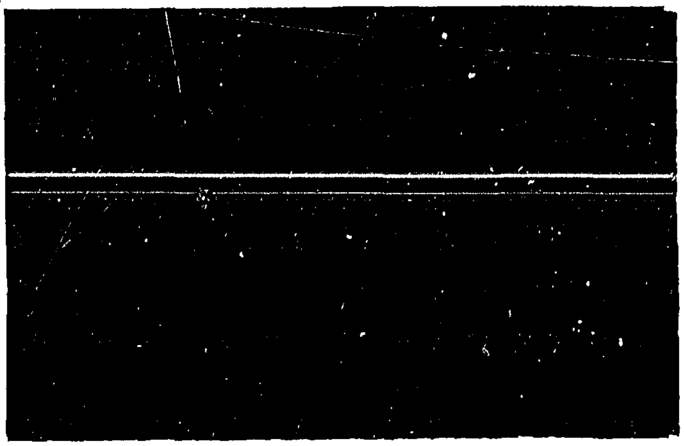
Canadian Fusion Fuel Technology Project



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.

A RECOMMENDED PROGRAM OF TRITIUM MONITORING RESEARCH AND DEVELOPMENT

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ABSTRACT

This report has been prepared for the Canadian Fusion Fuel Technology Project and, based on the information contained in a previous report (CFFTP Report No F-82003), presents recommendations for programs of research and development in tritium monitoring instrumentation. These recommendations, if implemented, will offer Canadian industry the opportunity to develop marketable instruments. The major recommendations are to assist in the development and promotion of two Chalk River Nuclear Laboratories' monitors and an Ontario Hydro monitor, and to support research and development of a surface monitor.

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1. INTRODUCTION

This report has been prepared for the Canadian Fusion Fuel Technology Project (CFFTP) by Ontario Hydro, Canatom Incorporated and Monserco Limited. The objective of the study is to identify specific tritium monitoring requirements which offer prospect for successful Canadian development of internationally marketable instruments. The CFFTP has identified three types of tritium monitors as being required for a fusion program: personal tritium monitors, real-time monitors for area surveillance, process control and environmental monitoring; and surface contamination monitors. Each of these areas is assessed in this report. There is a secondary objective to identify good research projects in tritium monitoring. Longer term studies are necessary if a tritium monitoring business is to evolve and keep pace with the requirements of the fusion industry.

In order to meet the above overall objectives the following four tasks are addressed:

1. Identify the tritium monitoring requirements for future fusion reactors, present research projects, and tritium and fusion research laboratories.

2. Survey the market for instruments presently commercially available.

3. Describe the tritium monitoring research programs of other countries.

4. Based on 1-3, suggest areas of research and development for Canadian industry.

Items 1-3 are discussed in another CFFTP report/1/ while item 4 is discussed in this report.

2. BACKGROUND

The first generation fusion reactors and all fusion ignition experiments will burn deuterium-tritium fuel because it will ignite at a temperature which is substantially lower than that of other fuels. The presence of tritium will require monitoring for reasons of both safety and process control.

The amount of tritium called for in some reactor designs is considerable. STARFIRE is a conceptual design of a 1200 MWe fusion reactor considered to be the 10th in a series of commercial reactors. Its total inventory of tritium is 6-11 kg (6×10^7 - 11×10^7 Ci) of which 0.4 kg is vulnerable to accidental release/2/. Tritium vulnerable to accidental release would be that contained in the fuel processing system, the plasma chamber and the vacuum chamber, while tritium considered non-vulnerable would be tritium stored in a vault, tritium in the solid breeder or tritium in glove boxes and secondary containments. INTOR/3/ (International Tokamak Reactor) is an internationally designed reactor experiment which is proposed to be the next large experiment after those now on-going or under construction. Its total tritium inventory is 3.4 - 3.9 kg of which 0.6 kg would be vulnerable. For comparison about 1.3 kg of tritium is generated every year in the moderator water of Ontario Hydro CANDU reactors and about 7 kg exists naturally in the environment, world-wide/4/.

In addition to potential accidental releases of tritium there will be chronic releases. Tritium will permeate from the blanket through structural materials and working fluids and into the reactor hall. It will also permeate from the coolant into the steam cycle. Estimates for INTOR are/3/: coolant, 3 - 10 Ci/d; building, $\leq$1 Ci/d; ventilation, 8 - 16 Ci/d and solid waste, $\leq$1 Ci/d. These numbers are quite uncertain since the formulae used to calculate these numbers may be incorrect/5/.

Tritium is radioactive and because of this is a health hazard/4/6/. It emits weak beta particles (18.6 keV maximum and 5.7 keV mean energy) with a half life of 12.6 years. The range of the beta particles in soft tissue is 5×10^{-3} mm. This is much too shallow to reach the sensitive tissues of the skin, at a depth of 5×10^{-2} mm, or the eye, at a depth of 3 mm. There is, therefore, no direct danger from tritium external to the body and it can be treated like any hazardous chemical - it must be kept from entering the body in dangerous amounts.

The danger is from internally absorbed tritium. The pathways are inhalation, absorption through the skin directly from the air and from surfaces, and ingestion. Because HTO is much more readily taken into the body than HT, it is about 10^4 times as toxic (and up to 10^6 if protective clothing is worn). Since tritium does not concentrate in any particular organ, the critical organ for exposure is the whole body.

Approximately 1.6% of inhaled tritium gas is absorbed into the blood stream. It has a biological half life of about one hour and it is estimated that doses received by lung tissue from tritium gas that is in the lung is about 60 to 150 times doses received from absorbed gas. The amount of tritium gas absorbed through the skin is negligible but it can be picked up from surfaces or ingested.

Virtually all of the inhaled and ingested HTO is absorbed into the body and it is readily absorbed through the skin. Equilibrium throughout the body is reached in about 2.5 hours and the biological half life is about 10 days.

The Maximum Permissible Concentration in air (MPCa) for occupational workers of HTO in Canada is 10 $\mu Ci/m^3$ (10^{-9} g of tritium/m^3) so that it would take about 1 km^3 to dilute 1 g of tritium as HTO to safe levels. The potential health hazards represented by such inventories as contemplated for STARFIRE and INTOR are therefore, enormous. Because of this there will be a prerequisite of adequate tritium monitoring for safety reasons.

The major difference between the safety monitoring requirements for fusion reactors and for present needs (CANDU reactors, weapons establishments, research laboratories) is the activated air products (principally ^{13}N) and gamma background with which the tritium monitor in a fusion environment will have to contend/7/. By the time fusion reactors are a reality, tritium safety monitoring requirements are apt to be more stringent than they are today simply reflecting the improvements in technology.

Monitoring of tritium for process control will be another area which will be important in fusion reactors and in research projects such as TSTA (Tritium Systems Test Assembly) at Los Alamos. Tritium gas over a wide range of concentration will have to be measured as well as tritiated liquids in process lines and in effluent. Backgrounds, especially in the effluents, will most likely be unique to fusion reactor systems and will require the development of special instruments. One of the problems in trying to develop instruments in this area is that it is not yet known exactly what the backgrounds will be. In fact, some of this information may not be available until the reactors are built and have operated for some time.

Types of monitors required for health and safety reasons are: area (primary, secondary and tertiary containment areas, and in general areas), surface, bulk, effluent, environmental and personal monitors/1/. In the primary containment area monitoring will be only for process control since repairs will normally be done remotely. Secondary containment areas such as glove boxes and pump jackets will require monitoring, with tritium gas being the predominant species. Areas such as the fuel cycle enclosure and auxiliary service rooms will comprise the tertiary containment areas and will need monitoring for both chronic and acute releases. It is expected that the instruments will have to differentiate (in real time) between the oxide and gaseous forms with an activated noble gas and gamma background. General areas will be those for non-atomic radiation workers and the general public. The allowable levels will be lower than in the tertiary containment areas and hence greater sensitivity will be needed but the real time requirement may be relaxed. Because they are inaccurate and inconvenient or do not work on irregular surfaces, the present day surface monitoring techniques are not satisfactory and improvements are needed. Bulk contamination by tritium is unavoidable because it permeates materials so readily. However, effective methods of monitoring are difficult and minimization of the problem (by choice of materials, for example) may be the best solution. Tritiated effluents will have to be monitored because of restrictions on environmental releases and because tritium is valuable enough to recover for reuse. A highly desirable instrument that is only now being sold commercially is the real time personal (very light weight - 1 kg) gamma compensated tritium monitor.* This would be kept in the immediate vicinity of a worker or could be used to do quick surveys of unmonitored areas or rooms.

Tritium monitoring for process control and inventory will be needed in various subsystems of the fuel cycle such as the fuelling system, the fuel reprocessing system, the blanket and the tritium recovery system/1/. Other tritium systems will need to be monitored to determine contamination levels and the information used to initiate clean-up and waste treatment systems. There is not much detailed information available about how these subsystems will be monitored but the sampling systems will be an intimate part of the overall reactor design and traditional methods will probably be used for the monitoring.

Commonly available types of tritium monitors include ionization chambers, proportional counters, scintillators, calorimetry, semiconductors, mass spectrometers, gas chromatographs and infrared spectrometers/1/. Commercial monitors are available for personal monitoring (Scintrex), area monitoring (Overhoff and Associates Incorporated, Johnston Laboratories, Beta Analytical Incorporated, Nuclear Enterprise Limited, Munchener Apparatebau Kimmel BM BH, Technical Associates and Scintrex), environmental monitoring (Beta Analytical Incorporated) and surface monitoring (Hughes Whitlock Limited and Beta Analytical Incorporated). In addition to the commercial monitors there are many prototype monitors, under development and research projects under way/1/.

CRNL developed monitor AEP 5321 to be manufactured by Scintrex Ltd.

There are many countries doing research in this area, throughout the world, with about half being done in Canada and the US/1/.

3. RECOMMENDATIONS

The recommendations given below of projects for the CFFTP to support have been chosen because they all, to a greater or lesser extent, "offer prospect for successful Canadian development of internationally marketable instruments" - to quote from the objective of this study. They are ranked by the degree with which they meet the objective.

It was found that the potential projects could be placed in one of the following four categories:

1. Business Opportunity
2. Research/Business Opportunity
3. Research Project
4. Other Projects

The first three categories refer to tritium instrumentation and the last refers to additional projects that the CFFTP might wish to consider and are related to tritium monitoring but do not, by themselves, lead to marketable instruments.

There are several aspects that must be assessed in determining whether or not a project can be considered a business opportunity:

1. The size and strength of the market, both of which are important. The strength of the market determines whether or not the item will be sold at all and will influence the price. The size of the market will also influence the price and determine the total profit for the manufacturer. The total profit determines the importance the manufacturer places on the product and his enthusiasm in promoting it. In the case of some of the instruments recommended below, the market will not be large and it may be worthwhile for the FFTP to assist in promotion.

2. The timing of the market. If the demand for a product will not exist for 20 or 30 years, a product can not be considered a business opportunity. This will be the case for some process monitors that will have to function under unique conditions in fusion reactors. Such instruments will be considered as part of the reactor design, not as an off-the-shelf item.

3. The stage of development. The study group has found from its interviews that there are many tritium monitoring instrument concepts that initially appeared quite promising but after careful examination turned out not to be practical. This experience seems to be quite widespread. Therefore, a promising project in its early stages should be regarded as a research/ business opportunity until the concept is proven. The CFFTP should give priority to supporting (if permitted) promising projects in later stages of development because they are more likely to succeed in producing a marketable instrument.

4. The competition. This aspect is most important in the US since they have in place protectionist policies. Any federally funded laboratory (and this is all the large ones) must buy US equipment. If they wish to buy foreign equipment they must show that the equivalent US equipment is inferior or non-existant. Therefore, in order to sell to the US market there must be no serious US competition. It must also be realized that even if there is no competition initially, it may subsequently develop. These aspects may not be as important in Europe and Japan but since the US will most likely be the largest market and is the most accessible, they are important considerations.

One suggestion made in the Request for Proposal (RFP) is a personal tritium dosimeter based on a continuous sampling of a body fluid such as breath or perspiration. The pursuit of this approach does not appear to be practical (barring breakthroughs) and is not recommended for the following reasons. The contribution to total dose due to uptake through the skin is 1.5 to 2 times the contribution from inhalation so that tritium is not absorbed into the body in a localized manner. It takes at least two hours for HTO to equilibriate throughout the body. Therefore, to obtain accurate real time dose measurements by direct sampling of body fluids, there must be many sample points distributed over the body. Such a system (if workable) would certainly be inconvenient for the personnel and probably unsatisfactory.

All of the major recommendations given below are related to the health and safety aspects of tritium monitoring. There are two reasons for this. Various groups in Canada have been doing research in this area for several years because of the health hazards associated with tritium contamination of heavy water. Therefore, there is considerable Canadian expertise in this area on which to capitalize and the three highest rated recommendations are to continue projects already under way. The second reason is the existence now of a market for this type of instrumentation, a market which will increase steadily as fusion research progresses. Neither of these reasons applies to the process monitoring area. Instruments in the process monitoring area for fusion reactors should not be developed far in advance. By the time they are used the technology with which they are built will be out of date, the conditions under which the instrument is to operate may have changed and, in a majority of cases, the innovation lies in how the sample is taken, not in how it is measured.

Based on the above, the information in reference 1, the opinions of the experts interviewed during the course of the study and in the assessments of the study group members, the following projects are recommended for support by the CFFTP. The recommendations are given in order of decreasing desirability as determined by the objective.

1. Business Opportunity

i) Assist in the marketing of the CRNL Portable Tritium Monitor AEP 5321. This monitor is now being manufactured under license to Scintrex Limited of Concord, Ontario. Minor design changes are still being considered. There is a genuine need for this instrument in Canada and in the US. Presently, fixed and portable monitors of airborne tritium are used as warning devices. From the measured concentrations, time limits in an area are calculated based on estimated dose for that concentration. If there is an acute release, then a warning is given and the area is evacuated. Measured dose can only be done by bioassay because it is required by government regulation and because no calculation can, with certainty, produce total dose. Since portable tritium monitors are used as warning devices they do not have to be extremely sensitive so the fact that the AEP 5321 has a sensitivity of only 1 - 2 MPC_a does not detract from its usefulness. This monitor does not discriminate between HT and HTO and since HTO is about 10^4 times as dangerous as HT the reading must be assumed to be due entirely to HTO. This is present practice in tritium laboratories and is found to be satisfactory. Often a reading is needed in a localized area where there is no sampling hose or in a room that is not monitored and whose degree of contamination is unknown. In these cases there is considerable value placed on small size, light weight and fast response. All of these characteristics are present in the AEP 5321 and are the qualities that make it a marketable item.

The only disadvantage is the directional nature of the measurement due to the side by side ion chambers. With some practice, however, in use of the instrument this disadvantage will lessen and will be out-weighed by the instrument's advantages. The present scales are in MPC_a's but since the MPC_a differs from place to place (in general 10 $\mu Ci/m^3$ in Canada and 5 $\mu Ci/m^3$ in the US), it would be desirable to have the output in $\mu Ci/m^3$.

It is expected that there would be 50 units sold in Canada and 100 sold in the US over the next 5 years. After that the market is expected to increase due to the coming on stream of large scale tritium burning fusion experiments.

At present there does not appear to be any competition for this monitor. Although there are portable monitors available, there are none that are as convenient and light-weight as the AEP 5321.

The carrying out of this project is, of course, subject to the cooperation of CRNL and Scintrex.

ii) Assist in the development of and eventually the marketing of the CRNL monitor for the separate determination of HT and HTO.

At present this monitor is still a laboratory instrument but is ready for field testing. After that it will probably need some minor changes and re-engineering before it can be marketed. It is recommended that the CFFTP assist in these developments.

The market for this instrument will not be large, perhaps 20 world-wide at present, but there is a need for it in stack monitoring. The critical group consists of those who live near the release point and since the hazards of HT and HTO are so different, it is important to know the relative amounts of HT and HTO released. This monitor may never be an off-the-shelf item as the AEP 5321 is, since the conditions under which it operates may be different in each tritium facility.

Although this project can still be considered a business opportunity, there are two reasons why it is not so attractive as the AEP 5321. Firstly, it is not as developed and secondly there is competition from the ANL monitor, which is similar in concept. Although the ANL monitor is less developed than the CRNL monitor (by about nine months) it is to be tested at TSTA and will have good exposure if it performs well. If both monitors perform equally well and are aimed at the same need, then, because of the preference for US products, it will be difficult to sell the CRNL monitor in the US. A difference which may make the CRNL monitor less attractive is that the Cox monitor will discriminate the HT measurement from radioactive gases; the CRNL monitor does not, although it could be made to do so.

2. <u>Research/Business Opportunity</u>

iii) Assist in the research and development of the Ontario Hydro portable plastic scintillator monitor for the separate determination of HT and HTO.

This monitor is in the early stages of development, is yet unproven and must therefore be considered a research/business opportunity. It does, however, appear promising and if it can be developed in the manner as presently conceived, it will be marketable perhaps in competition with the CRNL HT/HTO monitor although it could find a separate (and more lucrative) market if it is portable.

iv) Research and development of a more convenient surface monitor that can be used on irregular surfaces. This can also be considered a research/business opportunity but not nearly as strong as (iii) above. Presently, the smear technique is most often used but it is not very satisfactory since the results can vary by orders of magnitude from smear to smear. The usual procedure for surface monitoring for health and safety reasons is to clean any surface that has shown activity through a smear test and therefore accuracy is not required. However, there may be slow desorption onto the surface after a cleanup so that continued monitoring may be required and there is a need for a simple and easy to operate surface monitor. Therefore, any instrument which would be more convenient to use and more accurate than smears would find a market. One suggested approach is to use a laser, or a heated liquid to flash any volatile materials from the surface, which could then be counted.

A second topic in this area would be the development of a system for measuring the surface contamination of small curved surfaces and inside pipes and valves. There is a need for such an instrument and the market will grow as more experiments using tritium are brought on stream.

However, before either of the above are pursued, it would be advisable to conduct an investigation into the nature and mechanics of surface contamination. This area is not well understood.

3. Research Projects

v) A monitor for measuring tritide concentration in air. The health hazards of tritides in air are not yet fully understood so that a study in this area should be done before instrument development is initiated.

vi) A tritiated water (or other liquid) monitor. Several people expressed an interest in this type of monitor.

vii) An instrument or system that will take tritium gas out of the air without oxidation. This is important for two reasons: tritium in an oxidized form is much more dangerous to health than tritium gas and it is expensive to convert the oxidized form back into a gas for storage so it is advantageous to avoid this step. Such an instrument could be used as the basis of a monitor and, perhaps more importantly, be useful for clean-up systems intended for the cleaning up of large spills of tritium gas.

viii) An investigation of the use of spectroscopy to measure tritium. The only concept that was discovered that could circumvent the lack of sensitivity (compared to counting) in spectroscopic methods was the LLNL concept of supersonic expansion of the tritiated gas sample, leading to cooling and enhancement of the rotational spectral lines. Other avenues could be explored.

4. Other Projects

ix) The development of software packages for accountability purposes is an area that, although not directly related to the development of tritium monitors, could be useful for facilities where accountability (or inventory control) is required.

x) Assist in the development necessary to overcome the present problems associated with the automated urinalyzer developed at CRNL. This instrument has potential for use as a compliance device providing the management and administrative problems associated with the control and identification of specimens can be overcome. The advantage of this device over the bioassay method presently used for compliance is that it has a relatively fast response time and gives accurate readings of dose. It is possible that the device as presently developed is not sufficiently rugged for industrial use, and it does need fairly frequent and messy maintenance. These areas could be worked on and an industrial-type instrument developed.

In summary, the recommended areas for research and development are all related to the health and safety aspects of tritium monitoring because this is where the present market lies and this is the area in which Canadian expertise lies. The CFFTP should first concentrate on assisting in the development of the CRNL and Ontario Hydro monitors and second, open up some of the newer areas mentioned above.

APPENDIX

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Suggested Distribution List for A Recommended Program of Tritium Monitoring Research and Development.

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