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TRITIUM CONTAINMENT IN FUSION FACILITIES

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I. INTRODUCTION

The development of tritium containment technology for fusion facilities is currently being supported by the Office of Fusion Energy, U.S. Department of Energy. The approach being developed is based on several levels of tritium confinement. These levels include the primary process equipment and secondary enclosures around the primary equipment. The enclosures include such things as double wall tubing, double-wall containers, double-bellows and glove boxes or other sealed enclosures containing controlled atmospheres and will be continuously monitored for tritium. The building itself will provide a third level of confinement, Figure 1. In event of a tritium release into the building emergency detritiation systems will be activated to process the building air to recover tritium and reduce atmospheric releases. Similar, but smaller detritiation systems will be connected to the secondary enclosures. These systems will be designed to provide quick, efficient recovery of any tritium spilled into these areas. This will allow early access to these areas for repair and maintenance and will assure minimal releases of tritium to the environment.

As fusion energy research progresses towards a large-scale demonstration of feasibility an important aspect of this will be the development of those technologies related to the deuterium-tritium fuel cycle and tritium breeding and extraction systems. We must develop and demonstrate safe, reliable systems for handling these large quantities of tritium, including personnel and environmental protective systems.

The Los Alamos Scientific Laboratory is currently engaged in a program to develop and demonstrate all of those aspects of tritium technology required to provide a deuterium-tritium (DT) fuel to a fusion reactor. This project, the Tritium Systems Test Assembly (TSTA)[1], is sponsored by the Office of Fusion Energy, U.S. Department of Energy. The early and timely phasing of TSTA into the fusion energy program is necessary if the results obtained at TSTA are to provide significant input into the design of a D-T burning fusion machine in the late-1980's.

Tritium is a radioactive hydrogen isotope of mass three, decaying with a 12.3 year half-life by the emission of a Beta particle of 5.6 KeV average energy:

$$^{3}H \longrightarrow {}^{3}He + \beta$$

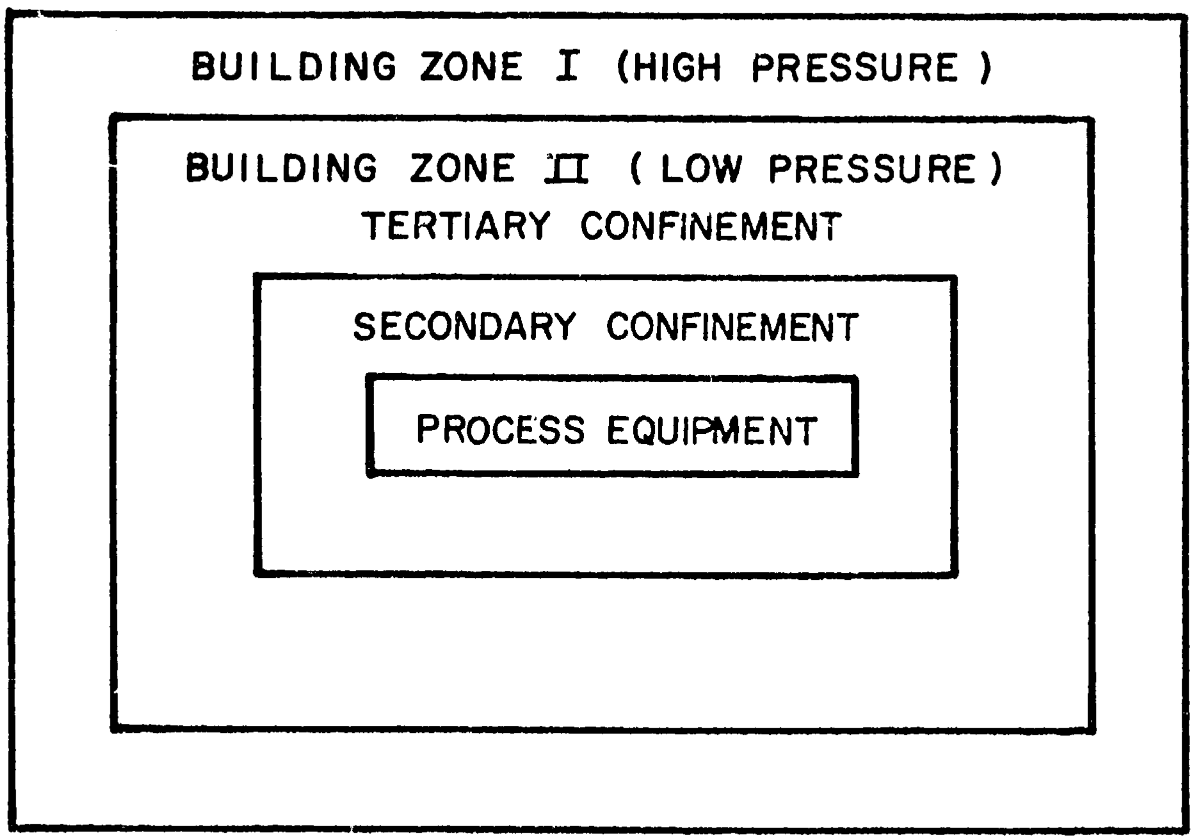


Fig. 1. Tritium containment scheme

The earlie fusion reactors will undoubtedly use a mixture of deuterium (a sta gen isotope of mass 2) and tritium as a fuel with the following on occuring:

$$^{2}H + {}^{3}H \longrightarrow {}^{4}He + n + 17.6\ \text{MeV}$$

(deute um + tritium ⟶ helium + neutron + Energy)

Because tritium is radioactive and because it chemically behaves the same as ordinary hydrogen special precautions must be developed to handle the material. One must be especially careful to construct tritium facilities using materials that will not suffer extensive radiation damage as the tritium decays and will not adversely interact with hydrogen (i.e., suffer hydrogen embrittlement).

The first fusion facility to use a deuterium-tritium fuel will be the Tokamak Fusion Test Reactor (TFTR)[2] at Princeton University. If the fusion program proceeds as currently envisioned the TFTR will be followed by a Ignition Test Reactor (ITR) where significant quantities of D-T will be handled in an attempt to demonstrate that a self sustaining DT plasma can be achieved. This ITR would later be followed by an Experimental Power Reactor (EPR) where the demonstration of production of useable electricity would be the goal. Table 1 lists the anticipated tritium inventories and fuel feed rates for these devices. One

TABLE 1
TRITIUM INVENTORIES IN FUSION FACILITIES

Facility	T_2 Inventory (kg)	Fuel Feed Rate (kg/day)	T_2 Release Goal (Ci/day)
TFTR	0.005	0.001	1
TSTA	0.02	0.5-1.5	1
ITR	0.25	0.25-0.5	1-10
EPR	4-6	1-2	5
DEMO[a]	6-12	2-6	5-10

[a] DEMO = 1000-MWe net output

can see that the tritium inventories will indeed become quite large in a fusion economy. It is therefore imperative that techniques be developed to assure that these large quantities of tritium can be handled on a routine basis. The remainder of this paper will be devoted to the description of some of the technologies and systems under development to assure this capability.

II. ENVIRONMENTAL PROTECTION SYSTEMS

Table 2 is a list of the key environmental control systems that have been identified and are being developed. A brief description of each of these systems follows.

TABLE 2

ENVIRONMENTAL AND SAFETY SYSTEMS FOR FUSION TRITIUM FACILITIES

1.	Primary Process Materials
2.	Permeation Barriers
3.	Secondary Containment
4.	Tritium Waste Treatment
5.	Emergency Tritium Cleanup
6.	Maintenance Procedures
7.	Tertiary Containment

The solution to solving the tritium confinement problem begins with the proper material choice for the primary process equipment. These materials must of course be hydrogen compatible over the entire temperature and pressure range of interest. Hydrogen embrittlement is a problem that may not appear to be severe in a hydrogen or deuterium system, but when a failure occurs in a tritium system as the result of hydrogen embrittlement the results can be and often are disastrous. The choice of materials for use in a tritium system must also consider the permeation rate of tritium through the material. This has been discussed by Maroni[3] in an earlier paper at this session. The ideal situation is to choose the primary containment materials so carefully that the additional confinement and control systems are never used.

Secondary containment concepts cover a wide range of sealed, enclosures around the primary process equipment. The current approach to secondary containment is to evaluate each component of the tritium system with respect to secondary containment requirements. If a component contains high pressure (>1 atm) tritium gas, any liquid-tritiated water, moving parts which are subject to failure (such as a metal bellows pumping system) or which might be readily subject to outside abuse then such a component should be secondarily contained. If a component is static, exposed only to low pressure tritium gas then secondary containment might not be required in all cases. The development of sound criteria for making this decision is part of the TSTA charter. Figure 2 and 3 are examples of a secondary containment glove box and double-walled liquid container being used at TSTA. The glove box can contain such items as transfer pumps, process equipment or be available for maintenance on tritium contaminated components. The air in the box can be monitored for

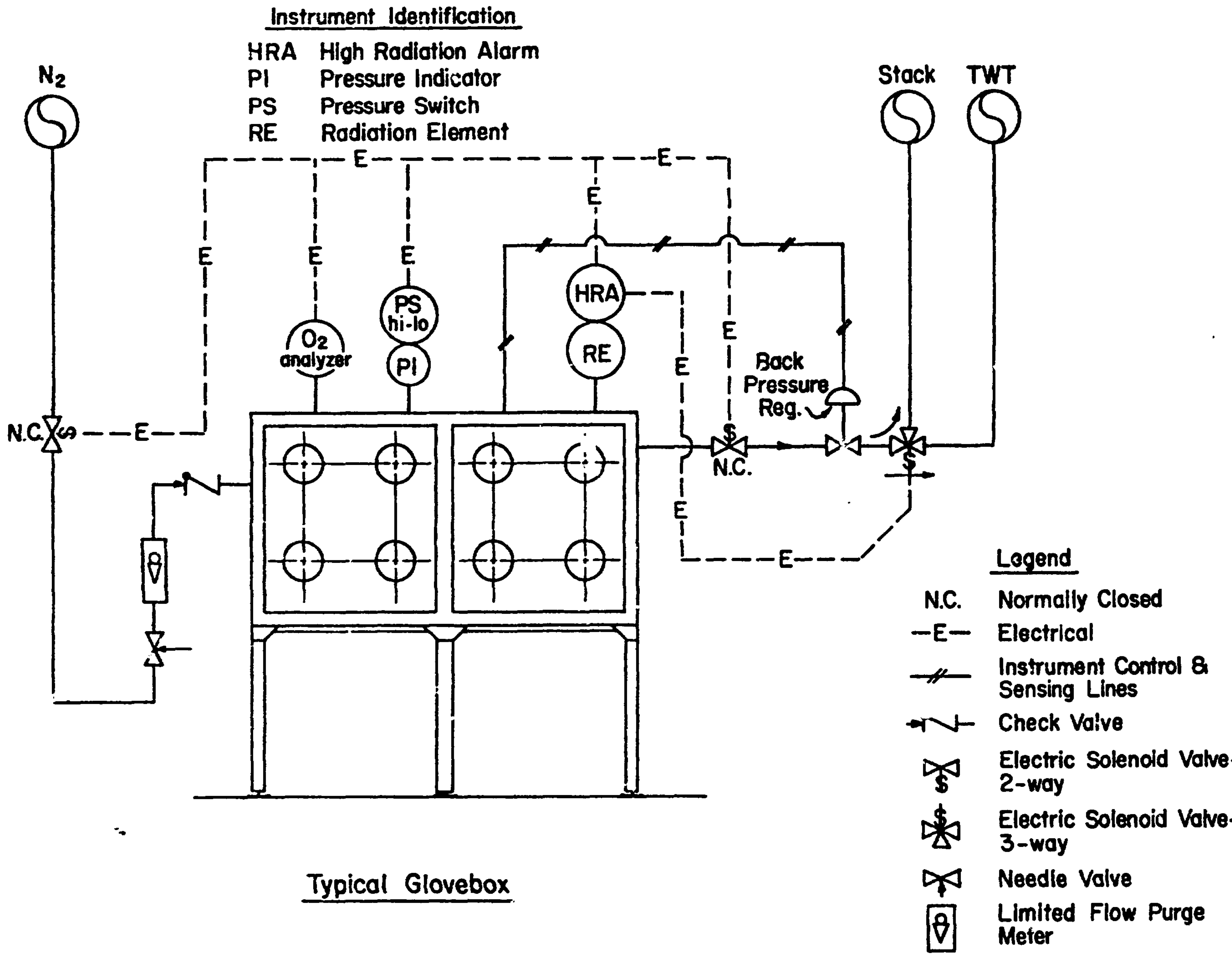


Fig. 2. Typical glovebox for secondary containment.

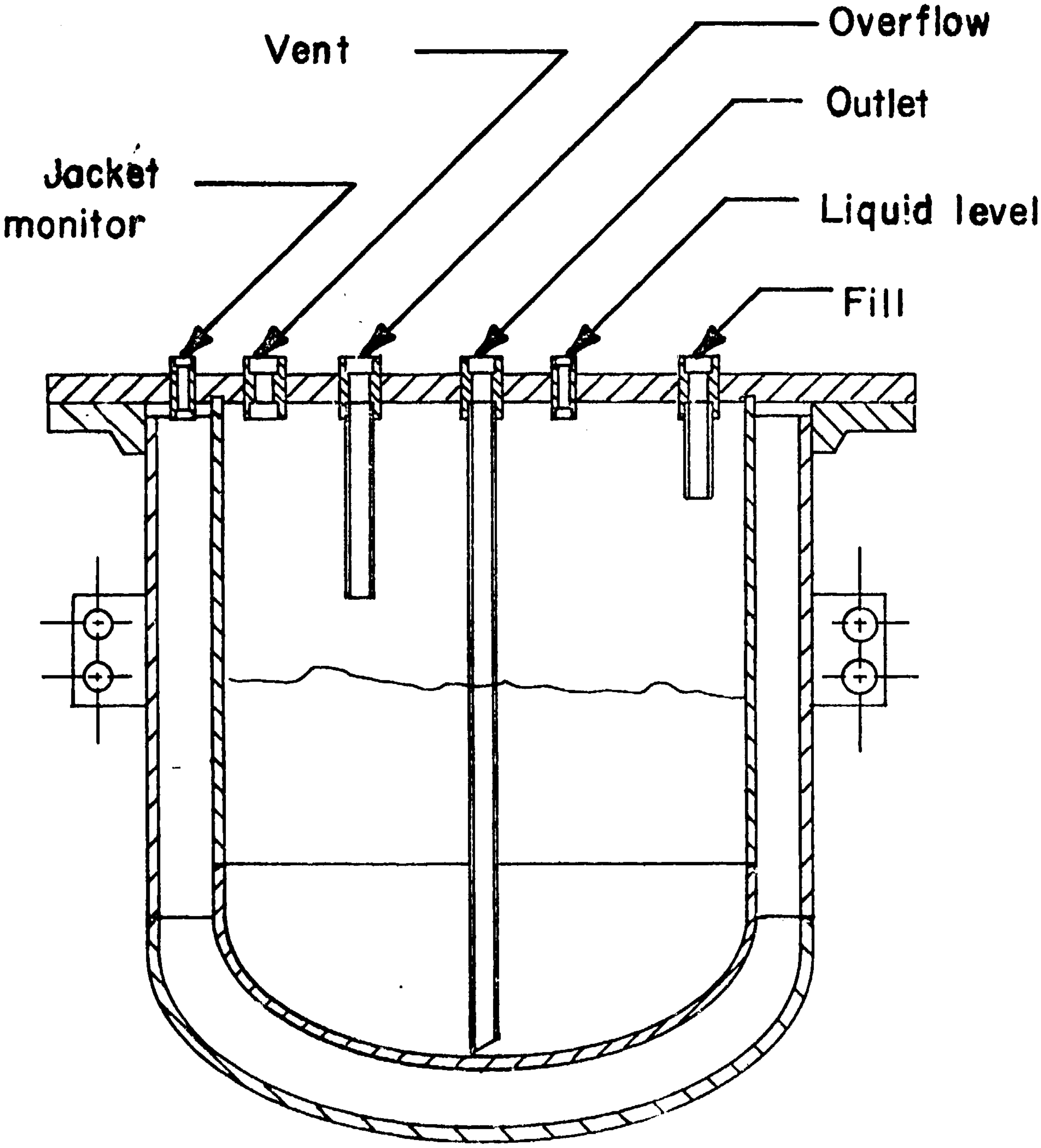


Fig. 3. Double-walled container for collecting tritiated water.

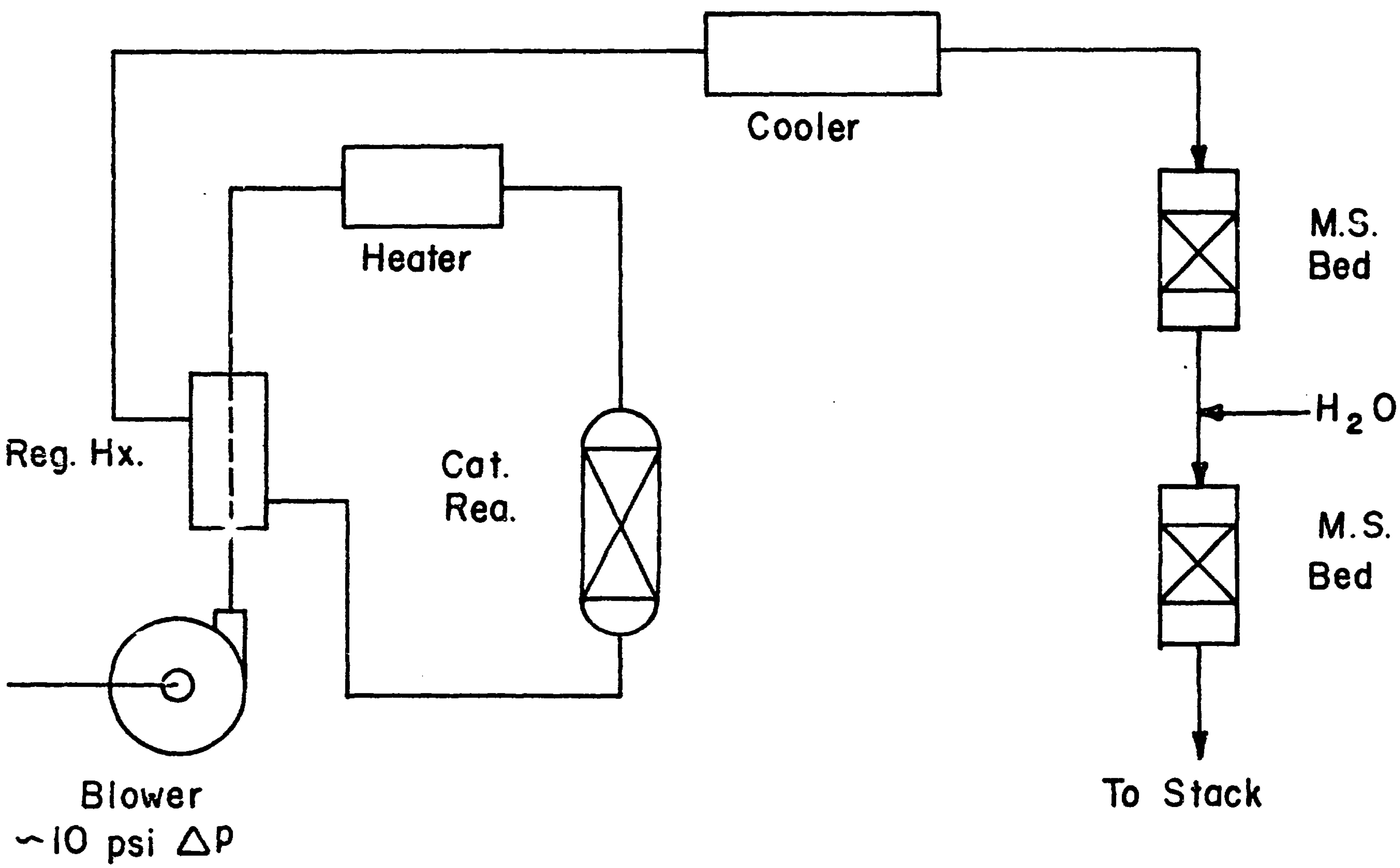
tritium, pressure and oxygen level. Oxygen will be maintained at low concentrations such that an explosive tritium-oxygen mixture does not occur if the primary equipment fails, releasing tritium into this volume. All of the air in this volume can be processed to recover any tritium captured here. Similarly, the air between the two walls of the liquid container can be monitored and processed. These are, of course, not the only means of double containment, but do serve to illustrate the philosophy involved.

A system which we at Los Alamos call a Tritium Waste Treatment (TWT) system will be a necessary part of any fusion facility. This TWT will serve to remove tritium from all routinely generated effluents prior to the release of these effluents to the atmosphere. Figure 4 shows a typical gas flow path for a system of this type. The tritium contaminated gas is heated to some 150-200° C and then passed over a heated reaction bed where the tritium gas, or tritium containing hydrocarbons are oxidized to tritium water. This gas is then cooled to ambient temperature and passed through a molecular sieve bed where the water is adsorbed on the sieve. Frequently the gas exiting this bed will still contain to much tritium to be released directly to the environment. In this case the gas flows through a water swamping stage where the water level is raised to $\sim$1000 ppm and then through a second molecular sieve bed. The resulting gas, free of tritium, can then be exhausted to the atmosphere. The TWT can process all routinely generated effluents in the tritium facility. Also, the TWT can and will be used to process the air in the secondary containment volumes to recover any tritium which might have been released into these volumes. The tritium collected as water on the sieve can later be recovered through standard molecular sieve regeneration schemes. This water can either be immobilized for burial, or if it contains sufficient tritium to be practical it can be electrolyzed and the resulting hydrogen isotopes fed to the plant isotope separation system for recovery of the tritium into the plant fuel cycle.

If the primary and secondary confinement systems are breached and tritium is released into the facility then the emergency tritium cleanup (ETC) system is automatically activated and starts processing the room air to remove and recover the tritium. The ETC works on the same principle as the TWT, that is tritium is recovered by conversion of the gas to tritiated water which is, in turn, collected.

The sequence of operations following such a tritium release will be to isolate the room air from the exhaust stack by a fast acting valve actuated by a signal from the control computer. The ETC starts processing the room air at a rate of about one volume percent per minute. The ETC operates in a recycle mode, with only a slight percentage of the gas being exhausted. This slight continual exhaust will be only enough to maintain the proper pressure balance in the cell versus the outside area. The collection ductwork for the ETC must be designed so that the system collects air from the locations where tritium operations occur and therefore have higher probabilities for experiencing a tritium release.

Fig. 4. Schematic of typical effluent treatment system using catalyzed $T_2 + O_2$ reaction to remove tritium from gas streams.



In the event of such a release the building proper serves as the tertiary confinement. This presents two major concerns; (a) the building must be sufficiently gas tight to prevent tritium escape to the environment during the ETC operation, and (b) the walls and other surfaces in the building must be properly coated to reduce tritium interaction with these surfaces during the cleanup cycle. Following such a release the ETC will be on-line until the tritium concentration in the room is reduced to a level sufficiently low that the ETC can now be turned off and the ventilation system reactivated and the room purged with fresh air, the remaining tritium being released through the building stack. In a large facility this cleanup phase may well take several days to accomplish. During this period there will be interaction of the tritium with walls, surfaces, etc. and some room temperature conversion of tritium gas to tritium water will take place. This water will create additional problems as it is adsorbed on surfaces. However, in spite of these problems current calculations and experimental data indicate that ETC systems can indeed recover essentially all of the tritium released in such an episode. Calculations on the ETC system being installed at TSTA indicate that a total tritium release of only a few Ci to the atmosphere might result from the release of 100 grams of tritium to the facility. The ETC at TSTA will be used extensively to obtain experimental data on the performance of these systems. This data base can then be used in designing later generation ETC's.

The final environmental control practice to be mentioned is that of maintenance procedures for tritium contaminated components. Tritium of and by itself does not require remote maintenance. Provided the worker wears the proper protective clothing hands-on maintenance is possible and in fact is now done routinely at several DOE Laboratories. The secret here is to design the system with some pre-thought to maintenance procedures and maintenance facilities. Design features which can be incorporated during the construction phase include purge systems so that all tritium wetted portions of the system can be evacuated and back-filled with clean gas prior to opening the wetted surface to atmosphere, the use of a double-valve arrangement across all breakable joints in the system, figure 5, and the inclusion of large glove boxes where smaller contaminated components can be moved prior to starting major overhaul on these components. The use of plastic tents or greenhouses, set up inplace around larger components are also used. The air from this temporary enclosure can be processed through the TWT prior to release to the environment.

III. CONCLUSIONS

Technology currently exists to permit large scale tritium operations, such as will be required for the fusion program, to be carried out safely and routinely. Systems and techniques are currently being developed and evaluated to assure only low level tritium releases to the environment from these facilities. The Office of Fusion Energy is currently supporting the development of these environmental protection systems as part of the Tritium Systems Test Assembly program at the Los Alamos Scientific Laboratory. These test systems will be fully installed and evaluation

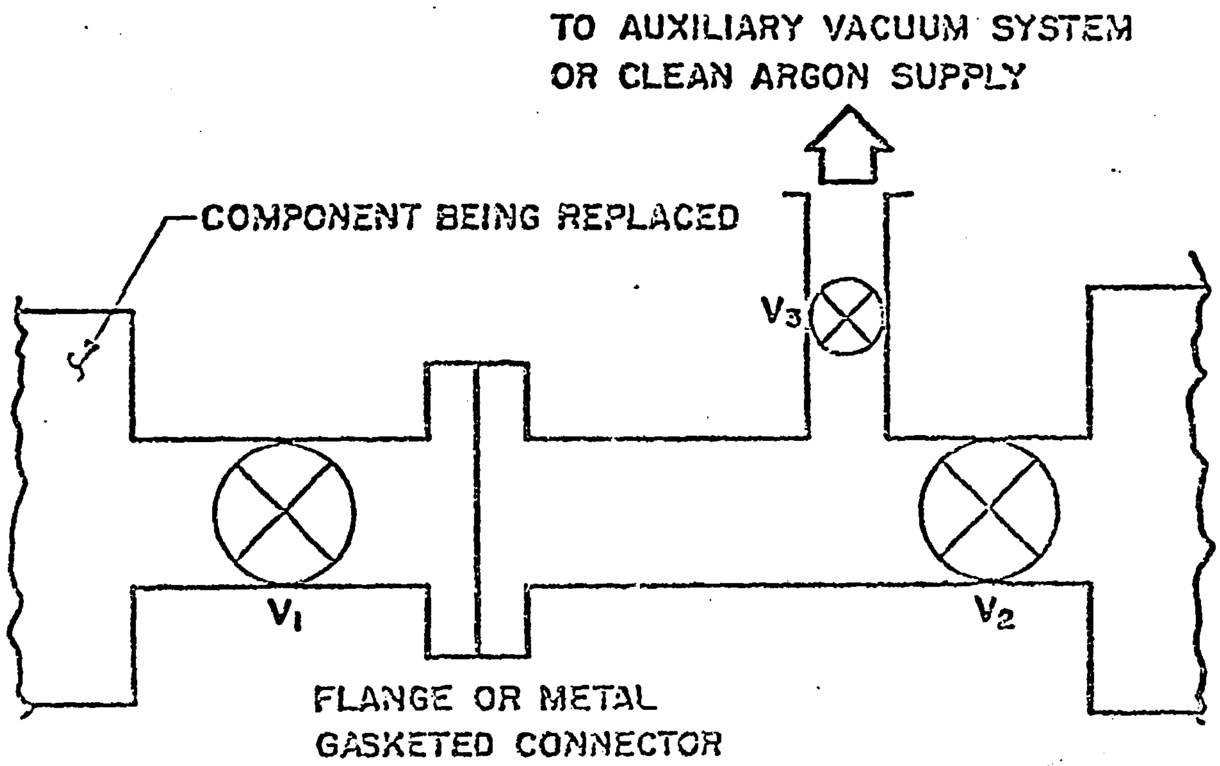


Fig. 5. Double-wall and purge system for tritium systems.

studies with tritium will begin in 1981. In addition to this test facility, there currently exists several Laboratory programs within DOE supporting and encouraging work on establishing environmental protection systems as part of on-going tritium programs. These programs are currently being supported by the Los Alamos Scientific Laboratory, the Lawrence Livermore Laboratory, Sandia Laboratory at Livermore and the Mound Facility in Ohio. The results and techniques developed in these programs will be available for inclusion in the environmental control systems for fusion facilities.

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