DETECTION OF GASEOUS HEAVY WATER LEAKAGE POINTS IN CANDU 6 PRESSURIZED HEAVY WATER REACTORS

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ABSTRACT

During reactor operation, the heavy water filled primary coolant system in a CANDU 6 Pressurized Heavy Water Reactor (PHWR) may leak through routine operations of the plant via components, mechanical joints, and during inadvertent operations etc. Early detection of leak points is therefore important to maintain plant safety and economy. There are many independent systems to monitor and recover heavy water leakage in a CANDU 6 PHWR. Methodology for early detection based on operating experience from these systems, is investigated in this paper. In addition, the four symptoms of D_2O leakage, the associated process for clarifying and verifying the leakage, and the probable points of leakage are discussed.

1. INTRODUCTION

Heavy water (D_2O) is used as moderator and coolant in the CANDU 6 PHWR. Leakage from these systems may lead to D_2O losses requiring make-up ; The recovered D_2O may be downgraded, requiring cleanup and upgrading, and in major leak situations possibly the reactor may need to be shutdown. The D_2O in the operating systems contains corrosion and/or fission products and tritiated heavy water (DTO) due to neutron exposure in the reactor core.

During normal operation, the D_2O is contained in a closed system i.e., such as the moderator system and the coolant system (sometimes called the heat transport system). Most leakages occurs from the hot, pressurized coolant system[1] because it is at high temperature and pressure, compared to the moderator system. D_2O leakage from the primary system may go to the surrounding atmosphere directly or into the cooling water e.g., feed water in the steam generator, recirculating cooling water in the purification system heat exchangers, etc.. D_2O leakages from the primary systems directly to the surrounding atmosphere are addressed in this paper.

Some D_2O may leak through routine operations of the plant via pump seals and valve packings in a controlled fashion. There are also likely to be chronic losses of D_2O from mechanical joints, particularly those associated with the heat transport system. These would include the feeder joints between the feeders and end-fittings, and the closure plug seals at the openings of the end fittings. These leakages are termed "chronic" leakages. Such chronic operations include:

- sampling
- deuteration and dedeuteration
- transfer of heavy water
- fuelling machine operations when the machine unlocks from the end-fitting
- draining of equipment for maintenance, etc.

D_2O may also escape as a result of acute events. For instance, when there is a leak in a steam generator or a heat exchanger tube, there is an additional leakage of heavy water, called "*acute*" leakage. These actue events include:
- spills
- steam generator tube leaks
- delayed neutron sampling tube leaks, etc.

D_2O leakage can occur as vapour or liquid depending on the operating temperature and pressure. Thus, the plant systems are designed to collect and recover the D_2O as quickly as possible with the minimum downgrading.

The total D_2O losses in a CANDU 6 PHWR average around 3.9 Mg/year. About 2/3 of D_2O losses occur via the airborne pathway, 70% of which are from the ventilated areas, and escape via the ventilation stack to the environment[1].

A computer system in the CANDU 6 PHWR maintains a heavy water inventory and heavy water monitoring program. This program in conjunction with physical inventory checks provides the operators with the daily inventory of heavy water in the plant.

Plant personnel have recognized that the trend of the daily inventory measurement allows them to determine the heavy water losses in a very accurate way. The information confirms the measured heavy water losses and allows accurate measurement of long term trends and changes in those trends. It also allows determination of any unmonitored losses by pathways not normally measured.

2. EFFECTS OF D_2O LEAKAGE

When D_2O leaks from operating systems, tritiated heavy water (DTO) also escapes with the D_2O and eventually increases the tritium concentration in the air surrounding the leak point. As a result the quantity of daily D_2O recovery from the D_2O vapour recovery system and/or quantity of daily D_2O loss through the stack D_2O monitoring system increase rapidly compared to those during normal operation.

The coolant system inventory remains within a narrow range during normal operation. The inventory in the circulating part of the loop remains constant and the volume in the pressurizer is controlled to a fixed level. Thus, any changes in the system inventory will be seen in the coolant system D_2O storage tank on which there is a low level alarm.

The level for the moderator system is monitored in the moderator head tank. Since the moderator temperature remains constant, it is possible for the level in the moderator head tank to proivde a rapid indication of leaks. There is an alarm on the head tank for low level, representing accumulated leakage of about 100kg relative to the nominal level.

3. MONITORING OF D_2O/DTO LEAKAGE

For detection of tritium in the atmosphere of the reactor or service building, fixed area monitors are provided as shown in Figure 1. For design purposes the maximum permissible concentration of tritium in air was taken as **3.7 x 10^5 Bq/m³ (10 μCi/m³)**, based on a forty-hour week, which corresponds to about 0.5 DAC (derived air concentration limits). The operating range of the fixed tritium-in-air monitor is 0.05 DAC to 20,000 DAC.

Monitors are centrally located, permitting measurements before an area is entered. Nineteen locations in the reactor building and five in the service building are monitored; Local read-outs are available at all these locations (see Table 1). Monitors will alarm when the tritium concentration exceeds the limits, which indicate a health hazard.

The D_2O vapour recovery system (see Figure 2) can be used for routine monitoring of heavy water leakage rates using existing practices. The D_2O which is recovered and drained from the vapour recovery tanks is checked every day to determine the D_2O isotopic, the tritium content and the volume of fluid collected. From these daily data, it is possible to determine the D_2O leakage rate and the systems from which the water come.

The continuous D_2O-in-air monitoring system is located in the reactor building outlet ventilation duct. Thus all air exhausted from the reactor building, including the purge flow from the vapour recovery driers is sampled for D_2O isotopic. This system is particularly valuable for detecting smaller leaks (see below) of D_2O, which evaporates before accumulating enough liquid to set off a beetle alarm, including leaks in areas not serviced by the vapour recovery driers.

An isokinetic air sample from the stack is passed through a desiccant column which adsorbs water vapour with D_2O vapour. The desiccant is changed and analyzed daily in the laboratory to determine the amount of D_2O loss and tritium activity which is released through the stack.

There are portable infrared monitors (sriffers) which can be used for the detection of changes in heavy water concentrations in air. These sniffers take a continuous sample of air and pass the air through an infrared cell. The portable unit reads out as ppm of D_2O.

The operator takes the instrument to the area of interest and monitors in the vicinity of the leak. At the leakage point, the concentration of D_2O in air will be the highest. The operator sweeps the room and the vicinity of each of the components in the area to determine which one is leaking.
This technique has been used successfully at PHWR plants in Canada to locate the small leaks.

It is also possible to detect leakage using visual inspection techniques. These would normally be leakages into air. Each technique is only applicable over a certain range as follows:

- Large leaks : > 10 kg/h
  These leaks would normally be detected visually. The leaks may be seen as steam plumes and are readily detectable. For large leaks the steam plume may be accompanied by water drop accumulating on the floor. Normally system operator must enter the area and monitor the system to find the leaks.

- Leak in the 1 to 10 kg/h range

These leaks would not normally be detected visually. If the leakage is from the coolant, there may be some staining of the metal at the leakage point due to the flashing of the water leaving lithium hydroxide which is white in colour.

Leaks from the moderator system would normally be seen as water drops or wetting in the area of the leak.

- Small Leaks : < 1 kg/h
  There are colour change tapes available which can be applied to an area and the extent of the colour change and the rate of colour change is used to determine if there is leakage and the rate of that leakage.

4. DISCUSSION

Acute leakage may occur through tubes as a result of fretting wear, cracks, or erosion, corrosion etc. Vibration at/of mechanical joints and inadvertent operations during heavy water handling may also cause acute leakages.

The reactor building is designed to reduce intermixing between coolant D_2O vapour from different sources and to confine vapourized D_2O by a suitable layout of the system and by proper atmospheric separation of areas which are prone to high specific activity D_2O leakage.

The vapour recovery system is used in conjuction with the operating dewpoint analyzers to roughly determine the room in which the leak is occurring[2]. The ducting isolation valves need to be manipulated to isolate one room at a time and to determine the trends in the dewpoints in each of the rooms. Judicious valving of the system allows the room with the leakage to be determined.

The most important function for the vapour recovery system in terms of the ability to detect leakage of D_2O is the trend information. This informs the operators of a possible leak and allows them to take action.

The leak rate can be determined in accordance with the amount of D_2O recovery and loss viz., D_2O leakage = D_2O recovery + D_2O loss. Approximate leak point can be determined by assessing the amount of D_2O recovered in D_2O vapour recovery system tank. Exact leak points can be determined by visual inspection.

Recently, tritium activity in the moderator is about 26 times higher than that in the coolant at Wolsong 1[3]. Thus, a small amount of moderator D_2O leakage increases the tritium concentration of the surrounding atmosphere around the leak point rapidly compared to the increase caused by coolant D_2O leakage.

Depending on leakage symptoms, D_2O leak points can be found systematically as shown in Figure 3. The representative areas for D_2O leakage and their leak checking points are shown in Table 2.

5. CONCLUSION

Acute D_2O leakage symptoms can be recognized by the daily D_2O loss and recovery trends. Routine radiation survey data in various areas of the reactor and service building carried out by the Health Physics Group are also useful in determining D_2O leaks. Acute D_2O leakage symptoms in a CANDU 6 PHWR are as follows :

- sudden increase of D_2O loss
- sudden increase of D_2O recovery
- sudden increase of tritium activity in the reactor or service building atmosphere
- sudden decrease of D_2O inventory

The first step after discovery of an acute D_2O leakage symptom is to determine if the source D_2O is coolant or moderator. If the tritium activity in the reactor or service building atmosphere is high, but the amount of D_2O lost and/or recovered is small, such a leak may be concluded to be a moderator D_2O leak. If the tritium activity in the reactor or service building atmosphere is high and the amount of D_2O lost and/or recovered is also large, such a leak may be concluded to be a coolant D_2O leak.

The next step is to investigate if there were recent D_2O handling activities *e.g.*, D_2O transferring work, deuteration and dedeuteration, D_2O sampling etc.. If so, a D_2O leak could have occurred during D_2O handling via an inadvertent operation by the operator. However, if there were no such perceived leaks during D_2O handling activities, then leaks may have been caused by system components. Leak points can be determined crudely from the D_2O recovery trend data for recovery tanks 1,2 (coolant recovery tanks) and 3 (moderator recovery tank) of the D_2O vapour recovery system.

The precise leak point can be confirmed, through visual inspection of the suspected leak point or room in the reactor or service building as shown in Table 2.

6. REFERENCES

[1] Tae-Keun PARK and K. AYDOGDU "Effect of Design Improvements in Heavy Water Management Systems to Reduce Heavy Water Losses and Tritium Releases at Wolsong 2.3 and 4", *IAEA-TECDOC-738*, pp 254-260, International Atomic Energy Agency (1994)

[2] S.W. SHIN, et al., "A Study on the Removal of Tritium for Wolsong Nuclear Power Plant Unit 1" *KRC-87N-J04,* pp147-176, KEPCO (1989).

[3] Tae-Keun PARK and Seon-Ki KIM "Tritium : Its Generation and Pathways to the Environment at CANDU 6 Generating Stations", *Nuclear Engineering and Design,* in press, (1996).

Table 1. Tritium-in-air Monitoring Areas

Room # (Typical)	Description
	Reactor Building Sampling Areas
R-305	Coolant system auxiliaries room - Direction 'C'
R-005	Cable access
R-303	Activity monitoring - Direction 'C'
R-405	Coolant system auxiliaries room - Direction 'C'
R-111	Moderator room
R-112	Moderator equipment enclosure
R-009	Basement in Direction 'C'
R-007	Transmitter room - Direction 'C'
R-103	Fueling machine maintenance room - Direction 'C'
R-104	Fueling machine maintenance room - Direction 'C'
R-306	Coolant system auxiliaries room - Direction 'A'
R-106	Autoclave room*
R-304	Activity monitoring - Direction 'A'
R-501	Steam generator room
R-406	Coolant system auxiliaries room - Direction 'A'
R-111	Moderator room - Direction 'A'
R-018	Liquid injection shutdown system, poison mixing room
R-008	Transmitter room - Direction 'A'
R-006	Coolant heavy water collection
	Service Building Sampling Areas
S-147	Reactor building exhaust and sampling cabinet
S-157	D_2O loading dock
S-004	Moderator deuteration and dedeuteration
S-005	Moderator purification area
S-018	D_2O supply tanks

* Autoclave circuit is not present at Wolsong 2,3&4

Table 2. Typical Areas for D_2O Leakage and Their Leak Checking Points

Dryer #	Room (Typical)	Leak Checking Points	Leakage Areas
1,2,3 &4	R-107 and R-108	feeder cabinets, fueling machine snout plug, steam generator manway leak-off lines, end fitting feeder connections, delayed neutron monitor sampling tubes, mechanical coupling, welding point, pipe hanger and support connections etc.	fueling machine vault
5			exhaust duct tower
7&8	R-111	mechanical coupling, joints, flanged joints etc.	moderator room
	R-112	tubing connections, moderator pump seal etc.	moderator equipment enclosure
9&10	R-405, 406, 305, 306	deuteration and dedeuteration work (tank level), valves, flanged joints, welding points, pump seal etc.	coolant auxiliary rooms
	R-103 and 104	valves	fueling machine maintenance room
	R-106	flanged joints	autoclave room
	R-007 and R-008	valves, connections etc.	transmitter room
11	R-501	tube bends	steam generator room

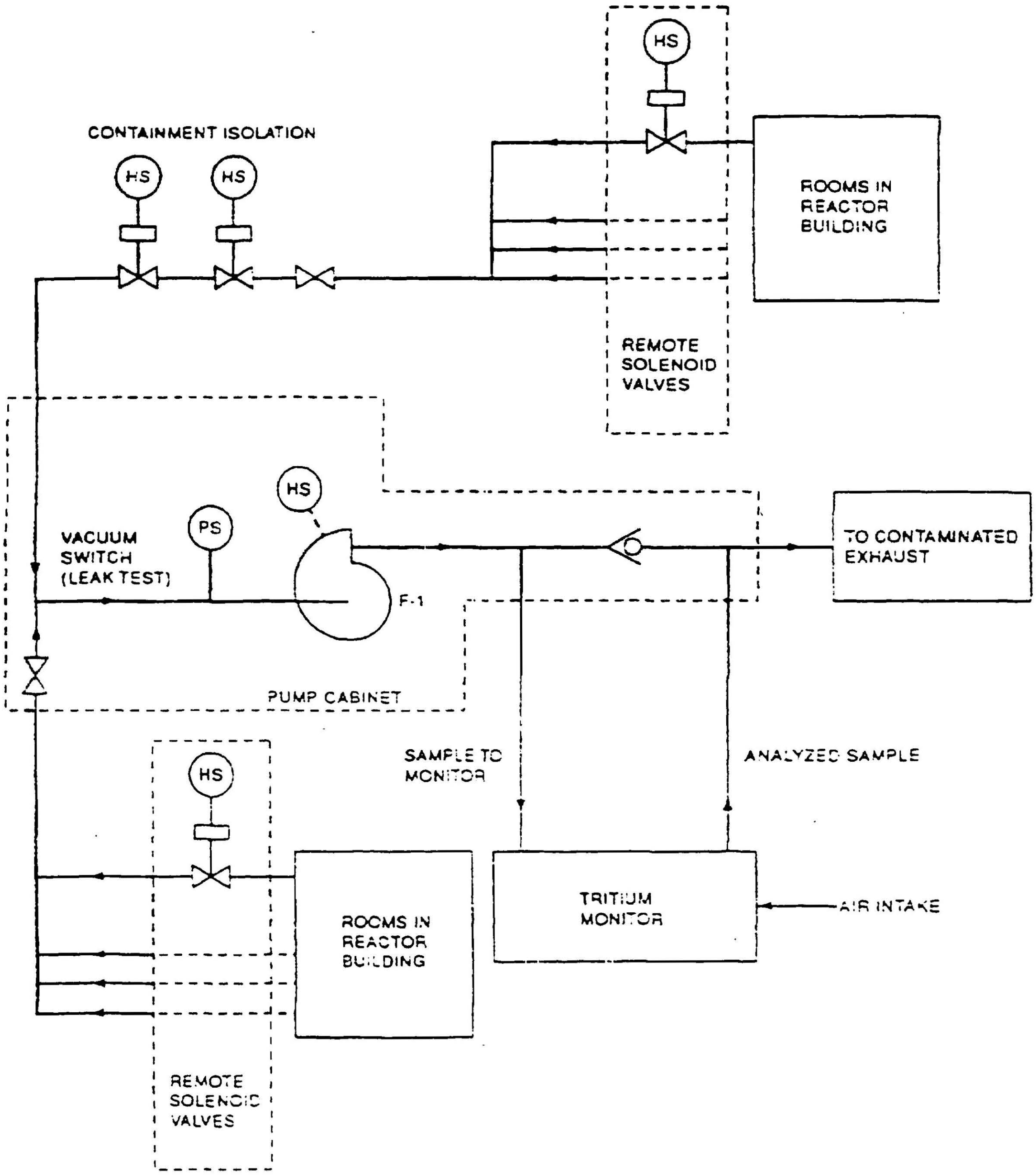

Figure 1 Schematic for Fixed Tritium In-Air Monitoring System

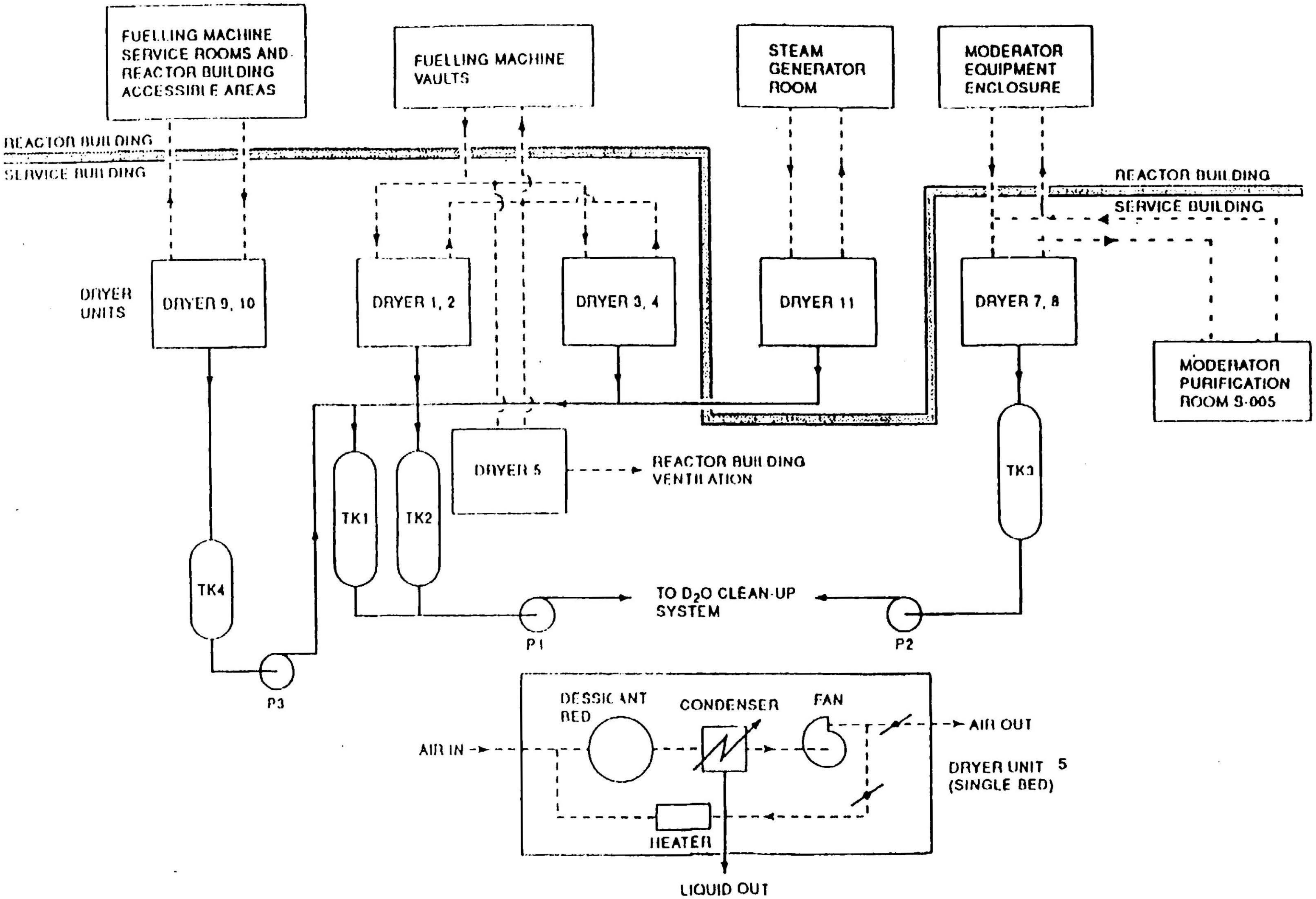

Figure 2 Schematic for D_2O Vapor Recovery System

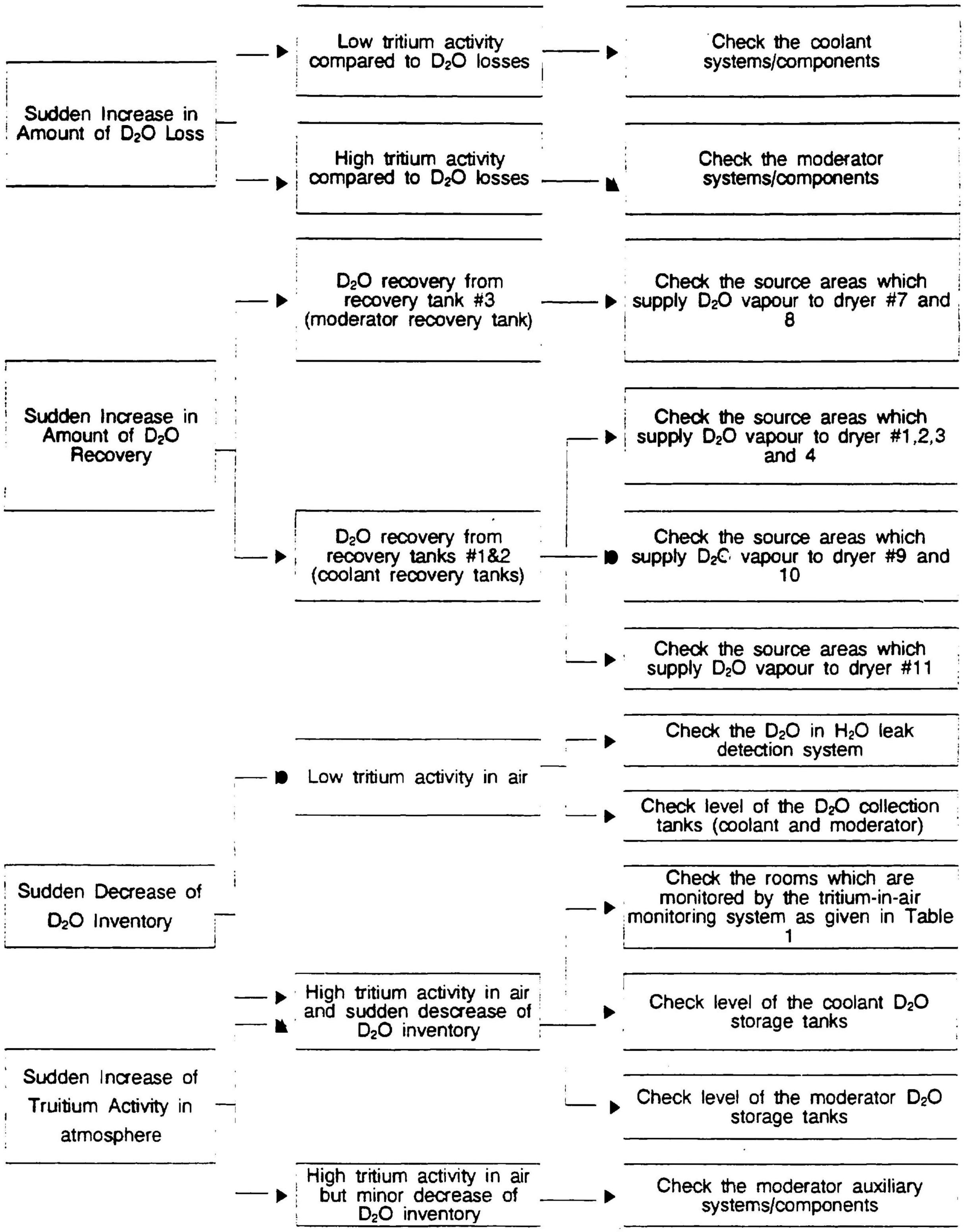

Figure 3. ALGORITHM OF D_2O LEAK DETECTION

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by

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