

Stack Monitor Operating Experience Review

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L. C. Cadwallader
S. A. Bruyere

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L. C. Cadwallader and S. A. Bruyere

Fusion Safety Program
Idaho National Laboratory
Idaho Falls, ID USA
Lee.Cadwallader@inl.gov

Abstract— Stack monitors are used to sense radioactive particulates and gases in effluent air being vented from rooms of nuclear facilities. These monitors record the levels and types of effluents to the environment. This paper presents the results of a stack monitor operating experience review of the U.S. Department of Energy (DOE) Occurrence Reporting and Processing System (ORPS) database records from the past 18 years. Regulations regarding these monitors are briefly described. Operating experiences reported by the U.S. DOE and in engineering literature sources were reviewed to determine the strengths and weaknesses of these monitors. Electrical faults, radiation instrumentation faults, and human errors are the three leading causes of failures. A representative “all modes” failure rate is $1\text{E}-04/\text{hr}$. Repair time estimates vary from an average repair time of 17.5 hours (with spare parts on hand) to 160 hours (without spare parts on hand). These data should support the use of stack monitors in any nuclear facility, including the National Ignition Facility and the international ITER project.

Keywords—stack monitoring, reliability, maintainability

I. INTRODUCTION

A stack monitor is a basic device used to sample the effluent air being exhausted from the facility vent stack to the environment. A representative stack gas effluent monitor [1] is shown in Figure 1. The US Department of Energy (DOE) and other federal regulations [2,3,4] give effluent monitoring design requirements. The main requirement is that emissions of radionuclides to the ambient air from DOE facilities shall not exceed amounts that would cause any member of the public to receive an effective dose of 0.1 mSv/year (10 mrem/year) [4]. The stack monitors sample gaseous effluents to indicate if that limit is being approached. The sampling and monitoring systems must provide adequate and accurate measurements under normal operations, anticipated operational occurrences, and any accident conditions. Monitoring systems should be calibrated at least annually. Stack monitors should have central readouts and alarm panels which are accessible after an accident to allow evaluation of conditions. Radiation monitoring, alarm, and warning systems that must function during a loss of power should have emergency power, with the type and quality based on the safety classification of the monitor. A long-standing design principle of these monitors is to have a backup unit in place so that if the primary

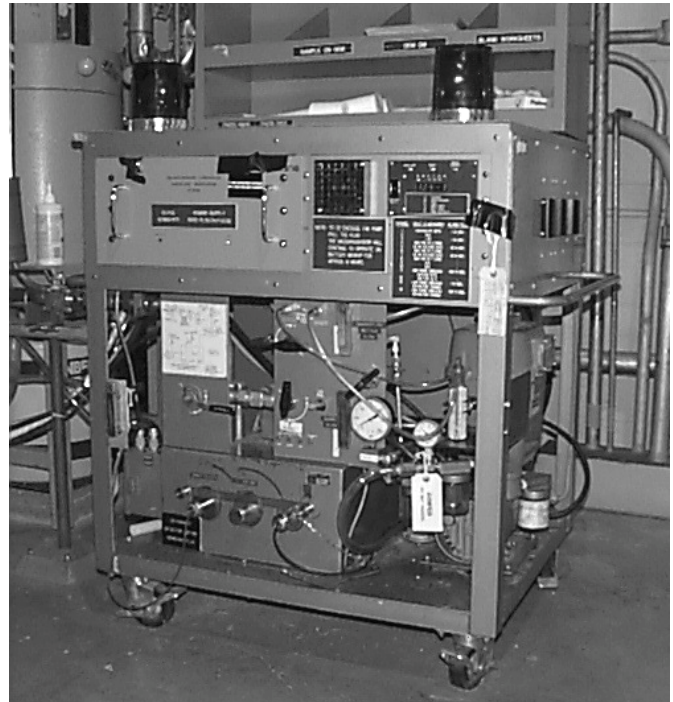


Fig. 1. A typical stack gas effluent monitor.
(reprinted with permission from [1]).

unit experiences a fault then a redundant unit can be activated to ensure continued monitoring of the stack gases [5]. Most fission-related facilities refer to stack monitors as system particulate-iodine-noble gas (SPING) monitors. The SPING monitor contains separate detector channels tailored to read specific energies of radioactive decay from particulates, iodine, and noble gases. Generally, sample air is drawn at a modest flow rate (e.g., 80 liters/s) and is routed from the facility vent stack to the isokinetic samplers and to the monitor channels located somewhere near the base of the stack. The sample line is usually kept short (e.g., a few meters) to preclude plateout in the line and to maintain some air flow via stack air momentum since the sample air flow through a filter paper provides a record of particulate releases even if the monitor's sample pump has failed [3]. A fusion facility is expected to focus on particulates and activated air as the primary effluents to be monitored with this type of equipment. Tritium monitoring,

which can be a detector channel in these stack monitors, is important for fusion facilities. In the US, facilities often use an ethylene glycol bubbler system to measure low levels of tritium gas in effluent air. Those units will be addressed separately in future work.

Some stack monitors use the same equipment as the continuous air monitor (CAM) that provides for worker breathing air protection within the facility. In that type of unit, particulate collection on filter paper is used to measure the activity of any airborne material [6]. Radiation detectors in CAMs are typically Geiger-Muller (GM) counters. Some stack monitor channels use these, while other stack monitors can be more sophisticated than CAMs, using scintillation counters with photomultiplier (PM) tubes, ionization chambers, solid-state detectors, or other radiation detection instruments.

II. EXPERIENCE DATA ASSESSMENT

The U.S. DOE operates an Occurrence Reporting and Processing System (ORPS) database to record equipment faults and human errors at DOE facilities [7]. The reporting period searched, 1990 to the end of 2008, encompassed hundreds of stack monitor units across the DOE Complex. A search of the database narrative descriptions for “stack monitor” returned 360 ORPS reports (see Table I). Some reports were deleted from this study because they described a stack gas effluent monitor correctly responding to airborne radioactive gas or particulate. Other reports were deleted because they referred to room air monitor issues rather than stack monitor issues. A third subset of the reports was deleted because a stack monitor was mentioned but the report addressed some other, unrelated equipment failures. These deletions left 263 reports of faults attributable to stack monitors. As derived from Table I, 92/263 or 35% of failures were electrical (including loss of power and power supply problems and electrical noise), 55/263 or 21% of the failures were radiation instrumentation faults, 51/263 or 19.4% were human errors, 40/263 or 15% of the failures were mechanical (mainly in the air pumping portion of the units – reference [3] states that vacuum pumps should be designed for ease of replacement), and 25/263 or 9.5% of the ORPS reports were environment-related monitor faults.

One important issue is the number of stack monitor failures where the monitor did not annunciate a fault or otherwise issue some type of trouble alarm. In human-error-caused failures, the monitor did not annunciate in 33/51 or 64.7% of the events. In 18/40 or 45% of the mechanical faults and 18/92 or 19.6% of the electrical faults, the affected monitors did not issue a trouble alarm. Facility personnel learned of most of these failures from testing performed each day or each shift. Therefore, the periodic (daily or more frequent) checks or inspections that stack monitors receive is warranted and is a best practice for this type of instrument, at least for the presently used level of technology. Frequent testing that does not create additional system wear or decrease useful system life is a benefit to operational reliability and is a best practice.

Past work examined CAMs used for personnel safety [6]. One notable difference between those data and these stack monitor data is that human errors by non-monitor workers are greatly reduced for the stack monitors. Most CAMs are

positioned to monitor room air and are generally accessible to many workers, while the stack monitors are generally located near the base of a facility vent stack and are typically shielded so that they register only radioactivity in the stack gases. There may also be shielding to protect the stack monitor electronics from exposure to accident doses, which further segregates the stack monitors from facility workers. Thus, stack monitors are more isolated from workers who do not test or maintain these monitors.

III. RELIABILITY AND MAINTAINABILITY DATA

The ORPS reports describe the failure modes of stack monitor units but do not give enough information on units in use and the time periods over which these units have operated to calculate failure rates. Instead, the literature was searched for published failure rate data on stack monitors. One recent document found on this topic was that authored by Grigsby [8]. Also, various Idaho National Laboratory (INL) records have been reviewed and provide enough data to support an order-of-magnitude failure rate calculation. The stack monitor data showed 15 failures requiring repair in 12 years of operation, $15/(12 \text{ years})(8760 \text{ hours/year}) = 1.4\text{E-}04/\text{unit-hour}$. It should be noted that this is a single unit failure rate value; the stack gases were always monitored by an independent, redundant unit in case of a failure in the primary unit. Therefore, the functional availability of stack monitoring by these redundant units was 100% in the time period studied. Grigsby reported an overall failure rate value of $1.1\text{E-}04/\text{unit-hour}$ for a set of forty continuous air monitors used as stack gas monitors over a study period of about two years. Grigsby's result is in good agreement with the INL cursory value for longer-term operation of one stack monitor. These two values set a representative “all modes” order-of-magnitude failure rate value for stack monitors of $1\text{E-}04/\text{unit-hour}$. The INL data also recorded false or spurious alarms. There were 71 spurious alarms over the twelve-year period, or roughly one alarm event every other month as an average. There were no INL events of the stack monitor failing to alarm when required by airborne activity. There have been too few events of high airborne activity challenging the INL stack monitors, so any statistical estimate of failure to alarm on demand is not meaningful.

Considering repair, Lingren [9] pointed out that maintenance and repair tend to be costly for stack monitors, and that wide-range stack monitors that can meet regulatory requirements for measuring stack gas radioactivity in normal and accident conditions are complex units. Grigsby [8] gave a quantitative mean time to repair (MTTR) value for stack monitor CAMs of 43.5 hours. Table II gives some routine maintenance and repair time estimates. At the INL, the average stack monitor repair time with spare parts on hand was 17.5 hours; without spare parts on hand, the average was 160 hours, meaning parts procurement time increases the equipment downtime. Calculating the overall MTTR from INL data gives 49.1 hours, which is only 13% from Grigsby's value. This result is a good comparison when one considers the variability often seen in maintainability data values.

TABLE I. Stack monitor data from DOE events reported in ORPS.

Fault Category	Subcomponent and fault or error	Monitor Alarmed the Fault	Monitor Did Not Alarm
Electrical			
Electronic noise	Electromagnetic noise interference	40	1
Electronic components	Capacitor, diode, or resistor failure to operate	5	2
Electronic components	Electronic module problem	6	2
Electronic components	Alarm set point drift	4	3
Electrical components	Wiring, fuse problem, or relay fault	6	7
Electrical components	Unknown problem	1	2
Electrical power	Monitor inadvertently de-energized by mechanical or electrical fault	12	1
	Totals	74	18
Radiation Instrumentation			
Exterior instrument part	Chart erratic readings	3	5
Exterior instrument part	Chart paper problem	0	2
Exterior instrument part	Check source problem	4	2
Internal instrument part	Detector tube mylar film torn or damaged	1	4
Internal instrument part	Detector tube amplifier failure	0	5
Internal instrument part	Detector tube (GM or PM) failure or degradation	17	5
Internal instrument part	Meter faults, internal switches or indicator needles sticking	3	3
Internal instrument part	Unknown broken part required repair	1	0
	Totals	29	26
Human Error			
Monitor worker	Power wiring connected incorrectly	0	2
Non monitor worker	Inadvertently de-energized monitor power	6	3
Monitor worker	Calibration setting performed incorrectly	1	12
Monitor worker	Calibration not performed within scheduled time	0	2
Monitor worker	Calibration source check problem	0	2
Monitor worker	Physical interference; monitor bumped/moved incorrectly	3	1
Monitor worker	Physical interference; monitor door ajar, air valve mispositioned	5	5
Monitor worker	New, stronger vacuum cleaner allowed extra source movement	0	1
Monitor worker	Chart paper left empty or filled incorrectly	1	4
Monitor worker	Water reservoir not filled according to procedure	1	0
Monitor worker	Newly installed air conditioner caused condensation buildup	1	0
Monitor worker	Insufficient thermal insulation used, monitor air line iced up	0	1
	Totals	18	33
Mechanical			
Mechanical part	Unknown mechanical parts, age, end of life failures	3	4
Mechanical part	Air filter, bypassed or clogged	1	4
Mechanical part	Pressure transmitter failed	5	1
Mechanical part	Mechanical parts - fittings, belt failures	2	1
Mechanical part	Air sample line vacuum pump failure	11	8
	Totals	22	18
Environmental			
Facility environment	Environmental fault-condensation or other	0	2
Facility environment	Chiller shut down interference	3	0
Facility environment	Foreign Material Intrusion; insects, dirt	3	1
External environment	Weather related - Lightning strike	4	0
External environment	Weather related - Rain/Water intrusion	3	0
External environment	Weather related - High wind at stack	1	0
External environment	Weather related - Ambient temperature too high or too low	7	1
	Totals	21	4
Results: electrical = 92/263; instrumentation = 55/263; human errors = 51/263; mechanical = 40/263; environmental = 25/263			

TABLE II. Maintenance and repair times for stack monitors.

Activity	Average time (hours)	Data source
Technician calibrates one of the SPING monitor channels	0.25	INL data
Technician performs SPING monitor routine air filter change	0.25	INL data
Technician calibrates a SPING monitor instrumentation logic channel to the facility control room	2.3	INL data
Technician replaces a SPING monitor GM tube	2.0	INL data
Technician replaces a stack monitor photomultiplier tube	2.25	[7] ^a
Technician replaces a failed power supply in a stack monitor	2.5	[7] ^a
Technician troubleshoots a stack air chiller, resets and restarts chiller unit	0.5	[7] ^a
SPING monitor general repairs with spare parts on hand	17.5	INL data
SPING monitor general repairs without spare parts on hand, requires ordering parts from a monitor vendor	160	INL data
SPING monitor overall mean time to repair	49.1	INL data
CAM stack monitor mean time to repair	43.5	[8]
Note a: A few ORPS reports gave repair times; these times are presented here. General notes: One technician performed these activities. The repair times were measured from the equipment being taken off-line for repair until the equipment was returned to service.		

IV. CONCLUSIONS

The stack monitor experiences show that the highest percentage of failures is in power interference and in electronic noise, followed by radiation instrument faults, human errors, then failures in the mechanical portion of these monitors and environmental conditions that affect the monitors. The current approach in the US DOE Complex is to have a redundant unit to provide continuous monitoring while a faulted unit is being repaired. Daily, or more frequent, operability checks and weekly functional tests are warranted because continuously operating stack monitors, with their issues of drawing air and keeping power supplied to the unit, need frequent checks to verify proper operation. As noted in Table I, these faults are not always annunciated as trouble alarms by the monitor unit; so daily visits keep the units available to perform their tasks. Daily visits and perhaps checkup visits each during 8-hour shift are a best practice for stack monitor operability.

The literature search for stack monitor failure rates to compare to these data yielded only one valuable result. Assessing the “all modes” failure rates from the literature and INL data gave a representative, order-of-magnitude failure rate of 1E-04/unit-hour. This value is reasonable to apply to stack monitor units if no component-specific, site-specific, or otherwise better data sets are available.

The failure modes, rates and repair times are useful for facility operations to assure that stack monitors are designed to operate well by negating failure modes, and by providing a redundant unit. The repair time data for these monitors can be used to estimate the number of radiological control technicians needed to support the stack monitors for routine work and repair work.

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