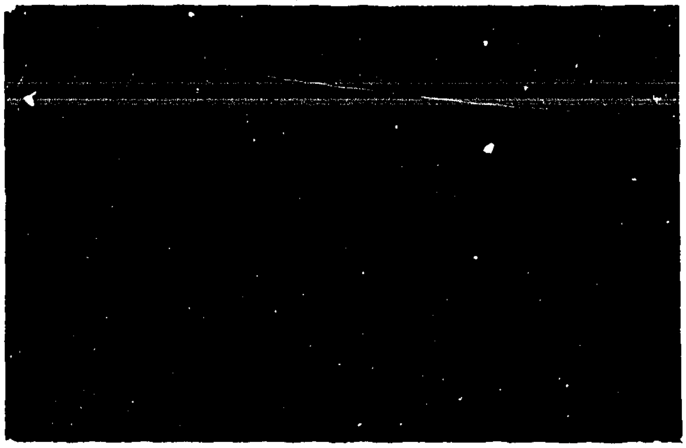
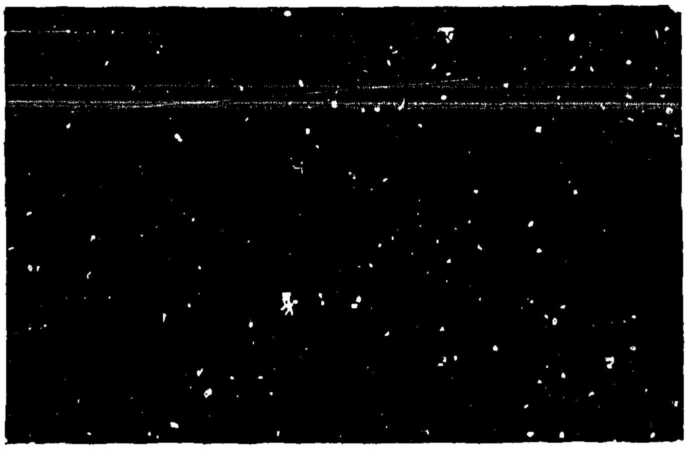
Canadian Fusion Fuel Technology Project





THE CANADIAN FUSION FUEL TECHNOLOGY PROJECT REPRESENTS PART OF CANADA'S OVERALL EFFORT IN FUSION DEVELOPMENT. THE FOCUS FOR CFFTP IS TRITIUM AND TRITIUM TECHNOLOGY. THE PROJECT IS FUNDED BY THE GOVERNMENTS OF CANADA AND ONTARIO, AND BY THE UTILITY ONTARIO HYDRO; AND IS MANAGED BY ONTARIO HYDRO.

CFFTP WILL SPONSOR RESEARCH, DEVELOPMENT, DESIGN AND ANALYSIS TO EXTEND EXISTING EXPERIENCE AND CAPABILITY GAINED IN HANDLING TRITIUM AS PART OF THE CANDU FISSION PROGRAM. IT IS PLANNED THAT THIS WORK WILL BE IN FULL COLLABORATION AND SERVE THE NEEDS OF INTERNATIONAL FUSION PROGRAMS.

Survey of Pumps For Tritium Gas

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PREFACE

This report has been prepared for the Canadian Fusion Fuel Technology Project (CFFTP). It is the result of a study to review various types of pumps for the pumping of tritium gas and to determine areas requiring further improvement or development /1/.

The survey of pumps suitable for use with tritium gas was conducted through literature surveys, discussions with manufacturers and with users at facilities which pump, or plan to pump, tritium gas /2/.

Approaches by Canatom to companies in USA and Europe on behalf of the Canadian Fusion Fuel Technology Project produced disappointing results. Manufacturers were reluctant to provide information on tritium pumps and users were reluctant to provide information on operating experience.

Letters and telephone calls were, generally unproductive. The best results were obtained as a result of meetings where the parties had previously known each other.

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SURVEY OF PUMPS FOR TRITIUM GAS

1.0 EXECUTIVE SUMMARY

This report has been prepared for the Canadian Fusion Fuel Technology Project (CFFTP) by Canatom Inc.

The report considers many different types of pumps for their possible use in pumping tritium gas in the low, intermediate and high vacuum ranges. No one type of pump is suitable for use over the wide range of pumping pressure required in a typical tritium pumping system. The favoured components for such a system are:

bellows pump (low vacuum)
orbiting scroll pump (intermediate vacuum)
magnetically suspended turbomolecular pump (high vacuum)
cryopump (high vacuum)

Other pumps which should be considered for possible future development are:

-Mound modified vane pump
-SRTI wobble pump
-Roots pump with canned motor

It is proposed that a study be made of a future tritium pumping system in a Canadian tritium facility, e.g. a tritium laboratory.

As a result of experience gained in the pump study it is recommended that future study in tritium related fields be conducted, as far as possible, using established personal contacts at manufacturers' and users' facilities.

2.0 INTRODUCTION

The purpose of this report is to summarize the results of a survey of vacuum pumps for pumping tritium gas. This pumping is a requirement of tritium laboratories, fusion research centres and future fusion-electric power plants. There are areas where further study and development are recommended and these are examined at the conclusion of the report.

3.0 BACKGROUND

Tritium, a weakly radioactive isotope of hydrogen, is produced in nature by cosmic ray bombardment of the upper atmosphere. It has been produced in fission reactors for over 30 years. Technologies to separate, contain, handle and utilize this radioactive isotope have been developed in Canada, the USA and Europe. The prospect of building fusion experiments and fusion-electric power plants which would circulate and consume large quantities of tritium has been an incentive for the design and development of tritium handling systems and components.

As an example of the fusion experiments the tritium handling system of the Tokamak Fusion Test Reactor (TFTR) at Princeton, New Jersey, is shown in Figure 1.

Predictions for a 1000 MW fusion-electric power station indicate that 600 g of tritium will be burned each day. Assuming a 5% burn-up of the contained tritium then, at any time during operation, 12 kg of tritium will be in circulation in the vacuum system.

It is expected that some of the present fusion materials technology will be transferred to the industrial uses of tritium which include luminous paints, lighting devices and accelerator targets. These targets are used for the generation of neutrons for radiation damage experiments, radiation hardening and for medical purposes.

Research on tritium compatible materials for use in tritium handling components is underway in academic, commercial and government laboratories. In particular, a major Tritium Systems Test Assembly (TSTA) has been built at Los Alamos National Laboratory (LANL), Los Alamos, New Mexico, to examine tritium technology.

Much of the existing information on tritium systems and components is classified and therefore unavailable.

4.0 MATERIAL PROBLEMS

The lubricants, pumping media and the seals used in many conventional pumps impose restraints on their use in the pumping of tritium gas. Oil may become contaminated with tritium and care is then required in its disposal. Alternatively, oil may escape to the pump exhaust and find its way into the process system with undesirable consequences.

Halogenated plastics or elastometers are subject to radiation damage from the decay of tritium. Molecules of tritium will interchange with molecules of hydrogen in elastometers and other hydrocarbons. Various steels are subject to hydrogen embrittlement in the presence of tritium.

Los Alamos Nuclear Laboratories (LANL) have expressed the viewpoint that no organic lubricants, elastometers or fluorocarbons should be used in the process-wetted passages of pumps for tritium gas.

Mercury and mercury vapour have long been widely used as the pumping fluid in many industrial and laboratory vacuum pump applications. Mercury pumps have been built for rough vacuum, vacuum booster and high vacuum. Mercury and tritium are entirely compatible and mercury pumps have been used in some tritium pumping applications. However, mercury is very mobile even in the liquid state and it is extremely difficult to confine it to the pump. Mercury amalgamates with, and attacks, many of the metals (e.g. aluminum, copper, silver) used in vacuum systems.

4.1 Tritium Gas Stream

In a fusion device, tritium is pumped as one component in a deuterium-tritium gas stream. Helium-3 results from tritium decay and helium-4 is produced from the fusion of deuterium and tritium. Some hydrogen will be present together with traces of nitrogen, oxygen and other gases. In handling tritium, its radioactivity and its flammability must be considered. All the normal precautions used in handling hydrogen must be observed.

5.0 SURVEY OF VACUUM PUMPS

Vacua may be loosely classified as low, intermediate and high. There are no hard and fast lines dividing the three classes but low vacuum may be conveniently considered as extending down to a few kiloPascals and intermediate vacuum down to a few Pascals. Roughing pumps, booster pumps and high vacuum pumps are used for the three ranges.

A convenient, and sufficiently accurate, unit conversion is:

760 torr = 1 atmosphere = 1 bar = 100 kPa

5.1 Low Vacuum Pumps

Low vacuum pumps which have been considered for tritium applications include:

dry rotary vane pump
oil-less piston pump
diaphragm pump
metal bellows pump
dry-contact scroll pump

The ranges of these and other pumps considered are shown in Table 1. The **oil-sealed rotary vane pump** is shown in the table for comparison purposes only; it is not recommended for pumping tritium gas.

The mechanically driven **dry rotary vane pump** and the **oil-less piston pump** suffer from shaft packings or piston seals which are not necessarily vacuum-tight. The "oil-less" packings are frequently made from self-lubricating fluorocarbons which are incompatible with tritium gas. These pumps are not recommended for tritium use. A **magnetically**

driven rotating vane pump has been developed by **Monsanto** /3/ and **Nova Magnetics** /4/ to overcome the disadvantages inherent in the mechanical drive.

Conventional **diaphragm pumps** are oil-less and may be completely leak-tight. Unfortunately, the plastic or elastomeric diaphragm becomes embrittled if used to pump tritium gas. They have been made tritium compatible by manufacturing the diaphragm from metal. One manufacturer, **Jordan Valve** /5/, supplies a suitable pump with three stainless steel diaphragms. A hydraulic fluid driven by a reciprocating piston drives the stacked diaphragms. This pump has been successfully used as a compressor but its modification for vacuum use is complex, large and costly. This has led to the preferential use of the **metal-bellows pump** .

5.1.1 Metal Bellows Pump

The metal bellows pump consists of bellows that are welded to a driver arm. A motor shaft rotates a cam which is mounted on a permanently lubricated and sealed ball bearing. The cam imparts motion to the driver arm. The gas passages are completely isolated from the motion transmitting mechanism. The compressions available from the pumps are fairly low but by series staging of these relatively small pumps, vacuums as low as 1.3 kPa may be produced. Below this limiting pressure the gas being pumped does not have enough momentum to operate the reed-type stainless steel check valves in the gas passages.

Metal bellows pumps have been used in tritium service for many years. Duplex models are available and the two pumping chambers may be connected in series, or parallel or used in separate pumping circuits.

Double bellows, double containment, pumps are available but are not required if the pump is mounted inside a glovebox.

The bellows pump is commercially available from **Metal Bellows Corporation** /6/.

5.1.2 Orbiting Scroll Pump

The orbiting scroll pump is available in a low vacuum version and an intermediate vacuum version. Gas is compressed between two interleaved vanes with spiral channels. The pumping action is obtained between a fixed vane and a moving vane. Each revolution of the moving vane corresponds to one compression stage. The pump is more fully described under intermediate vacuum pumps in Section 5.2.3

5.2 Intermediate Vacuum Pumps

The most difficult region for tritium pumping is the range between a few kiloPascals and a few Pascals. The principle contenders for service in this range are the "wobble" pump, the canned-motor Roots blower and the controlled clearance orbiting scroll, or spiral vane, pump.

5.2.1 Wobble Pump

The wobble pump consists essentially of a diaphragm attached to a wobbling bellows. The French built **SRTI** /7/ wobble pump comes in two basic types, the PBT and the PR, which have been developed for use with radioactive and hazardous gases. The PBT version is a five cylinder volumetric pump in which a metallic bellows seals the grease-lubricated drive train from the pump chamber. The cylinders are arranged vertically and in a circle on a support plate.

The pumps can be staged in series or used with the PR version to obtain higher compressions. A flowrate of approximately 17 L/s is obtained at a pressure of 13 kPa.

The PR wobble pump is a completely dry leak-tight compression pump of the volumetric type. A circular plate, or impeller, rocks in a rotary manner within the pump chamber. This imparts rotary motion to the contained gas.

5.2.2 Roots Pump

The Roots pump consists of synchronized rotors in a pump chamber which is placed between a gear box and a drive motor. Canned motors which provide complete sealing from the atmosphere are now available. The main problem for tritium use is caused by the incomplete isolation of gear and bearing lubricants from the pump chamber. A Roots pump has been built with **Ferrofluid-TM** /8/ shaft seals in order to minimize this problem. Another approach has been to install vacuum-tight seals on the rotor shafts and evacuate the gear case with a conventional vacuum pump. Any tritium leaking past the shaft seals is pumped to a waste treatment system.

5.2.3 Orbiting Scroll (Spiral Vane) Pump

The spiral vane pump is another name for the orbiting scroll pump. A patented, totally dry and fluid-tight vacuum pump has been developed and marketed by **Normetex** /9/. The pumping area is totally isolated from the lubricated parts of the pump mechanism and the external atmosphere. The volumetric pumping action is obtained by two spiral vanes, one fixed and one moving. The vanes are completely contactless and no lubricant is required. Each revolution of the moving vane, which has three turns, corresponds to one compression stage. The movement is provided by three crank shafts equidistantly spaced at 120^{o} and supported in precision bearings.

The continuously monitored sealing device consists of two concentric metal bellows. This provides total and positive isolation of the pumping circuit.

Arthur D. Little, Inc. /10/ is developing several scroll-principle designs for tritium service.

5.3 High Vacuum Pumps

The high mobility of mercury results in mercury diffusion devices being unsuitable for tritium service. This limits consideration of high vacuum applications to turbomolecular pumps and capture pumps.

5.3.1 Turbomolecular Pump

A turbomolecular pump, also known as a turbopump, consists essentially of a bladed turbine that compresses gas by momentum transfer from high speed rotating blades to gas molecules. Early turbopumps did not give adequate compression or speeds for the light gases hydrogen and helium. The organic lubricants used for the high speed bearings were not compatible with tritium. Failure of the turbopump power supply could cause diffusion of oil vapour resulting in contamination of the vacuum chamber. These difficulties have been overcome by the use of magnetic bearings which completely eliminate mechanical bearings and lubrication problems. A turbopump in which the high speed rotor is suspended in vacuum by an electro-magnetic field is commercially available from **Leybold-Heraeus** /11/. Pumping speeds in excess of 500 L/s are possible with hydrogen and helium.

Another manufacturer **Balzers** /12/ has introduced a hybrid design with a conventional lower bearing and a permanent magnet upper bearing. This has a pumping speed up to 60 L/s.

5.3.2 Capture Pumps

Capture pumps reduce the pressure in a vacuum system by collecting or trapping gas molecules on their internal surfaces. The capture is achieved by various means. These include:

- -electrostatic trapping (ion pumps)
- -chemical reaction (titanium sublimation, getter and metal-hydride pumps)
- -physical adsorption (sorption pumps)
- -condensation (cryopumps)

The various capture mechanisms are more effective for some gases than others and are reversible for some gases and not for others. The effectiveness in trapping hydrogen isotopes is crucial in tritium pumping. Helium trapping is also important due to the production of He-3 in tritium decay and He-4 in fusion.

The capture pumps with the largest history of use are the **sorption pumps.** Activated charcoal and molecular sieves, supplied by **High Vacuum Equipment Corp.** /13/, used at liquid nitrogen temperature will capture all gases except helium and neon.

Ion pumps operate by trapping molecules in an electrostatic field and are effective for the hydrogen isotopes. Since the pumping is irreversible they are unsuitable for most tritium applications.

Hydride pumps in United States tritium facilities have used uranium hydride beds for many years. These are not commercial items and each tritium facility has its own favourite design.

After hydriding, uranium breaks down to a fine powder which is difficult to contain. The powder may ignite spontaneously when exposed to air. The advantage of uranium is that it will capture tritium gas at room temperature to pressures as low as 10^{-5} Pa and will release the gas at 400°C in atmospheric pressure. Since oxygen, carbon and nitrogen are captured irreversibly, the uranium hydride bed can be used to purify hydrogen isotopes.

Getter pumps that use zirconium - aluminum alloys, such as those manufactured by **SAES Getters** /14/, have high speeds and reversible characteristics for hydrogen isotopes and are irreversible for impurities such as oxygen and nitrogen. The physical properties of this getter material are much superior to those of uranium. It maintains its shape and does not powder.

Cryopumps capture molecules on cold surfaces by means of weak Van der Waals forces. The gas is released when the surfaces are warmed. Commercial cryopumps, available from **Air Products** /15/ and **CTI-Cryogenics** /16/, operate from helium refrigerators which cool the cryogenic surfaces.

Large cryopumps operating at liquid helium temperatures are favoured for the evacuation of plasma chambers at present fusion facilities. Hydrogen isotopes are captured by condensation on smooth metal plates refrigerated to 4.2 K. Helium in the plasma gas can be absorbed by activated charcoal or molecular sieves. **Compound cryosorption pumps** have helium cryosorbing surfaces and deuterium-tritium condensation panels.

6.0 SUITABILITY OF PUMPS FOR TRITIUM USE

Problems with organic lubricants and with mercury, described in Section 4, have led to several of the pumps surveyed not being recommended for pumping tritium gas. Other pumps require modification before being used with tritium. Modifications include changes in bearing and seal materials, reduction in the amount of lubricating oil or improvements in the drive units.

6.1 Vane Pump

The oil-sealed rotary vane pump uses organic lubricants and is not recommended for tritium operation. Most commercially available dry rotary vane pumps and oil-less piston pumps suffer from shaft packing or piston seal problems which make them unsuitable for tritium use. Los Alamos Nuclear Laboratories (LANL) invented a rotating vane tritium pump which formed the basis of the pump manufactured by Monsanto Research Corporation for use at the Mound facility /3/. Monsanto have modified the design which uses a lubricant developed by Monsanto called polypherylether, and which requires disposal of 5 mL of contaminated lubricant every 8,000 hours of service. The carbon rotary vanes produce a fine carbon dust.

Mechanically driven units have been phased out and replaced with magnetic drives. During the course of this study a visit was made to Nova Magnetics /4/ who have an agreement with Monsanto Research Corporation to manufacture vane pumps. Nova Magnetics have designed, manufactured and sold magnetic drives suitable for use with Monsanto vane pumps. This has eliminated the leakage which, in the mechanical drive, came from dynamic pump seals. Monsanto have purchased these magnetic drives for tritium pumps and are very satisfied with their performance /17/.

Nova Magnetics have planned to modify the Monsanto design to facilitate manufacture, assembly and commercial production. As a result of the lack of demand for these pumps, production drawings have not yet been made.

Chalk River Nuclear Laboratories (CRNL) have used the Mound modified vane pump intermittently for two years and report good experience /18/. CRNL are completing their evaluation of the Mound modified vane pump and are planning to use this type of pump, manufactured by Nova Magnetics, in their tritium extraction plant (TEP) /19/.

6.2 Diaphragm Pump

The metal diaphragm pump is bulky, expensive and nylon faced check valves require replacing annually.

The pump is supplied with teflon pads for sealing purposes. Tritium degrades teflon and a product of the interaction is hydrogen fluoride (tritium fluoride) which quickly corrodes welds in the vacuum system. LANL propose to machine a recessed groove in the sealing surface and replace the teflon with all metal (wire) seals.

As a result of experience at LANL the diaphragm pump is not recommended by them for pumping tritium /20,21/.

6.3 Metal Bellows Pump

The metal bellows pump has hermetically sealed bellows giving excellent containment and isolation of the gas being pumped. It has no wearing parts and no need for lubrication. Bellows rupture, releasing tritium, is an unlikely event and may be designed for by a double bellows or by operation in a glovebox.

Sandia National Laboratories have used this device for three years with good experience /20/ and it is recommended by LANL and CRNL /21,18/. It is cheap ($5,000) and readily available.

6.4 Orbiting Scroll Pump

The **Normetex** /9/ pump has seen wide use in pumping gases such as tritium and uranium hexafluoride.

The pump has been used in facilities in South Africa, India and Holland and has been tested in Germany for 30,000 hours without failure.

LANL have evaluated the Normetex pump in the TSTA facility. Two units with pumping speeds of 4.3 L/s were obtained in 1980 and three units with pumping speeds of 5.7 L/s were obtained in 1982. LANL are well satisfied with these pumps and propose to incorporate them in their test facilities /20,21/. Ontario Hydro Research Division are also planning to evaluate the scroll pump.

6.5 Wobble Pump

The diaphragm - bellows **SRTI** /7/ PBT series wobble pump has given good service at LANL /20,21/. It is a five cylinder pump in which a flexible metallic bellows totally separates the grease lubricated gear train from the pumped gas volume. It is, however, very bulky (900 kg with motor) and very expensive (Cdn $40,000).

6.6 Roots Pump

The main disadvantage encountered with the Roots pump is the incomplete isolation of gear and bearing lubricants from the pump chamber. A tritium compatible version has been ordered by the Joint European Torus (JET) but no experience has been reported to date.

During a visit to Kernforshungsanlage (KFA), Julich, it was ascertained that A. Pfeiffer Vakuumtechnic Wetzler GmbH, a part of the Balzers group /12/, had built a Roots pump for tritium service. Testing was reported to be taking place at the Max-Planck Institut Fur Plasmaphysik in Garching /22/. A request for information has not yet produced a response.

6.7 Turbomolecular Pump

An evaluation of turbomolecular pumps by LANL (TSTA) led to the conclusion that the pump best suited to tritium service in the high vacuum range is the Leybold-Heraeus electromagnetic bearing pump. The design contains several elastomer seals which LANL intend to replace with metal seals /21/.

A disadvantage of the magnetically suspended turbomolecular pump for fusion experiments is that the pump will be located in high intensity magnetic fields. The effects of this have not yet been established by LANL or the manufacturer.

The Tokamak Fusion Test Reactor (TFTR) at Princeton, New Jersey and the Joint European Torus (JET) at Culham, England both plan to use electromagnetic bearing, turbomolecular pumps.

6.8 Capture Pumps

Of all the capture devices, large scale **cryopumps** operating at liquid helium temperatures are the best prospect for plasma chamber evacuation at fusion experimental facilities. Their great disadvantage is that they are storage devices with capacities that are small compared to the gas volumes in fusion reactor facilties. Once the storage capacity has been reached, after a few hours, the cooling must be discontinued, the cryogenic panels allowed to warm and the vapourized gases pumped away.

The cryopump panels can then be refrigerated once more and the cycle repeated. It is a batch flow process. A combination of mechanical pumps, selected from those discussed in previous sections, must be used to remove the vapourized gases released during the regenerative process.

Three different compound cryosorption pumps are being evaluated at the Los Alamos TSTA facility. In all of these the first stage, cryocondensation, pumps all the hydrogen isotopes but not helium. One pump, being built by the Los Alamos National Laboratory, uses a molecular sieve surface cooled to liquid helium temperatures to pump helium. The second pump, developed at Brookhaven National laboratory, uses a charcoal surface cooled to liquid helium temperatures to pump helium. The third pump, built by the Lawrence Livermore National Laboratory, uses argon cryotrapping to pump helium.

Consideration is being given to the possibility of maintaining the separation of stored hydrogen and helium isotopes during regeneration. By careful temperature and pressure control it should be possible to first regenerate the helium panel and then warm the cryocondensation panel to recover the hydrogen isotopes. While separate regeneration of hydrogen and helium isotopes is possible, indications are that this can be very time consuming and therefore lengthen the regeneration time cycle.

In fusion facilities it is desirable to have two cryopumps on each vacuum line. One pump regenerates while the other is pumping. The regeneration time should be kept as small as possible in order to reduce the tritium inventory in the reactor system.

6.9 Recommended Pumps

The most suitable pumps for tritium gas are:

- **metal bellows pump**
- Mound modified vane pump
- bellows-sealed wobble pump
- roots pump with canned motor
- **magnetically driven orbiting scroll pump**
- **turbomolecular pump with electro-magnetic bearings**
- **cryopump**

The pumps are listed in order of increasing vacuum. Those indicated in bold type are those most highly recommended by users.

The orbiting scroll pump is highly rated by LANL (TSTA) and they intend to use it with the metal bellows pump. TFTR and JET have selected the turbomolecular pump for the main vacuum system and it has been selected for use at the TSTA facility. The cryopump has been selected for use with neutral beam injection at both TFTR and JET. CRNL are planning to use the Mound type vane pump, manufactured by Nova Magnetics, in their tritium extraction plant.

7.0 SYSTEMS APPROACH TO PUMPING TRITIUM GAS

As a result of the survey of pumps in the low, intermediate and high vacuum ranges it is concluded that no single pump is suitable for pumping tritium gas over the pressure ranges required. The development of a single pump for tritium gas is not foreseen. A systems approach is therefore required for any given application. The specification of system pressures, temperatures and flow rates should enable a system to be assembled from preferred pumps with known tritium handling abilities.

For example, gas in a plasma chamber at 10^{-5}Pa may have to be pumped continuously to an isotope separation system at 10^{3}kPa. Several series connected pumps are required to cover this wide range. An example is shown in Figure 2 in which a **cryopump** pumps gas at high vacuum from a plasma chamber and on regeneration the gases are evacuated by a vertical axis, magnetic bearing **turbopump** to intermediate vacuum. The gases are then pumped by an **orbiting scroll pump** to the low vacuum range from which the pressure is raised to 10^{3}kPa by two **metal bellows pumps** in series.

CRNL have three tritium vacuum pumping systems in their tritium laboratory. These systems use combinations of Mound modified vane pumps, turbopumps, diffusion pumps, metal bellows pumps and cryopumps.

8.0 FUTURE DEVELOPMENT

The pumps listed in Section 6.9 are, with varying degrees of modification to materials, suitable for use in tritium applications. The United States has several fusion facilities and tritium laboratories, but the market is not large enough, nor are user needs clearly enough known to justify pump modification by manufacturers.

Modification of pump components by the user, not the manufacturer, is therefore the norm. Individual solutions have been found by the users for specific application to specific problems. Solutions are principally aimed at:

- -Improvement in bearing and seal materials
- -Reduction in quantity of lubricating oil
- -Better drive units.

The market in Canada for tritium pumps is very much less than in the United States and the American route of user-modified pumps will have to be followed here.

Canada is not likely to have a fusion facility in the near future. Canada does have a tritium laboratory, with three tritium pumping systems, at Chalk River Nuclear Laboratories (CRNL). Ontario Hydro is building a Tritium Recovery System (TRS) at Darlington Generating Station and Atomic Energy of Canada is building a Tritium Extraction Plant (TEP) at CRNL.

With the recovery, storage and regeneration of tritium at Canadian tritium recovery plants there may well be a need for a further tritium laboratory in Ontario.

A tritium pumping system is likely to require pumps in the low, intermediate and high vacuum ranges. As a result of this survey, it is concluded that the requirements of such a system can be conveniently met by the:

-metal bellows pump /6/
-orbiting scroll pump /9/
-magnetically suspended turbomolecular pump /11/
-cryopump /15,16/

It is therefore recommended that the Canadian Fusion Fuel Technology Project conduct a limited study which establishes the conceptual design of a tritium pumping system at a Canadian tritium facility; e.g. a tritium laboratory. Such a study should cover all components of a tritium pumping system. In addition to the preferred pumps listed above, the study should include pipes, fittings, flanges, valves and gauges. The material problems encountered in a tritium pumping system are common to all its components.

9.0 CONCLUSIONS AND RECOMMENDATIONS

It is concluded that, at this time, no single pump exists with the capability of meeting all the requirements of pumping tritium gas.

The following appear to be the most suitable of the pumps surveyed:

- **metal bellows pump**
- **orbiting scroll pump**
- **magnetically suspended turbomolecular pump**
- **cryopump**

Other pumps which should be considered for possible future development are:

- Mound modified vane pump
- SRTI wobble pump
- Roots pump with canned motor

Since tritium recovery plants are being built by Ontario Hydro and Atomic Energy of Canada Limited it is recommended that consideration be given to a possible future facility for pumping tritium gas. This may be located at the Darlington Tritium Recovery System, at Chalk River Laboratories or at the Fusion Fuels Technology Project site.

If such a future facility is identified it is recommended that a study be initiated of a system which combines a pumping requirement with facilities for testing, evaluating and modifying or developing the preferred pumps listed above. The study should encompass all the components which would be used in pumping tritium in such a facility.

It is strongly recommended that further study be conducted, as far as possible, using established personal contacts at manufacturers and pump users' facilities.

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   Canadian Representative: Cancoppas Limited, 1031 North Service Road E., Oakville, Ontario, L6H 1A6

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APPENDIX A

TABLE I

Characteristics of Vacuum Pumps

PUMP TYPE	P_{min} (Pa,abs)	P_{max} (kPa,abs)	P_{out}/P_{in} (FLOW = 0)	SPEED (m^3/ks)	ADVANTAGES	DISADVANTAGES
OIL-SEALED ROTARY VANE	10^{-4}	200	10^9	0.1-10	WIDE RANGE; HIGH COMPR.	NOT TRITIUM COMPATIBLE
DRY ROTARY, DRY PISTON	10^3	10^3	100	0.1-10	WIDE RANGE; HIGH COMPR.	NOT HERMETIC; MATERIALS PROB.
METAL DIAPHRAGM	$3(10)^3$	10^5	30	1-5	HERMETIC; RELIABLE	BULKY; EXPENSIVE
METAL-BELLOWS	$2(10)^3$	300	15	1-3	HERMETIC; RELIABLE; COMPACT	LIMITED VAC. CAPABILITY
DRY-CONTACT SCROLL	10^4	100	5	0.05	COMPACT	LIMITED SPEED & PRESS. RANGE
CONTROLLED-CLEARANCE SCROLL	10^{-5}	10	10^4	5-100	HIGH SPEED; RELIABLE	TRANSFER ABOVE 10 kPa
BELLOWS-SEALED WOBBLE	10^{-3}	10	1-10	8-140	HERMETIC; HIGH SPEED	BULKY; EXPENSIVE; LIMITED COMP.
CANNED-MOTOR 2-STAGE ROOTS	10^{-4}	10	700	50	HIGH SPEED	OIL CONTAMINATION
AIR-BEARING TURBOPUMP	10^{-7}	100	10^{12}	500	HIGH SPEED; HIGH VACUUM	NO TRANSFER CAPABILITY
MAG-BEARING TURBOPUMP	10^{-7}	10^{-5}	10^5	500	HIGH SPEED; HIGH VACUUM	NO TRANSFER CAPABILITY

(Courtesy of Don Coffin, Los Alamos National Laboratory)

APPENDIX B

FIGURE 1

Tritium Handling System on TFTR

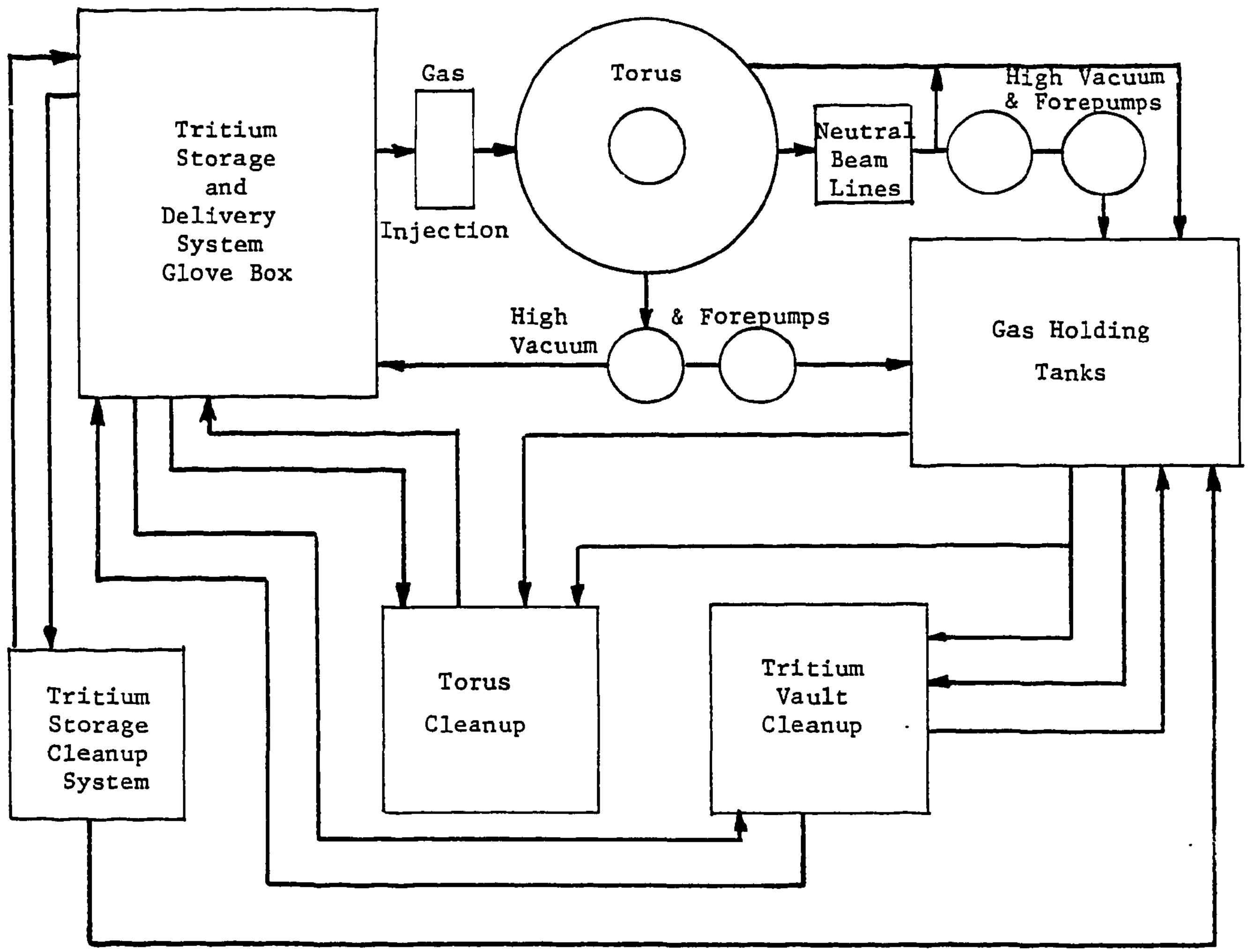

FIGURE 2

Example of Tritium Pumping System