

FIRE SAFETY

Evaluation of Personal Alarm Devices for Firefighters

John Sharry and Robert A. da Roza

Although three of the models of the personal alarm devices (PAD) tested had received letters of acceptability and compliance from the State of California/Occupational Safety and Health Administration (Cal/OSHA), we found that none of the models met all of the Cal/OSHA specifications. Additional tests showed other deficiencies in the PADs' design. This points out the need for the purchaser or user of such devices to specify acceptance criteria and perform his own tests.

Introduction

The Standards Board of the State of California/Occupational Safety and Health Administration (Cal/OSHA) recently developed and passed a standard that requires firefighters engaged in interior-structure fires use a personal alarm device, or PAD, with a self-contained breathing apparatus (SCBA). The PADs will summon aid in the event of an emergency involving the firefighter so equipped. The specifications for the PADs are given in the General Industrial Safety Orders from Cal/OSHA (Title 8. General Industry Safety Orders, Article 10.1). Implementation of these orders was originally scheduled for March 31, 1983, but this was extended to September 30, 1983.

The LLNL Fire Department and Hazards Control's Safety Science Group conducted tests of the four available devices to determine the best device to purchase. The tests determined if the devices complied with the specifications given by Cal/OSHA and also if such a device were useful, i.e., that it accomplish its purpose of aiding rescuer firefighters to find another firefighter who is immobilized (Table 1).

Although three of the models tested had received letters of acceptability and compliance from Cal/OSHA, our tests showed that none met all of the Cal/OSHA specifications. Also, we revealed other deficiencies in the PADs by some additional tests to which we subjected the units. Our "water-on-the-speaker" test showed that water collected on the diaphragm speakers prevents sound transmission. The "cold-salt-water" test show how severely some of the units leaked. The "interferring-sounds" test only scratched the surface of this large problem and points out that sound frequency, pulsation rates, and tone changes must be considered as part of a PAD specification. Information gained from a signal-attenuation experiment and a field trial show the need for a louder alarm: the 95 dBA alarm was clearly the more desirable alarm.

Results

At first, we tested four units of each manufacturer's model (Table 2) following the test parameters specified in Table 1. Due to the importance of the water intrusion and 80°C tests, a second group of units was purchased and tested; two units were tested in a special oven and all of them were subjected to sea water.

Table 3 summarizes our results. In addition to a pass/fail result, a notation is included to indicate performance. Weak performance means that the unit was emitting an audible sound, but it was below the specified 85 dBA. A fail notation without indication of weak performance means that the unit did not emit any sound. We describe specific performance results as against the Cal/OSHA specifications in the following section.

Table 1. Specifications required by the Cal/OSHA standard and the tests performed to verify PADs.

Specification(2)(A):

Controls shall be incorporated in alarm devices for manual activation and reset, and shall be protected against accidental deactivation. Such controls shall be designed to be operated by a gloved hand.

Specification (2)(B);

Alarm devices shall contain a motion detector which will activate the alarm if the firefighter is motionless for not less than twenty (20) seconds nor more than forty (40) seconds. The alarm shall also include a pre-warning device to signal the firefighter that the alarm is approaching the point of activation.

Specification (3)(A);

Alarm devices shall emit a signal with a sound pressure level of not less than 85 dba measured at a distance of three (3) meters for not less than one (1) hour using an eighty percent (80%) charged battery. Signal frequency used shall not be less than 2000 Hz nor more than 4000 Hz.

Specification (3)(B);

The alarm shall operate in a temperature range of -10° to 80°C and for a period of two minutes at 140°C.

Specification (3)(C):

Alarm devices shall be designed to withstand damage created by deterioration of the type of battery recommended by the manufacturer for use in such devices.

Specification (3)(D):

Alarm devices shall remain operable after being submerged in sea water for at least one hour at a depth of two meters. Upon examination, the interior shell shall show no signs of water intrusion or corrosion. Effective May 12, 1983, this regulation was amended to remove the second sentence*

Specification(3)(E):

Alarm devices shall be impact and shock resistant, and shall be designed to remain operable after being dropped six (6) successive times from random positions onto a concrete floor from a height of not less than two meters.

Specification (3)(F):

Alarm devices shall not weigh more than 350 grams, including batteries.

Specification (4)(A):

Alarm devices shall be equipped with a visual or audible device to indicate when the battery has been discharged to not less than 80 percent of its rated capacity.

Discussion

Spec. (2)(A) Manual Activation

The switch on the Life Gard Model R-100A, hereafter called Life Gard I, did not always function properly when moved gently to the ON position, but it did when snapped over hard. Manually activating the Securus S-O-S switch in either the ON or Off position is difficult, especially with a gloved hand. It must be pressed very hard and held until the alarm starts. The PAL switch was so tricky and difficult to use that the firefighters using the PAL asked to have it removed from the tests.

Spec. (2)(B) Motionless Activation

All devices signaled correct warnings after the proper period of stillness by the firefighter. However, a common complaint was that the device may sound off while the firefighter was moving. After the first warning sound, a sharp rap is needed to keep it from sending the actual alarm. In the lab, the devices were swung on a pendulum with a two-second period. All devices activated themselves while moving thusly. It would be useful to have an engineering standard for defining motionlessness as applied to PADs.

Table 2. Manufacturer's models tested according to Cal/OSHA specifications.

1. Life Gard Personal Distress Device	Model R-100A
2. Life Gard II Personal Distress Device	Model R-200
3. Securus S-O-S Personal Distress Locator	Model PDL-3
4. PAL	

Table 3. Pass/Fail summary results for the four PADs tested.

Cal/OSHA specification	Life Gard I	Life Gard II	Securus S-O-S	PAL
2(A) Manual activation	switch failed	OK	Hard to use reliably	could not tell position
2(B) Motionless activation	OK	OK	OK	OK
3(A) sound level @ 22°C	2P ^a	3P	4P, 1F ^b	2P, 1F
sound frequency	2P	2P	4P	3P
Battery life	Pass	Pass	Pass	Pass
3(B) Temperature -10°C	1F(W) ^c	3F(W)	1F(W), 3F	3F(W)
80°C	2F(W)	2P, 3F(W)	3F(W), 2F	4F(W)
140°C	1P	1P	1P	1P
3(C) Damage by battery leakage	Fail	Pass	Fail	Pass
3(D) Water intrusion deionized water	2F	2P, 2F	2P, 2F	4F
sea water		10P, 5F	6P, 2F	2P, 4F
3(E) Impact resistance		1P, 2F	2P, 1F	3P
3(F) Weight	Pass	Pass	Pass	Pass
4(A) 80% Battery capacity indicator	No	Yes	No	No

^a P = passed specification.^b F = failed specification.^c W = weaker than specification.

Spec. (3)(A) and (B) Sound Level and
Frequency at Temperature of Use

All measurements were made at three meters. Each device was tested for the performance described in (3)(A) at the three extreme temperatures given in (3)(B) plus room temperature (22°C).

We assumed that the -10°C temperature simulated the cold soaking of a PAD on the outside of a fire truck in cold weather and its subsequent use (automatic mode for the PAD). Therefore, after we checked the PADs' operation, we placed several in a freezer at -10°C for one hour to chill them. Upon removal from the freezer, we checked the manual mode (where the firefighter can signal an alarm on his own) and listened for the sound.

The tests at 22°C were run for over one hour and then the current drain was measured to estimate the remaining lifetime of an 80%-charged battery. The minimum voltage required to obtain an audible signal was also measured.

The upper end of the temperature range over the which a PAD might be used is given as 80°C. The PAD should produce the signal given in (3)(A) for one hour at 80°C. for the test, we turned the switch to its automatic position while at room temperature then set it in an oven preheated to 80°C. The sound level was checked immediately temperature then set it in an oven preheated to 80°C. The sound level was checked immediately and every 15 minutes by opening the oven door. The decrease in sound-pressure level relative to the starting measurement is noted in Table 4.

The U.S. Testing Company, an independent testing agency, had expressed concern that our sound-level measurements with the PADs in an oven might be inaccurate due to reflections from the oven surfaces. We, therefore, designed and built a special oven that could be quickly removed from the PAD whenever a sound measurement was made (Fig. 1). The results from this new test oven agree well with previous results from the old test oven. The two tests run with the new oven are the last entries shown for Life Gard II and Securus SOS at 80°C in Table 4.

The test at 140°C simulated a short period of high temperature to assess possible damage. We placed a room-temperature PAD in an oven preheated to 140°C for two minutes. After removing PAD from the oven, we checked its manual mode of operation.

Table 4 also shows the sound-pressure level at 22°C for several units of each make of PAD. A range is given for each unit because the loudness

Figure 1. Test oven (a) closed and (b) open, showing PAD.

Table 4. Sound-pressure level and frequency response of the PADs tested,

PAD	Signal frequency db @ kHz	sound level at 3 m, dBA slow response				Pulse rate (pulses/s)
		-10°C	22°C	80°C	140°C	
Life Gard I		1P(W)		2F	1P	2.4
	76 @ 2		84-85	-17.5		
	84 @ 4		85-86	-11		
LifeGard II	76 @ 8					
		3P(W)		2P, 3F	1P	2.0
	95 @ 2		94-96	-11.5		
Securus S-O-S	87 @ 4		94-95	-12		
				-4		
				-19		
			94-95	-10		
		3F		5F	1P	1.8
	81 @ 2	1P(W)	84-90	fail, 25min		
	90 @ 4		80-84	-27		
			86-90	-14		
			88-89	fail, 30min		
PAL			85-86	-16		
		3P(W)		4F	1P	1.2
	81 @ 2		84-88	-5		
	88 @ 4		82-84	-12		
	77 @ 8		82-86	-10		
				-5		

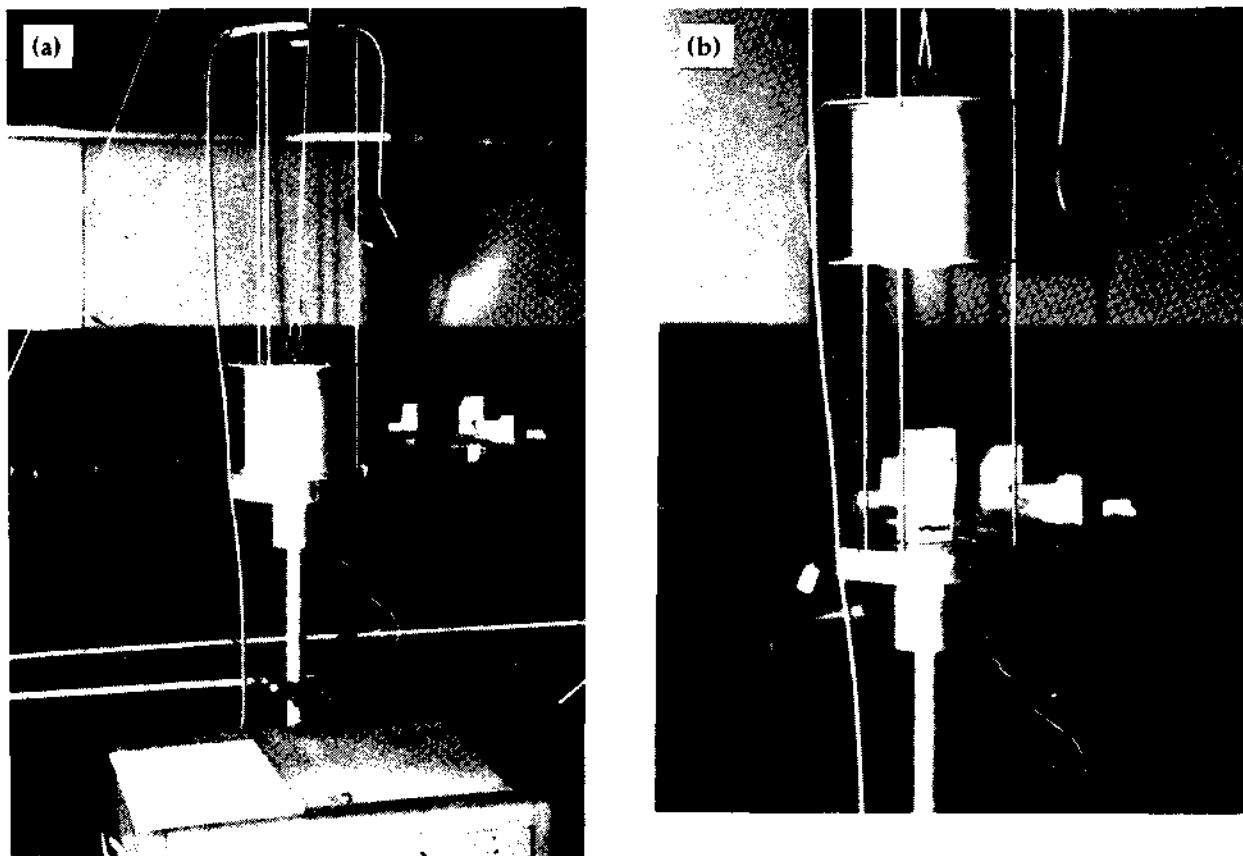


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	76 @ 2		84-85	-17.5		
	84 @ 4		85-86	-11		
Life Gard II	76 @ 8					2.0
		3P(W)		2P, 3F	1P	
	95 @ 2		94-96	-11.5		
	87 @ 4		94-95	-12		
				-4		
Securus S-O-S			94-95	-19		1.8
				-10		
		3F		5F	1P	
	81 @ 2	1P(W)	84-90	fail, 25 min		
	90 @ 4		80-84	-27		
			86-90	-14		
			88-89	fail, 30 min		
PAL			85-86	-16		1.2
		3P(W)		4F	1P	
	81 @ 2		84-88	-5		
	88 @ 4		82-84	-12		
	77 @ 8		82-86	-10		
				-5		

drifted up and down during the two-minute observation. This varying amplitude is in addition to the intentional pulsing of each model. The approximate pulse rate is also given in Table 4. The signal frequencies were measured with an octaband analyzer, so they are rather coarse. Entries of P(W) for the -10°C test meant that the alarm was a little weak--no measurements were taken. An entry off at -10°C meant that no alarm could be heard. The entries of F for the 80°C test meant that the sound pressure level was below 85 dBA at 3 meters at the end of one hour. The negative numbers indicate in decibels how far it was below its sound level at 22°C. Only one unit, a Life Gard II, had a sound level above 85 dBA after one hour at 80°C. Exposing the PADs to a temperature of 140°C for 2 minutes had no noticeable effect. They were just as loud afterwards and suffered no physical damage.

Spec. (3)(C) Damage by Battery Leakage

The Life Gard I has a large opening between the battery compartment and the electronics compartment, measuring 4 by 11 mm. The Securus S-0-S has a long (2.5 by 52 mm) open slot connecting the two compartments, plus a 6 by 15 mm opening at one side. The openings in these two devices are large enough so that any corrosive liquids formed by the battery could damage the electronics. The Life Gard II and PAL have small holes in the compartment divider just large enough for the battery connector wires. Also some sealant is placed where the wires go through the holes. It is unlikely that liquid would go from one compartment to the other.

Spec. (3)(D) Water Intrusion

The first group of devices we tested were submerged under two meters of deionized water for one hour. Upon removal, they were dried externally, checked for operation, then opened to see any water leakage. We did not use sea water on this first batch so we could save units from being severely damaged. A second group of units was tested by the revised Cal/OSHA spec; i.e., sea water was used and only operation of the unit after submergence was checked.

The battery in each unit of the first group had been changed at least once before the water intrusion test. All gaskets and seals were inspected before the test to assure that they were as the manufacturer intended. Even though deionized water was used for this group, about half of these units that leaked never operated properly after being dried out. In the second group of submerged PADs, the cover on the electronics compartment of the Life Gard II was not touched. These were all brand new units. The results of these tests are shown in Table 3.

Spec. (3)(E) Impact Resistance

Three units of each model were drop-tested except the Life Gard I. Only two Life Gard I were available and both were inoperable after the water

submergence test. The speaker diaphragms were dislodged from one of the Life Gard II units on the fourth drop and the sound stopped after the fifth drop of the other unit. The yellow part of the case broke on the second drop of the Securus S-O-S unit; the break was in an unlikely place and was probably due to a rare flaw in the plastic.

Spec. (3)(F) Weight

All devices weighed less than the 350 grams allowed.

Spec (4)(A) 80% Battery Capacity Indicator

For this test, the battery was replaced by a variable voltage dc power supply capable of supplying sufficient current to operate the PAD. Only the Life Gard II gave a clear and accurate indication of when the battery was discharged to 80% of its rated capacity. Its LED flashed brightly until the 80% voltage was reached then it quit flashing. On the Life Gard I, the LED just gradually decreased in brightness until the battery was almost dead. On the PAL originally tested, serial number 4027, the LED noticeably dims too soon. Batteries would be replaced too often. More recent PAL units operate like the Life Gard II. The Securus S-O-S has no LED. Below 80% voltage, it emits a constant tone instead of the pulsing alarm tone to indicate low voltage. However, the sound pressure level is so low that the tone cannot be heard in a moderately noisy environment.

Special Tests

To evaluate the usefulness of the PADs, we also evaluated several additional conditions:

(1) We poured a few milliliters of water on the PAD as it lay with its speaker aimed upward. The Life Gard II and Securus S-O-S units, with vibrating disk speakers, completely stopped producing sound during this test. They recovered as soon as the water was poured off. The two PADs with cone-shaped speakers protected by a thin plastic sheet continued to sound during this test but the sound level was too low to be useful.

(2) The PAD was allowed to float in a tub of water, salt, and ice for one and one-half hours at a temperature of -6°C . This was actually our first attempt to test the PADS at -10°C . None of the PADS worked properly when first removed from this cold bath. When warmed up, the Securus S-O-S worked properly and was dry inside. The other three models had leaked severely resulting in corroded electronics. Even after washing in deionized water and drying thoroughly, none recovered.

(3) A firefighter might encounter noises that would mask the alarm of the PAD or that might sound the same as or similar to a PAD alarm. These two situations could hamper the rescue of an immobile firefighter. In a residential fire, it is very likely that a residential-type smoke detector would be sounding continuously during a fire (the national standards on residential smoke detectors are ANSI/UL 217-1979 and ANSI/NFPA 74). The specification for the sound-pressure level is 85 dBA at 10 feet with no mention of sound frequency. We measured the sound-pressure level and frequency on seven residential smoke detectors. Most smoke-detector alarms were louder than the standard and the sound is almost all in the 2000 and 4000 Hz frequency range. This is the same frequency range specified for PADS. All gave a continuous signal except the First Alert which had a pulse overlaying a continuous signal. It would be very hard to detect a PAD signal when near any smoke detector, especially a First Alert.

The signal from the Securus S-O-S was attenuated by 11 dBA by an interior stud and plasterboard wall. In a quiet hallway with a background noise level of 58 dBA, this is readily discernable at 10 feet. In a lab with equipment and a operating fume hood, it was barely detectable at 10 feet.

(4) We combined some of these effects in a field trial in a large equipment penthouse that contained several rooms and contained two boilers, several compressors and many blowers. The PAL sound level in the penthouse varied from 72 dBA at the entry door to 91 dBA in a far room. The dividing walls were made of sheet metal and all the doors were open. An alarming PAD was placed somewhere in the penthouse and an alarming smoke detector, Semhart Smoke Alarm, was placed about in the center of the complex of rooms.

A firefighter using an SCBA entered the penthouse and searched for the alarming PAD. The PADS emitting an 85 dBA signal could not be heard until the searcher was past the smoke detector and within about 20 feet of the PAD. The PAD emitting a 95 dBA signal could be heard as soon as the searcher entered the penthouse unless the PAD was in the furthest corner. A firefighter on the outside of the penthouse with the outside doors closed did not hear the alarming PAD.

Specific Unit Faults

Life Gard I

- o The switch failed to operate properly.
- o The sound level was too low at 80°C.
- o It leaked badly and the electronics are not protected from a leaking battery.
- o It has no weak battery **indicator**.
- o This unit is not certified to meet Cal/ OSHA specs.

Life Gard II

- o The sound level at 80°C was too low on one of the five units tested, slightly low on two units and satisfactory on two **units**.
- o Seven of the nineteen units **leaked**.
- o Two out of three units were damaged in the drop test.

Securus S-O-S

- o The switch is hard to use for the manual ON operation.
- o Three out of four units tested would not work at -10°C.
- o At 80°C two units quit alarming after one half hour and the other three were too quiet after one **hour**.
- o Four out of twelve units failed the water intrusion test, and one out of three failed the impact test.

PAL

- o The switch is difficult to use and was disliked during both field testing by the firefighters and lab testing by the **experimenters**.
- o One of three units was a little quiet at 22°C, and all four tested at 80°C were too quiet.
- o The battery drain while alarming is twice that of other models.
- o Eight out of the ten failed the water intrusion test.

Conclusions

It is obvious from our work that a redesign effort is needed on all devices as well as better design and quality control standards established. While the authors agree with NFPA President Robert Grant's call for such devices (See Fire Command, October 1979), the devices currently on the market do not meet the demands of the fire service and the expenditure of funds on such devices would be a waste. Although each fire department that purchases PADs cannot put their devices through all the Cal/OSHA specification tests, they should do the **water-intrusion** test at least and return to the vendor all units that fail. The need for such devices is obvious; however, the devices, to serve a useful purpose, must be reliable, easy to use, and sound an alarm of sufficient loudness to be heard in the firefighting environment.

Our test results have been shared with Cal/ OSHA and the PAD manufacturers. It is expected that the manufacturers will make improvements in their products. The results reported here are on units purchased on the open market between May and October, 1983.

Acknowledgment s

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