failure and consequence analysis including that of a seismic event causing damage to the Ontario Hydro Tritium Recovery Facility. The probability of a hydrogen release resulting in fire or explosion was assessed, and the damage resulting from the largest possible shock wave was evaluated. Maximum radiological doses (caused by tritium dispersion) to the public and to operators of the adjacent nuclear installation were calculated.

Extensive experience in the seismic qualification, design, and analysis of equipment and piping carrying tritiated heavy water in the CANDU nuclear power plants has been acquired.

7.3 Seismic Analysis

Seismic qualification, design and analysis of equipment and piping carrying tritiated heavy water in the CANDU nuclear power plants is routine. AECL has designed CANDU nuclear power plants for free-field ground motion acceleration ranging from 0.05 g to 0.2 g. In addition, several experimental and theoretical studies were conducted to evaluate CANDU systems for severe earthquakes. The analysis was conducted to determine the impact of seismic events on pressure vessels, piping, rotating machinery, valves, controls, containment buildings, various structures and other related equipment.

7.4 Environmental Assessment

Models and programs are available to assess the environmental impact of chronic and accidental releases from tritium facilities. These models are tested by active experiments and are constantly being upgraded by further research and development. Recent work is examining the conversion of elemental tritium to the oxide form in the atmosphere, animals and plants.

7.5 Licensing

AECL and Ontario Hydro have performed analyses, prepared submissions and obtained licenses for operating nuclear power plants, heavy water plants, tritium production plants and tritium laboratories in Canada.

This capability and experience has been successfully applied to projects outside Canada. Analysis for licensing purposes has been performed on behalf of the University of Rochester in the USA and JRC, Ispra in Italy (refer to Appendix B).

7.6 Commissioning

7.6.1 Commissioning of Nuclear Reactors

There are 14 commercial CANDU reactors in service at Pickering and Bruce, all of which were built and commissioned, and now operated by Ontario Hydro staff. In addition, AECL and Ontario Hydro staff formed the commissioning teams for CANDU 600 reactors in Korea, Argentina, Quebec and New Brunswick.

The systems commissioned included:

1. Primary heat transport and auxiliaries.
2. Main moderator and auxiliaries.
3. Heavy water management.
4. Safety shutdown.
5. Containment.
6. Vapour recovery driers and exhaust cleanup systems (for use with tritiated heavy water).
7. Tritiated heavy water upgraders.
8. Emergency core cooling.
9. Feedwater and condensate.
10. Boiler level and pressure control.
11. HVAC (active and inactive systems).
12. Service systems
    - instrument air
    - recirculated cooling water.

7.6.2 Commissioning of Systems Containing Elemental Tritium

CRNL commissioned and now operates the CRNL Tritium Laboratory and the NRX Tritium Production Facility (Sections 2.1, 4.3).

The tritium laboratories at Ontario Hydro Research Division, McMaster University and University of Toronto Institute for Aerospace Studies have been commissioned with, and currently operate with, tritium.

The Darlington TRF described in Section 4.1 is in the final stages of commissioning and is expected to start extracting tritium in 1987.

7.7 Technical Support to Operating Plants

Both Atomic Energy of Canada and Ontario Hydro provide a technical support to nuclear power plants, heavy water plants and (tritiated) heavy water upgrading facilities. This covers problem analysis, design, construction, operation, in-service inspection and research and development support to upgrade and improve performance of the systems.

CFFTP has arranged for technical support to be supplied by AECL and Ontario Hydro to tritium facilities in Canada and offshore.

8.0 REMOTE HANDLING TECHNOLOGY

Remote handling technology has been developed in Canada to service two major industries, nuclear power generation and aerospace.

The nuclear industry has evolved from the initial development of the CANDU reactors in the 1950s to the current technology which is continually advanced to maintain the state-of-the-art capability, efficiency and reliability demanded in today's competitive economic climate.

One major advantage of the CANDU reactor is its capability to refuel while operating at full power. Also contributing to CANDU's performance record are remotely controlled inspection techniques and the repair and maintenance of complex electro-mechanical equipment and systems. These required the development of complex and innovative machines, and the evolution of engineering, manufacturing and testing capabilities to provide the resource base for this industry.

The development of remote handling for the CANDU facilities has directly involved approximately 50 000 man-years of research and development. The spinoff from this work to other areas such as aerospace and robotics, as well as the continuation of development in nuclear fuel handling, nuclear facility maintenance and repair, is advancing this technology and upgrading skills ranging from research through design to application.

Canada has had an expanding aerospace industry since the early 1960s, which has generated a number of applications for remotely operable, highly reliable electro-mechanical equipment to function in the space environment. The development, design, manufacture and successful flight tests of the space shuttle remote manipulator system by SPAR Aerospace has highlighted some of the remote handling capabilities of Canadian industries.

CFFTP enjoys the benefit of a successful cooperation with private sector manufacturers and consultants in Canada. CFFTP often draws upon the expertise of Canadian firms to support various aspects of its work.

This close association with Canadian engineers, researchers and consulting firms has brought about a further extension of technological synergy - a joining of forces which as a whole offers broader, more competitive and more comprehensive services.

CFFTP and its associates, such as SPAR Aerospace, CAE Electronics, Canadian General Electric and AECL, have developed a particular expertise in remote handling technology through direct involvement in the design, development, test and commissioning of specialized tools and tooling systems for major repair and maintenance projects, particularly those that take place in adverse environments and areas with limited access.

The supporting organizations are prominent suppliers of manipulator and inspection systems utilizing sophisticated teleoperator controls having sensory feedback, machine vision and artificial intelligence. CFFTP's accessible facilities include testing and development laboratories, fabrication shops, controlled environment and test chambers and mechanical/electrical component testing equipment.

CFFTP offers a range of services that are designed to optimize operations through improved equipment reliability, new equipment development and product/equipment testing. CFFTP client services include:

1. Engineering

(a) Tool design for component repair and maintenance.

(b) Procedure development for component repair and maintenance.

(c) Remote inspection equipment design.

(d) Automatic cutting and welding machine design.

2. Manufacturing

(a) Specialized components.

(b) Inspection and proof testing of components.

(c) Inspection equipment manufacture.

(d) Cutting and welding equipment.

3. Testing and development

(a) Testing of components related to automated equipment.

(b) Testing component endurance.

4. Operating support

(a) Assistance in trouble shooting and solving operational problems.

(b) Inspections in areas difficult to access or with hostile environment.

(c) Providing specialists, tools, materials and parts for on-site repair work.

(d) Training personnel in mechanical component operation and maintenance.

A key element is the adaptability of CFFTP to supply its specialized resources to a wide range of specific needs.

The following project descriptions outline some of the more prominent undertakings of the remote handling resource in Canada and some CFFTP fusion applications.

8.1 CANDU Fuelling Machines

The very successful CANDU heavy water pressure tube reactors owe a large part of their performance record to the ability to refuel without a shutdown.

The development of on-power, remotely controlled fuelling machines by Canadian General Electric and AECL now extends into the fourth generation. A combination of research, development, design, and application has yielded improvements in their performance, reliability and cost. Nearly 100 reactor-years of applied remote fuelling has yielded much understanding of remote handling system requirements.

Each fuelling machine works in conjunction with a second identical machine at the other end of the reactor. The machines are coordinated through a computer which initiates all activities. When fuel is to be exchanged, one machine goes to a transfer port through which it receives a charge of new fuel bundles. Both machines then proceed to the end fittings of the channel to be refuelled.

Once the channel end fitting has been located and its position verified, the machines latch on, pressurize, check for leakage and then remove the channel closure plug and shield plug. The machines then work in unison to insert the new fuel from one machine and accept the irradiated fuel into the other.

When the fuel has been transferred, the machines replace the plugs, check for leaks, then disconnect. The machine with the irradiated fuel goes to the irradiated fuel transfer station and discharges the fuel.

Each machine is a complex combination of mechanical, electrical, and hydraulic actuators in a housing which meets a variety of nuclear, pressure vessel and safety codes. Unifying all functions is a computer system which takes its instructions from sensors and instrumentation on the machine, plus a control console which provides operator interaction and a degree of visual supervision. An optimal combination of redundancy, reliability, automation, and adaptability ensure that the machines function as they were designed to do.

8.2 CANDU Retubing

Inspection of the CANDU reactors has shown that the pressure tubes containing the reactor fuel are elongating at a rate faster than anticipated from the effects of neutron bombardment of the tube material. Sophisticated, remotely operated inspection and measurement equipment was therefore developed to monitor pressure tube characteristics. Subsequently, equipment for pressure tube replacement in both the short-term and long-term was developed.

The downtime cost of commercial nuclear power reactors is considerable. This requires that these machines perform the work quickly and effectively and necessitates a combination of mechanical complexity, automation, manual supervision, preplanning, rehearsal and operational techniques.

8.2.1 Large Scale Fuel Channel Replacement

This program involves the design, development and manufacture of a remote manipulation and control system (RMCS) for complete remote retubing of CANDU nuclear reactors. The main elements of the RMCS system are:

1. Remote manipulator system (RMS) consisting of a carriage assembly on rails supporting a hydraulically actuated jointed arm manipulator with end effector.

2. Remote work station (RWS) consisting of a carriage and turret support assembly with a turret assembly containing tool modules.

The RMCS program required the design and integration of a variety of electrical, mechanical, data handling, sensing and remote supervisory control subsystems.

8.2.2 Single Fuel Channel Replacement

This program is a fuel channel replacement program for reactors that require a limited number of channels replaced. Removal and replacement tools were developed and a calandria tube transfer flask designed and modified.

A full-scale tube replacement demonstration has been performed at a mock-up facility by personnel dressed in clean-air pressurized protective clothing and masks.

8.2.3 Single Channel Shifting Tool

A special purpose machine to reposition fuel channels in reactors has been developed. The main features of the channel shifting tool are as follows:

1. Ten precision jack stations with flexibly mounted guides, air latches and sensors.

2. Dual drive air and stepping motors.

3. Remote central console containing operational controls, status indicators and digital readout displays.

4. Laser measuring system.

8.2.4 Bruce West Shift Program

The shift program at the Bruce Nuclear Generating Station involves remotely detaching the reactor fuel channels from the calandria stop collars, shifting the channels in the west direction and, finally, rewelding the channels to the stop collars at the new location.

The program equipment includes:

1. Two shielding cabinets fitted with a rotating disk and rotating turret which permits access to fuel channels.

2. Tool support carrier and feed mechanism.

3. Specialized tooling such as an x-y positioner and high torque cut and reweld tooling.

8.3 Spacer Location and Repositioning (SLAR)

In a CANDU reactor, tube spacer garter springs are positioned inside calandria tubes to prevent the hot pressure tubes from contacting the cool calandria tubes. A number of spacers in reactors under construction were found to be out of position. Locating and repositioning tools were designed and associated techniques were developed. These included a walker device that locally flexes the pressure tube to move the spring as well as various sensory devices (infrared and fibre-optic).

An extension of this work is the development of a SLAR tool that can be used on operating reactors. The tool comprises eddy current and ultrasonic probes, a mechanical pressure tube bending device to free the spacer and an inductive coil to move the spacer.

8.4 Remote Vault Inspection

To inspect the floor of an operating CANDU calandria vault liner, a multiple articulating arm was developed to deliver and manipulate illumination, cameras and helium leak detection equipment. Development of the arm and testing was done on a full-scale mock-up.

8.5 Shuttle Remote Manipulator System (SRMS)

This project has the unique benefit of high public visibility, hence it is one of the best known of all Canadian technical undertakings. The shuttle remote manipulator system (SRMS) is a human-like arm, 50 ft in length, that is mounted along one side of the storage bay in the NASA Space Shuttle and is used for handling cargo in space. The shoulder, elbow and wrist joints of the arm are self-contained units containing drive motors and high reduction gear trains. The SPAR Aerospace remote manipulator design team started from the development of the basic operating requirements, leading to the evaluation of a number of concepts and, subsequently, the extensive development and testing of operating techniques, as well as prototype hardware. A series of iterations between performance requirements and design capability yielded a design specification upon which the bulk of the detailed engineering was based.

State-of-the-art technology was utilized in materials, components and control methods, leading to the expenditure of considerable effort in the qualification of the new equipment for operation in a space environment. Innovative and sophisticated test rigs were developed to permit the testing of the arm in a gravity field.

Extensive interaction between the NASA Shuttle Orbiter and Payload teams and the Canadian Remote Manipulator System team was established and has proved effective and efficient, culminating in the very successful flight tests of the arm.

The Canadian involvement in the development, design, construction and testing of the arm spanned approximately a decade, encompassing several thousand man-years of work. This expertise is now available to be applied to fusion remote handling requirements.

8.6 TFTR Remote Handling

CFFTP undertook a cooperative venture with the Princeton Plasma Physics Laboratory (PPPL)for the development of remote handling technology to be used on the Tokamak Fusion Test Reactor (TFTR). CFFTP placed a group of specialist engineers from Canadian remote handling industry at PPPL to define remote handling requirements and to set priorities on those requirements. The activities of the group included a review of existing remote handling technology and its adaptation to TFTR requirements.

The cooperative venture was extended to produce a design for a maintenance manipulator known as the in-vessel manipulator. The manipulator is to be used for interior maintenance and inspection of TFTR. It will consist of a multi-jointed arm permanently fixed to a torus port. The manipulator will be capable of entering and working anywhere inside the torus while the Tokamak is at operating vacuum and temperature. The manipulator arm will carry a variety of specialized equipment at its end for performing the varied maintenance operations and inspection tasks inside the torus. The remote handling team at PPPL were supported by a Toronto-based design support team drawn from Canadian industry.

8.7 JET Remote Handling

CFFTP has attached a senior Spar Aerospace Engineer in the position of Leader of the Remote Handling Applications Group at the Joint European Torus (JET) Project. His task is to prepare JET for routine use of remote handling and to then direct remote handling operations when preparations are complete. Preparation work includes:

1. Mapping of the machine.

2. Preparation of remote handling procedures.

3. Development of specialized techniques such as remote cutting and welding.

4. Design and development of special tools and equipment.

5. Detailed refinement of existing installed components to facilitate their manipulation by remote handling equipment.

6. Setting up the man-machine interfaces and control room, the electronics and the computer links.

The overall pattern of remote handling equipment uses transporters to carry heavy components to all parts of the machine or to place and hold end-effectors in position to perform special tasks. The end effectors in some cases grip components and in some cases carry special purpose or general purpose tools. On the outside of the machine a bridge crane or a telescopic mast with a horizontal, articulated and telescopic arm to position a servo-manipulator is used. To reach inside the vacuum vessel, a fully articulated boom is used. This boom is cantilevered from a trolley supported outside the vacuum vessel on a carrier beam. The principal end-effector will be a force-feedback, master-slave, servo-manipulator.

8.8 NET Remote Handling

SPAR Aerospace, in association with CFFTP, has conducted a Development Study for the Next European Torus (NET) comprised of two tasks:

1. Defining requirements for NET in-vessel remote handling.

2. Developing a concept design for an in-vessel handling unit (IVHU) satisfying these requirements.

Following an initial trade-off between different configurations of in-vessel remote handling units (IVHU), two concepts were developed. One concept is an articulated boom IVHU consisting of an end-effector supported by a series of structural links, each connected to its neighbor by a joint drive assembly containing a motor, a gearbox (or equivalent), position sensors, etc.

An alternative concept, the in-vessel vehicle system (IVVS), consists of a telescopically deployable boom supporting an end-effector. This is served by a vehicle traversing the top of the boom conveying tools, materials, etc., to and from the vessel exterior.

APPENDIX A

CANADIAN MANUFACTURERS OF TRITIUM EQUIPMENT

All of the organizations listed have supplied components in Canada for applications where tritium is present in different forms or concentrations. The suppliers are qualified to the level necessary for the particular tritium service application.

Equipment Item	Manufacturers
Molecular sieve driers	. Johnson Matthey Ltd., Toronto, Ont. . Matheson Gas Products Canada Inc., Whitby, Ont. . Union Carbide Canada Ltd., Toronto, Ont. . Pall (Canada) Ltd., Brockville, Ont. . Giffin Sheet Metals Ltd., Toronto, Ont. . Napier-Reid Ltd., Markham, Ont.
Glove boxes	. Spectrum Engineering Corp. Ltd., Peterborough, Ont. . Numet Engineering Company, Peterborough, Ont. . CRNL Atomic Energy of Canada, Chalk River Nuclear Laboratories (AECL/CRNL), Chalk River, Ont.
Catalytic recombiners	. Numet Engineering Company (AECL Licensee). . CRNL/Spectrum Engineering Corp. Ltd.
Control valves	. Velan Inc., St. Laurent, Quebec.
Isolation valves	. Fischer & Porter (Canada) Ltd., Downsview, Ont. . Velan Inc.
Vacuum pumps (vane type)	. Nova Magnetics Limited, Dartmouth, Nova Scotia.
Pumps	. Hayward Gordon Ltd., Mississauga, Ont. . United Pumps of Canada Ltd., Rexdale, Ont.
Tritium storage beds	. AECL/CRNL. . Ontario Hydro. . E.S. Fox Ltd., Welland, Ont.
Vacuum systems	. High Vacuum Systems Inc., Mississauga, Ont.

Shipping containers	. AECL/CRNL. . Ontario Hydro Research Division. . Numet Engineering Company.
Tritium monitors portable, fixed discriminating, non-discriminating	. Scintrex Ltd., Concord, Ont. . AECL/CRNL.
Piping/Tubing	. Several suppliers available.
Pressure gauges	. Several suppliers available.
Flowmeters (Rotameters)	. Brooks Instrument, Markham, Ont. . Fischer & Porter (Canada) Ltd.
Leak tight doors	. Canadoor Ltd., Scarborough, Ont. . Dominion Bridge, Toronto, Ont. . Canadian General Electric Company Ltd., Toronto, Ont. . Intertech Engineering Corp., Toronto, Ont.
Plastic suits - (Ontario Hydro Mark III suit for tritium protection)	. Safeco Mfg. Limited, Scarborough, Ont.
Getter systems	. AECL/CRNL.
Gas cromatographs	. Labserco Limited, Oakville, Ont.
Electrolysis	. Canadian Electrolyzer Corp. Ltd., Etobicoke, Ont.
Remote handling equipment	. Spar Aerospace, Weston, Ont. . CAE Electronics, Montreal, Quebec . Canadian General Electric, Peterborough, Ont. . Atomic Energy of Canada Ltd., Mississauga, Ont.

APPENDIX B

OFFSHORE TRITIUM TECHNOLOGY PROJECTS

B.1 INTRODUCTION

This appendix describes some of the projects performed by CFFTP for offshore clients.

B.2 ACCELERATOR TRITIUM SYSTEMS - PHASE 1: PRELIMINARY ENGINEERING

International Facility:	ENEA Frascati Neutron Generator, Italy.
Contract Duration:	Six months, commencing May, 1985.
Resource Organizations:	CFFTP, Ontario Hydro AECL/CRNL.

Preliminary engineering of a target exhaust cleanup system and an emergency air cleanup system was performed by CFFTP on behalf of Frascati in 1985. The exhaust cleanup system will remove tritium from the vacuum pump exhaust gases. In addition to the vacuum exhaust cleanup system and its glovebox, a utilities glovebox and target changing glovebox have been conceptualized.

B.3 MICROBALLOON FILLING STATION FOR INERTIAL CONFINEMENT FUSION STUDIES - PHASE 1 : DESIGN

International Facility:	University of Rochester Laboratory for Laser Energetics.
Contract Duration:	Five months, ending October 31, 1985.
Resource Organizations:	Ontario Hydro, Nuclear Materials Management Department.

The Laboratory for Laser Energetics (LLE) at the University of Rochester commissioned CFFTP to design its tritium handling and microballoon filling systems. The systems will be used for storing and handling tritium, and for filling microballoon laser targets with tritium. The microballoon targets will be irradiated by lasers in the study of inertial confinement fusion.

The systems designed included:

1. Tritium storage and handling facilities.
2. Microballoon target charging loop.
3. Glovebox.
4. Walk-in fumehood.
5. Instrumentation and control systems.

The storage and charging systems use uranium beds as interim storage and transfer devices.

Operating inventory of the systems is expected to be 5 kCi. Design work was directed so that for radiation safety purposes, radiation doses from tritium will meet the ALARA principle (as low as reasonably achievable). This principle was applied to minimizing research worker radiation doses and public doses.

A Phase II program consisting of the detailed design and preliminary procurement activities was begun late in 1986, leading to a further contract for manufacture and supply is expected late in 1987.

B.4 ETHEL CONCEPTUAL DESIGN (ISPRA, ITALY)

International Facility:	JRC, Ispra - European Tritium Handling Experimental Laboratory (ETHEL).
Contract Duration:	Six months, commencing March 1, 1986.
Resource Organization:	CFFTP, Ontario Hydro, Ansaldo, Monserco Limited, AECL/CRNL, SNIA Techint.

JRC, Ispra has awarded four contracts for conceptual design and costing of a tritium laboratory (Phase 1). The laboratory will handle up to 100 g of tritium which will be used in various experiments in support of the NET project. CFFTP teamed with Ansaldo, Nira (prime contractor) and SNIA Techint of Italy to bid for the contract and the team received one of the four awards. The systems within CFFTP's scope are tritium receiving and storage, tritium transfer system, data acquisition system, waste management system and the monitoring system. Ansaldo is responsible for the building and services and SNIA is responsible for the secondary containment and air detritiation system.

B.5 VACUUM PUMP STUDY

International Facility:	NET Study Team, Garching, West Germany.
Contract Duration:	Twelve months, commencing April 1, 1986.
Resource Organizations:	Leybold-Heraeus, CFFTP, AECL/CRNL, Grumman.

A design study of the NET vacuum system is being performed. This will include both a compound cryopump and a turbomolecular pump option. Leybold-Heraeus of West Germany is the prime contractor. Tritium expertise and compound cryopump expertise are being provided by CFFTP and Grumman Aerospace, respectively. The study will establish the cost, safety and technical risk associated with each option. CFFTP's role will be in assessing tritium impact on radiological safety, maintenance and certain materials' aspects of the two options.

B.6 STUDY OF ISOTOPE SEPARATION METHODS

International Facility: KfK, Karlsruhe, West Germany.

Contract Duration: Two months, commencing September, 1985.

Resource Organizations: CFFTP, OHRD, AECL/CRNL.

KfK, Karlsruhe awarded CFFTP a contract to study the options available to perform the separation of all six hydrogen isotope combinations (H_2, D_2, T_2, HD, HT and DT). The separation device is to be used as a service facility in the KfK Tritium Laboratory project, which is currently in the design phase. The study showed that a gas chromatograph column would best meet the facility needs.

B.7 STUDY OF A GAS CHROMATOGRAPH ISOTOPE SEPARATION SYSTEM

International Facility: KfK, Karlsruhe, West Germany.

Contract Duration: Six months, commencing December, 1986.

Resource Organizations: OHRD, Ontario Hydro Nuclear Materials Department, Labserco Ltd.

KfK, Karlsruhe awarded a contract to study a 3 L/h throughput gas chromatograph unit to separate all six isotopes of hydrogen to meet the specific requirements of the KfK Tritium Handling Laboratory.

B.8 REMOTE HANDLING TECHNOLOGY

Refer to sections 8.6, 8.7 and 8.8 of the main report.