

Tritium Room Air Monitor Operating Experience Review

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TRITIUM ROOM AIR MONITOR OPERATING EXPERIENCE REVIEW

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Monitoring the breathing air in tritium facility rooms for airborne tritium is a radiological safety requirement and a best practice for personnel safety. Besides audible alarms for room evacuation, these monitors often send signals for process shutdown, ventilation isolation, and cleanup system actuation to mitigate releases and prevent tritium spread to the environment. Therefore, these monitors are important not only to personnel safety but also to public safety and environmental protection. This paper presents an operating experience review of tritium monitor performance on demand during small (1 mCi to 1 Ci) operational releases, and intentional airborne in-room tritium release tests. The tritium tests provide monitor operation data to allow calculation of a statistical estimate for the reliability of monitors annunciating in actual tritium gas airborne release situations. The data show a failure to operate rate of $3.5E-06$ /monitor-hr with an upper bound of $4.7E-06$, a failure to alarm on demand rate of $1.4E-02$ /demand with an upper bound of $4.4E-02$, and a spurious alarm rate of 0.1 to 0.2/monitor-yr.

I. INTRODUCTION

Personnel exposure monitoring is a fundamental safety precaution for a variety of airborne substances. Because fusion experiments tend toward use of kg quantities of tritium fuel, there is a chance that tritium can be released into the building atmosphere. Fixed point tritium air monitors are part of the protection scheme for personnel working with or near tritium fuel.

There are generally three failures of concern for tritium monitors: the failure to monitor, the failure to sound an alarm when required, and sounding a spurious alarm when no alarm condition exists. These failures are typically referred to as failure to operate or failure to function, failure to alarm on demand, and spurious alarm. All alarm systems have requirements or best practice standards that state the monitors must have high reliability, reliable actuation, and rare spurious actuations. Many standards address reliability on a qualitative level by stating that the monitoring system must be a simple design to promote high reliability, use low maintenance subcomponents, and avoid false alarms. This paper

addresses quantitative failure rates of tritium air monitors used in fusion research. These monitors may detect airborne tritium in elemental or oxide form.

II. MONITOR EXPERIENCES

To understand how tritium monitors are used in fusion facilities, we will look at monitor use in two facilities. At the Tritium Systems Test Assembly (TSTA) facility at Los Alamos National Laboratory, staff members used fixed tritium monitors for personnel protection and for building isolation in case of an airborne tritium release. These monitors were Kanne chamber type units that drew samples of room air into the chamber for readings of ion pairs created by beta decay. The TSTA monitors had three alarm levels. The first level was set at 1 derived air concentration (DAC) of tritiated water vapor (HTO) in air, or $20 \mu\text{Ci}/\text{m}^3$ at that time. At that alarm, all non-essential personnel would promptly evacuate the area and designated personnel would quickly investigate the alarm to determine if the alarm was genuine. The second alarm level was set at 5 DAC ($100 \mu\text{Ci}/\text{m}^3$). At the second alarm level, any investigators would also evacuate but could return if they donned appropriate protective gear. The third level alarm was set for 500 DAC ($10 \text{mCi}/\text{m}^3$), which would sound an entire facility evacuation alarm and also isolate the TSTA building ventilation system.¹ The system never reached the highest alarm and only rarely reached the middle alarm in the years that TSTA operated. The TSTA monitors were operated at an artificial background setting of $5 \mu\text{Ci}/\text{m}^3$, slightly above a true zero reading, so that if an artificially low or erratic reading was caused by abnormal instrument drift or other malfunctions it would be notable to the operators. Either a Ba-133 or Cs-137 check source was used for monitor checks.¹

In the Safety and Tritium Applied Research (STAR) lab at the Idaho National Laboratory (INL), the two tritium monitors are the typical Kanne chamber type with room air drawn through the chamber. One of the monitors is shown in Figure 1. The STAR lab tritium air monitors have two alarm points: a low alarm at ≈ 0.5 DAC, which at STAR is $15 \mu\text{Ci}/\text{m}^3$ HTO above nominal background, and a high alarm at 5 DAC ($100 \mu\text{Ci}/\text{m}^3$). The U.S. Code

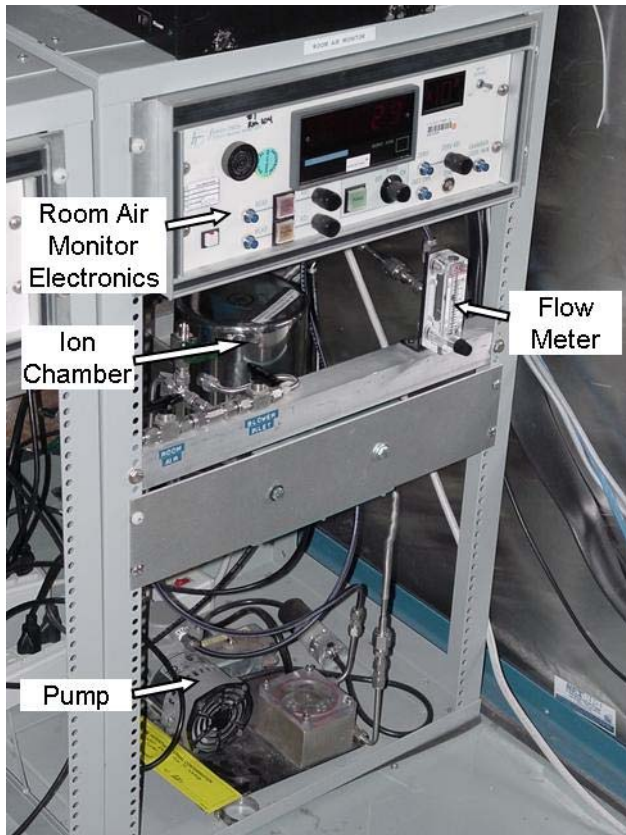


Figure 1. Tritium room air monitor unit at the INL STAR laboratory.

of Federal Regulations presently defines the DAC for HTO vapor as $7E+05 \text{ Bq/m}^3$ ($18.9 \text{ } \mu\text{Ci/m}^3$) of air.²

STAR personnel evacuate if the low level alarm sounds. Their procedure is to promptly evacuate the building, account for employees and visitors, and then use a cellular telephone or proceed to the nearest telephone in a nearby building to report the event to radiological control personnel and laboratory management.

The STAR instruments have functioned well and the staff members have confidence in them. The monitors are given a daily inspection, a weekly source check with a Cs-137 source, and a detailed calibration every 3 years. The 3-year calibration time window is longer than the typical 6-month or 1-year interval. The long calibration time interval is allowed because of the strict tracking of check readings during the weekly source checks (within $\pm 10\%$ variance). If the instrument varies outside the $\pm 10\%$ range it must be recalibrated immediately at the health physics instrument lab. The procedure calls for transporting the electronics portion of the monitor to that lab to perform a bench test, which takes one day. If one of the two STAR monitors is being calibrated, the staff does not perform any major process evolutions at the facility. If there is cause for concern while one unit is gone then a radiological controls technician places a portable monitor unit in the room until the second STAR unit is returned. STAR does not have a spare tritium monitor on hand.

TABLE I. Tritium Air Monitor Hourly Failure Rates from Fusion Facilities

Facility	Failure Mode	Failure Rate (per hr)	Error Bound (per hr)	Reference
Tritium Process Laboratory (TPL)	Fail to function	See below ^a		[4]
TPL	Fail to function	$1.1E-05$	$2.5E-05$	[5]
TPL	Fail to function	$5.9E-06$	Not given	[6]
Joint European Torus (JET)	Erratic/no output	$8.8E-07$	$4.2E-06$	[3]
TSTA	Reads high or low	$2.2E-06$	$1E-05$	[1]
TSTA	All modes	$4.3E-06$	$1.5E-05$	[1]

a. Using the failure count from [4], 13 failures of the tritium air monitoring system, and 7 monitors [6] operating for 19 years = $13 \text{ failures} / [7 \text{ monitors} \times 19 \text{ yr} \times 8760 \text{ hr/yr}]$, gives a result of $1.1E-05/\text{monitor-hr}$ as the point estimate failure rate. A standard error bound would be $[1.1E-05 / (7 \text{ monitors} \times 19 \text{ yr} \times 8760 \text{ hr/yr})]^{0.5}$ or $\pm 3E-06/\text{monitor-hr}$. The TPL value appears to be $1.1E-05/\text{hr}$. Combining this result by using a geometric mean with the JET “erratic/no output” and TSTA “all modes” values gives $3.5E-06/\text{monitor-hr}$ with an upper bound of $4.7E-06/\text{monitor-hr}$.

III. DATA ASSESSMENT

The first mode of monitor failure described above, failure to operate, has been analyzed in several operating experience data sets.^{1,3-6} These data are given in Table I. The combined failure to function rate value from the three diverse data sets is estimated to be $3.5E-06$ /monitor-hr with an upper bound of $4.7E-06$ /monitor-hr. The failure to operate rate includes the detector, electronics, internal power supply, air flow, contamination, and air pump faults but does not include loss of electric power to the monitor unit.

The second failure mode is the failure of a monitor to alarm on demand, where demand is defined as a valid, actual situation that requires the monitor to alarm. As mentioned, tritium is usually effectively confined and there are consequently very rare demands to these monitors. As a generality, most monitor units in fusion usage do not experience enough demands to obtain a statistically significant failure rate for this failure mode. The data examined here (listed in Table II) are from tritium release tests and small operational releases at TSTA and STAR. All of the monitors addressed in these experiences are the most widely used Kanne chamber type, which draws room air into an ionization chamber by means of a small air pump.⁷

TSTA recorded a few operational release events.^{1,8} Due to some research regarding tritium movement in

room air, there have also been several small-mass tritium release tests performed at TSTA^{9,10} and at the Tritium Process Laboratory (TPL) caisson facility at Tokai-mura operated by the Japan Atomic Energy Agency.¹¹⁻¹³ The TPL tests documented in the literature were highlights from 70 tests with tritium release levels between 0.26 and 26 GBq; the tritium monitor was out of order twice (did not function on demand) during that run of tests.¹⁴

The TSTA monitors were used in the large room tests to track tritium spread throughout the room and measure equilibration of the tritium concentration. In the smaller caisson tests at TPL, the monitor was used to measure the change in tritium concentration. The TPL caisson tests also used several “nude” ion chamber tritium monitors to detect tritium; those units were not included in the data set because they are a somewhat different instrument than the typical room air monitor that uses a pump and gas chamber. There have also been at least twelve very small leaks (< 1 mCi) of process tritium at the STAR laboratory. The STAR leak events have all been small amounts but have been more frequent than those at TSTA. The STAR events alone are not sufficient for statistical evaluation, but these events do contribute to a combined data set. The small releases at STAR produced between 15 and 80 $\mu\text{Ci}/\text{m}^3$ concentration ranges in room air, which was sufficient to alarm a monitor. In these events, the challenged monitor functioned on demand, performing as

TABLE II. Monitor Operational Data from Small Tritium Releases

Event/Test Designator	Tritium Released (mCi)	Number of Monitors	Number of Releases ^a	Reference
1	≈ 60 est.	8	1	[1]
2	≈ 60 est.	8	1	[1]
3	145	8	1	[8]
4	1,000	8	3	[9]
5	1,000	8	2	[10]
6	7	1	1	[11] ^a
7	7.5	1	1	[12]
8	70	1	4	[13]
9	7-700	1	62	[14] ^b
10	< 1	1	12	INL STAR lab over ≈ 4 years

Release event totals $8(1)+8(1)+8(1)+8(3)+8(2)+1(1)+1(1)+1(4)+1(62)+1(12) = 144$ monitor-demands

a. Note: There were six “nude” ion chambers on the caisson as well but those units were not included here.

b. There were two faults in the monitor over 10 years. In the other listed release events, there were no monitor failures on demand.

intended. It is noted that the data in Table II constitute only a small set of data for a small number of tritium monitors but these are valid data of demands to monitors from actual tritium release conditions and the data can be used to estimate the monitor failure rate for failing to alarm on demand.

A statistical approach for calculating failure rates was outlined in Ref. 1, and is used here for demand failure rates. The point estimate failure rate is the total number of failures on demand divided by the total number of demands for the data given in Table II.

$$\lambda = (\text{total failure count})/(\text{total demand count}) \quad (1)$$

The upper bound failure rate¹ would be

$$\lambda = \chi^2(0.95, 2(n+1))/2D \quad (2)$$

where

n = total failure count

D = total demand count.

The calculated chi-square distribution value for n=2 is 12.592 for the 95% upper bound.¹⁵ Using this value and the demand count data from Table II, the tritium air monitor average failure rate for failure to alarm on demand is $[2/144] = 1.39\text{E}-02/\text{demand}$ with a 95% upper bound of $[12.592/2(144)] = 4.372\text{E}-02/\text{demand}$.

The third failure mode, spurious alarms, has been known to occur with tritium monitors like other types of fixed monitors, but it is a somewhat rare event. For example, STAR experience is that a false alarm occurs at the facility perhaps once every 3 years, or 0.33/yr. Therefore, each of the two monitors has a spurious tritium alarm rate on the order of 0.17/yr. This appears to be a typical frequency estimate for a tritium research facility using a set of tritium monitors. The TSTA spurious alarms were also rare.¹

The spurious alarm rate can vary with the age of the monitor, the age of the facility, the quantity of tritium used in the facility, the monitor manufacturer or brand name, and monitor recalibration frequency. There can be other factors for false alarms as well, including the monitor sensing radon gas rather than tritium,¹⁶ the presence of foreign vapors that cause the monitor to alarm (such as welding fumes),¹ or the monitor sensing a non-tritium beta-gamma emitter.

The spurious alarm failure mode has not been investigated in any detail because such alarms err on the side of caution. Room or facility evacuations prompted by a spurious alarm are more of a nuisance and an operating cost burden than a safety issue—if the spurious alarms are infrequent enough so the staff does not become inured to the tritium alarms. In regard to human behavior when alarms sound, Proulx¹⁷ states that specialists in fire protection tend to agree that more than three nuisance or false alarms in a year undermine credibility of fire alarm

systems and people tend to ignore the alarms. Certainly there is a higher level of professionalism in nuclear facility operations than in residential or public buildings, but if false alarms occurred with high frequency then workers may suspect a false alarm first and may not evacuate very quickly. The spurious alarm frequency noted at STAR is sufficiently low, and much lower than the valid alarm frequency from operational releases, so there is no concern about personnel responding correctly to an alarm.

IV. RESULTS COMPARISON

The military specification for reliability of fixed and portable tritium monitors states that the monitors shall have a mean-time between-failures of 3,000 hours or more (a failure rate of $3.3\text{E}-04/\text{hr}$ or lower), and a mean corrective maintenance time to repair a monitor not exceeding 30 minutes (a mean time to repair of 0.5 hr).¹⁸ All values from the failure to function data given in Table I surpass that specification. The military specification does not give a value for failure to alarm on demand. Therefore, to check the validity of the value calculated here ($1.39\text{E}-02/\text{demand}$), reliability values for other types of alarms were sought for comparison. Some monitor demand performance data were located for smoke detection systems used for fire protection in nuclear power plants.¹⁹ The failure of a smoke detector to alarm when challenged with a valid fire and smoke condition varied from $1\text{E}-03/\text{demand}$ and even as low as $1\text{E}-05/\text{demand}$ for nuclear power station smoke detection systems. Because smoke detection is an engineered system to protect human health and safety, these performance values are believed to be generally comparable to the tritium air monitor results. The nuclear power plant smoke detection system not only sounds a local alarm for personnel evacuation, but it will also signal for ventilation shut down, smoke control system actuation (e.g., close smoke dampers), and actuation of water flow to “dry pipe” sprinkler systems if such systems are used in the facility. Thus, the nuclear power plant smoke detection system has similar functions to the tritium air monitoring system. The upper end of the nuclear fission power plant rate was about fourteen times less than the tritium monitor results. Because tritium monitors are believed to be reliable, it is possible that with more tritium release tests the calculated tritium air monitor failure to alarm on demand value would decrease further and be more comparable to the upper end of the nuclear power plant smoke detection system value of $1\text{E}-03/\text{demand}$.

Another type of monitor that is important for personnel safety is a nuclear criticality alarm system. A literature search revealed little data about the reliability of these detectors, but a recent purchase contract specification cited an acceptable range for failure to alarm

on demand of $1\text{E}-02$ to $1\text{E}-03/\text{demand}$ and a spurious alarm rate of < 0.1 event/year.²⁰ A vendor study gave a failure to alarm on demand value of $1.7\text{E}-03/\text{demand}$ with a 1-year test interval, and $1.3\text{E}-04/\text{demand}$ rate for a 1-month test interval. The spurious alarm frequency for a criticality alarm system was given as $0.05/\text{year}$. Criticality alarm systems are intended for personnel and public safety; a criticality alarm not only signals for a quick evacuation of workers to evade prompt radiation exposure, but also actuates a lockdown of facility ventilation and de-energizes processes so there are no activated material releases to the environment. For the criticality alarm systems, apparently a $1\text{E}-02$ to $1\text{E}-03/\text{demand}$ failure rate range is considered adequate for personnel safety when the rarity of a nuclear criticality event is taken into account. The tritium monitor value of $1.39\text{E}-02/\text{demand}$ calculated here is just outside the $1\text{E}-02$ to $1\text{E}-04$ range given for a criticality alarm system. This is a surprisingly good result given that the tritium monitor data are sparse. However, the INL staff hold confidence in these units as equipment that operates well, suggesting that longer operation times will result in continued correct operation and lower demand failure rates. The STAR tritium monitor spurious alarm rate was estimated to be greater than that of criticality monitors, which are not prone to false alarms.

V. CONCLUSIONS

Fixed monitoring for airborne tritium is necessary for personnel safety. Examination of monitor failure rates for failing to operate has yielded a combined value of $3.5\text{E}-06/\text{monitor-hr}$ with an upper bound of $4.7\text{E}-06/\text{monitor-hr}$. This is a factor of ≈ 94 below the published quantitative reliability level of $3.3\text{E}-04/\text{monitor-hr}$ stated in a military standard. The issue of monitors sounding a valid alarm has also been examined. The tritium release tests that have been conducted in fusion tritium facilities not only provided valuable information about tritium movement and behavior within buildings and enclosures, but have also produced a set of demand trials that exercised the tritium monitors used in these facilities. Two of the tritium monitors were noted to have failed in this compilation of tests and operational releases. The test data are recognized to be sparse, but the data described in Table II constitute a larger data set than has been readily available for these monitors in the past. Statistical treatment of these test data gave a failure to alarm on demand failure rate of $1.4\text{E}-02/\text{demand}$, with an upper bound failure rate of $4.4\text{E}-02/\text{demand}$. In comparison to other types of monitors having the same types of requirements to provide for personnel safety, it was found that the value for tritium air monitors was ≈ 14 times higher than nuclear power plant smoke detection monitor systems (a poor comparison over 10 times) and a factor of 1.4 higher

than the specified reliability range for a nuclear criticality alarm system (a good comparison within three times). This was a good result considering the small data set. Because the INL staff trusts the tritium air monitors to give proper responses and the operating experience they have witnessed leads them to conclude that the monitors are reliable, it is suggested that additional tritium monitor operation would yield lower demand failure rates than the $1.4\text{E}-02/\text{demand}$ calculated here. Monitors sounding spurious or unwanted alarms has not been treated in detail but operating experiences indicate the value should be on the order of 0.1 or 0.2/monitor-yr, which was greater than cited values for other monitors but is still a low value.

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