Catching up with runaway hot plates☆

In recent years, there have been numerous reports of "runaway hot plates". This is to say, hot plates that heat uncontrollably regardless of the temperature setting or whether the controls are in the off position. Some of these events have resulted in injuries to laboratory personnel and damage to research facilities. Investigations into the cause of several of these events have determined that failure of a non-mechanical switch, a "triac", in the hot plate can result in the circuit failing open, causing uncontrolled heating. The number of events in recent years has led to greater awareness of the issue; however, in spite of this, devices utilizing this technology continue to be sold and used in research laboratories without additional controls to ensure their safety.

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INTRODUCTION

Hot plates are used for many applications in research laboratories and can be standalone devices (i.e., heating only) or can be a combination device that includes stirring functions. The ubiquitous nature of these devices can lead to a casual approach with respect to the hazards that they present. This complacency increases the risk of burn injuries and fires due to contact of skin, combustible materials, or flammable chemicals with hot surfaces. Many of these issues emerge due to human error, poor work practices, and failure to consider these interactions when selecting a hot plate or setting up an experiment. These issues are common and are not discussed in detail in here. However, as a result of events that have damaged facilities at each of the authors' institutions, we have become aware of a more insidious issue associated with the design of hot plates–specifically that these plates can heat spontaneously and/or uncontrollably under certain conditions. In this paper, we detail this problem and the results of our investigations into the extent of this issue and provide recommendations for the prevention of future occurrences.

On April 2nd, 2014 a BLEVE (Boiling Liquid Expanding Vapor Event) and fire destroyed a laboratory chemical hood and caused significant damage to a laboratory at Oak Ridge National Laboratory in Tennessee. Portions of the combination sash were jettisoned across the room, damaging a flammable materials storage cabinet, and the heat of the fire burned a hole into the epoxy surface of the hood. The lab was unattended at the time of the event, and the hood was empty except for a combination hot plate and stirrer (aka stirring hotplate) and a closed 250 mL flask containing hexane. A vacuum pump below the hood was plugged in but turned off as was the heating controller on the hot plate (the stirring controller was in the "On" position). Although initial theories regarding the cause of the fire focused on the vacuum pump, it was later confirmed through forensic analysis that the hot plate had spontaneously and uncontrollably begun heating. An investigation into the reason and mechanism for this phenomenon is noted below.

HOT PLATE DESIGN AND OPERATION

In general, hot plates operate by applying power to a resistive circuit attached to a ceramic plate. The level of heating is controlled by varying the power provided to the resistor. Earlier designs for hot plates included bimetallic switches that controlled the duration of the power delivery cycle or mechanical switches, which directly controlled the amount of power provided to the heating element. More recent designs have incorporated a bidirectional or bilateral triode thyristor, more commonly known as a TRIAC, which is a solid state switching device embedded on a printed circuit board. This

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provides indirect control of the power provided to the heating element. The use of a TRIAC in the hot plate design provides some improvement in safety over the previous designs due to reduced spark risk and potential corrosion of the bimetallic thermostat.[1] TRIACS also have the benefit of being relatively inexpensive to manufacturer in comparison to other technologies.

Following the fire at its own organization, Oak Ridge National Laboratory studied in detail the mechanisms by which hot plates incorporating TRIAC switches operate and how they could fail. In the paragraphs below and Figures 1–4, the electrical schematics for the normal operational and potential failure modes for these devices are outlined.

Mode 1 — Normal Condition (Device Off)

At the start of normal operations, the hot plate is plugged into a receptacle, but the heat control switch is turned off. The microprocessor does not turn on the solid state switching component, and, therefore, no power reaches the hot plate heating element (Figure 3).

Mode 2 — Normal Condition (Device On)

The heat control switch has been turned on. It provides an input to the microprocessor, which in turn sends a control signal to the switching component. The switching component controls the 120-V power to the heating element according to the microprocessor's signal (Figure 4). The temperature feedback loop helps the microprocessor keep the heating element at the desired temperature.

Mode 1 — Failure Condition (Device On)

Unfortunately, a well-known failure mode of the switching component typically used in hot plates is that it fails closed (i.e., as a short circuit). A switching component in this condition will allow current to flow directly to the heating element, no longer responding to the microprocessor's control signal. As a result, the hot plate will heat to its maximum temperature. The temperature feedback loop is of no help in controlling the hot plate temperature. This hot plate has run away (Figure 5).

Figure 1. Infrared thermometer indicating elevated temperature on surface of hot plate while heating controls are in "OFF" position.

Mode 1 — Failure Condition (Device Off)

The heating control switch has been turned off. But, the failed solid state switching component still passes 120-V power to the heating element, permitting the hot plate to stay hot because the microprocessor cannot control the switching component (Figure 6).

EXTENT OF CONDITION

At the time of the Oak Ridge fire, researchers and others at the facility were not aware of the propensity of certain hot plates to heat spontaneously or uncontrollably, nor the mechanism for this failure. Initial communications with other government laboratories indicated that the incident was isolated. However, after a second runaway hot plate was discovered (fortunately before any damage had occurred), efforts were made to determine the extent of this

Figure 2. Damage to hood following BLEVE event.

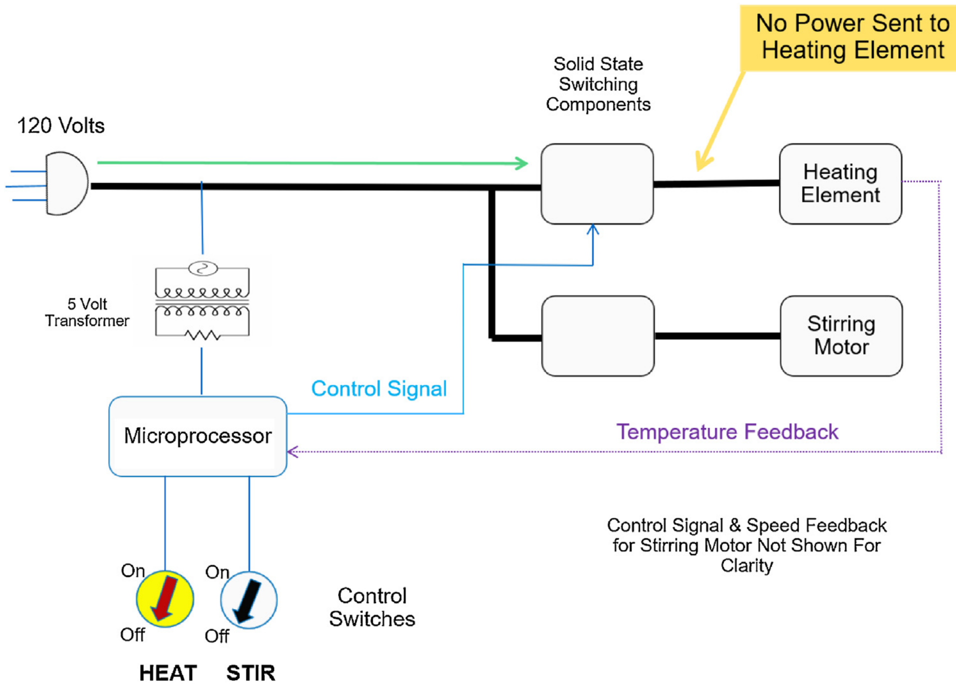

Figure 3. Electrical schematic for hot plate plugged in during normal operations.

condition in order to determine appropriate corrective actions and to communicate this risk to others.

Information regarding the frequency of events involving runaway hot plates was obtained via internet searches of publicly available websites, discussions on the ACS Division of Chemical Health and Safety List-service, and a survey conducted asking safety professionals their experience with his issue. Collectively, these sources revealed that numerous research institutions had experienced incidents involving hot plates over a long period

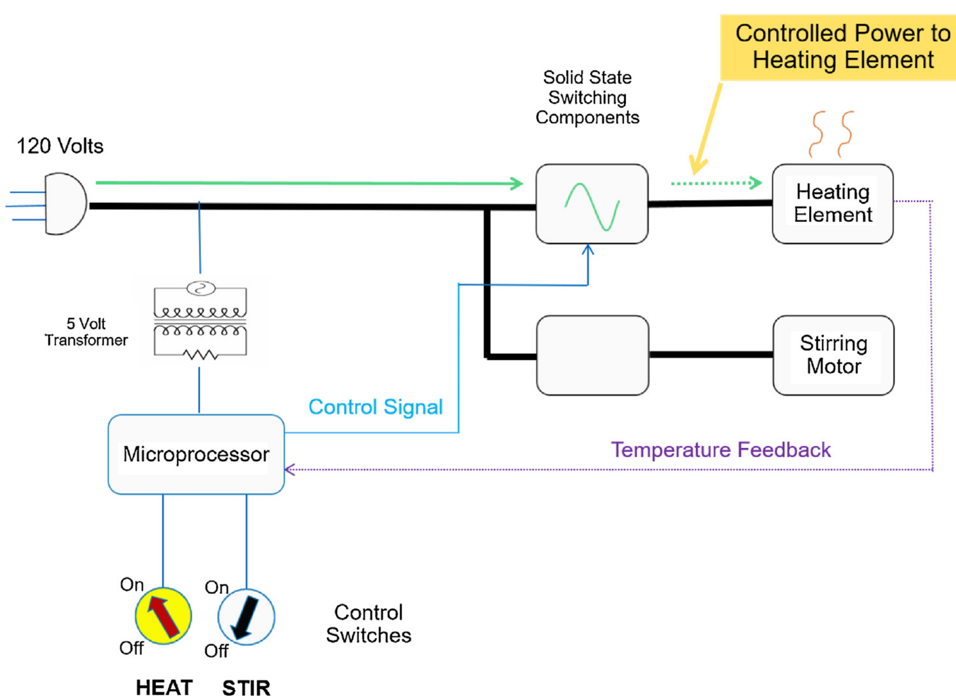

Figure 4. Electrical schematic for hot plate plugged in with power on during normal operations.

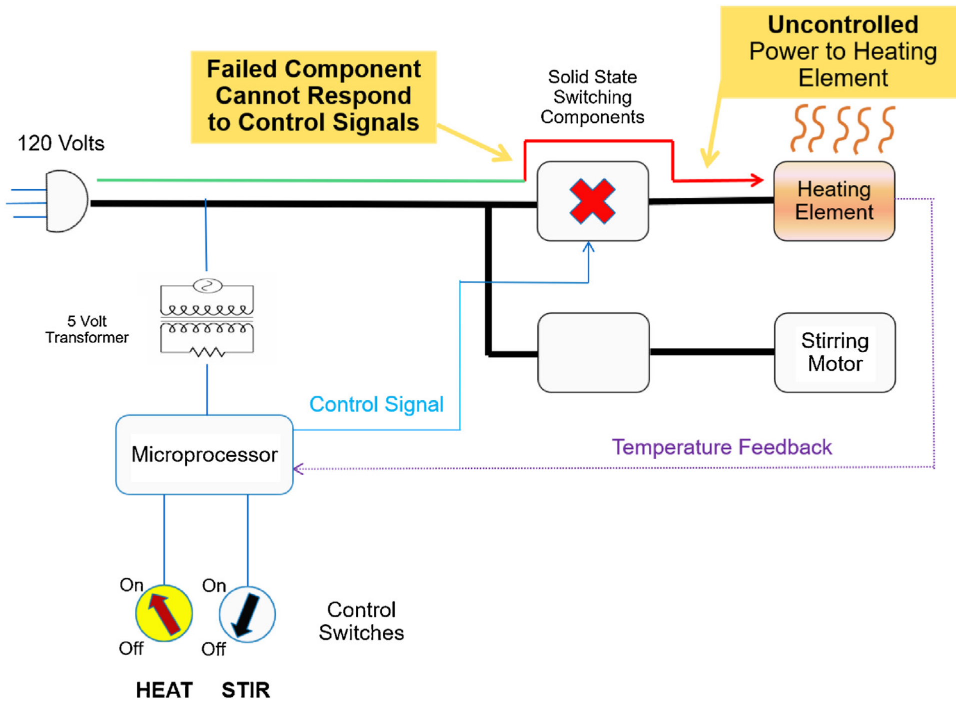

Figure 5. Electrical schematic for hot plate showing effect (uncontrolled heating) of failed solid state switching component.

of time–some with significant damage as a result. A summary of hot plate events that can be found on publicly available websites is shown in Table 1.

Several of the event reports referenced in Table 1 provide detailed analysis of the cause of defective hot plates consistent with that described previously in this article, listings of models susceptible to runaway events, and/or recommendations for prevention of recurrence. Some of these are

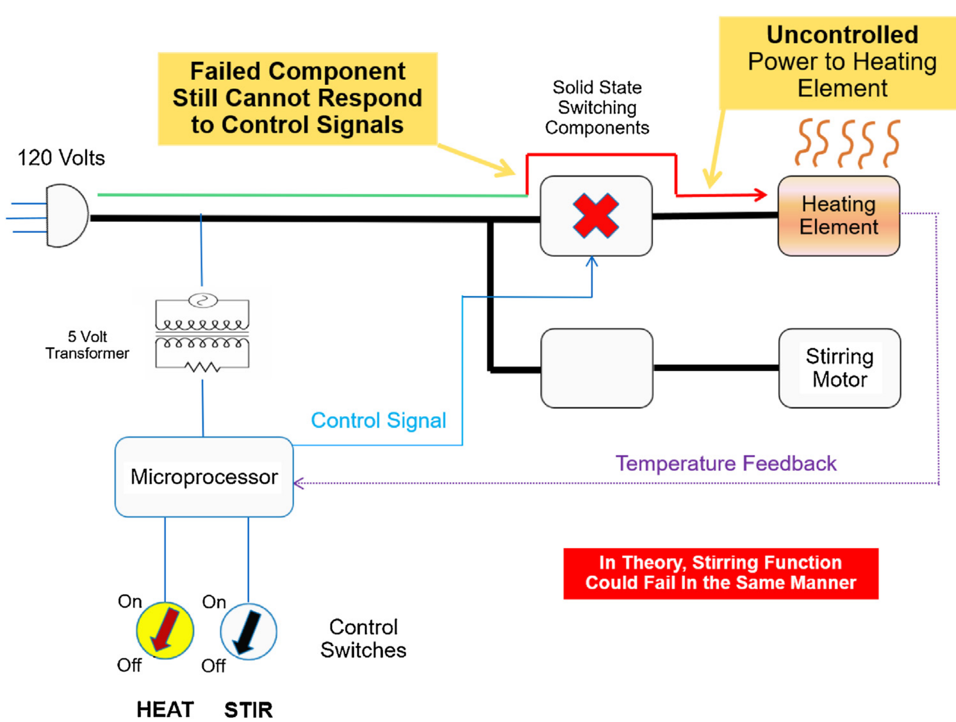

Figure 6. Electrical schematic for hot plate showing effect (spontaneous uncontrolled heating) of failed solid state switching component when heating controls are in off position.

Table 1. Summary of Events Involving Hot Plate Described on Publicly Available Websites.

Institution (Date of Report)	Type of Hot Plate Involved	Cause Identified	Damage
Lawrence Berkeley National Laboratory[2] (June 2005)	Corning PC 420	Heating while in off position	Fire in fume hood
University of California, Santa Cruz[3] (April 2007)	Corning PC-420	Heating while in off position	No specifics- cites several "several explosions or fire events involving defective hot plates that resulted in injuries to laboratory employees or damage to laboratories"
Massachusetts Institute of Technology[4] (July 2009, April 2010, February 2011)	Corning PC-35 Corning PC-351	Not specified	"Fires occurred"
University of California, Berkeley Cruz[5] (~June 2011)	Corning PC-400D	Heating while in off position	Discovered prior to adverse impact
University of Pennsylvania[6] (March 2011)	Not Indicated	Heater turned on instead of stirrer	Fire in fume hood
University of Pennsylvania[7] (May 2012)	Not Indicated	Heater left on	Fire in laboratory
Oak Ridge National Laboratory[8] (April 2014)	Fisher Isotemp	Heating while in off position	BLEVE damages hood and laboratory
University of Pennsylvania[9] (July 2014)	Corning PC-320	Heating while in off position	Fire in fume hood
Oak Ridge National Laboratory[10] (January 2015)	Cimerac	Heating while in off position	Discovered prior to adverse impact
University of Pennsylvania[11] (March 2015)	Corning PC-420D	Heating while in off position	
University of Pennsylvania[12] (January 2016)	Corning PC-420D	Uncontrolled (runaway heating)	Small fire
Emory University[13] (March 2016)			Fire – Damage to fume hood
North Dakota State University[14] (December 2017)	Not indicated	Heating while in off position	Large fire – significant damage to laboratory and smoke damage to facility

summarized later in this article. Information of this nature was also obtained from reports on other accessible websites[15] but which did not identify any specific events beyond those listed in Table 1.

In 2017, a survey was conducted by members of the ACS Division of Chemical Health and Safety to solicit additional information concerning hot plate failures and institutional failure prevention practices. This electronic survey was conducted using Google Forms and distributed via email on the ACS Division of Chemical Health and Safety's e-mail list (DCHAS-L[16]) as well as the Campus Safety Health and Emergency Management Association's community pages.[17] The survey was conducted from April 12 through 21, 2017 and 25 individuals responded regarding their knowledge of incidents involving hot plates.

Twenty-one of the respondents to this anonymous survey reported a total of forty events involving hot plates, specifically citing: spontaneous heating (13), runaway/uncontrolled heating (19), or another unspecified malfunction (8). Respondents identified five specific hot plate makes and models involved in these events (see below) and identified equipment ages ranging from over 5 years old (4) to under 5 years (6) with some hot plates of unknown age (3).

Like previous reports, the survey identified several specific hot plate models involved in the various events as shown in Table 2. Information regarding damages incurred as a result of these events was also obtained as part of this survey, however they are not repeated here as the range of impacts (no impact to significant damage) are similar those reported in Table 1.

In the time between the initiation of this project and its publication, several additional events have been brought to the attention of the authors via personal communications or as obtained from news reports. Given the pervasive use of hot plates in research laboratories, the number of events involving faulty hot plates far exceeds the limited number reported herein, and efforts to communicate this risk and prevent recurrence are warranted.

Table 2. Hot Plate Models Involved in Events Identified by Survey Respondents.

Spontaneous Heating Events (Age of Plate in Years)[a]	Runaway-Heating Events (Age of Plate in Years)[a]
• Corning PC 420 D (0.25–5)	• Cimarec H-4954.xx (0.25–5)
• Corning PC 320 (0.25–5)	• Cimarec – two incidents, models not specified (0.25-5)
• Corning – model not specified (0.25-5)	• Corning PC 220 (>5)
• Corning PC 35 (>5)	• Corning PC 420 (3–5)
• Corning PC 351 (>5)	• Corning PC 420 D (<0.25)
• Fisher brand – model not specified (>5)	• Thermo Fisher – model not specified (unknown)
• VWR 7 × 7 with Aluminum Top (0.25–5)	• Commercial hot plate intended for home use (<0.25)
• Thermolyne SP46925 (>5)	
• Not Known/Identified (>5)	

[a] Age of plate after purchase as reported by respondents.

MINIMIZING RISKS ASSOCIATED WITH RUNAWAY HOT PLATES

Approaches have been proposed or promulgated to prevent faulty hot plates. In our research, the approaches identified fall into two categories–elimination of the risk by replacing the susceptible hot plate models with versions that provide greater safety controls, and administratively controlling the risk by instituting policies for the continued use of hot plates susceptible to failure. Elimination is the most effective way to protect workers and facilities from this hazard and is recommended by the authors as the preferred method for addressing this hazard.

ELIMINATE HEATING FUNCTIONALITY

Many of the runaway/uncontrolled heating issues previously noted occurred on dual functionality hot plates that provide both heating and stirring capabilities, some occurring when only stirring was required (i.e., heat control in off position and stir control in the on position). It has been observed that while stirring devices without heating capabilities are often available, hot plates with stirring functionality are often utilized only for stirring out of convenience–to avoid requiring two separate devices for stirring and stirring/heating or to avoid having to switch out the devices between experiments. If only stirring is required, the authors recommend that non-heating plates be used.

ELIMINATION OF THE HAZARD VIA REPLACEMENT WITH INHERENTLY SAFER DESIGNS

Where possible, the most proactive and conservative approach to is to replace units having the failure-prone design with units that have inherently safer designs or alternative heating mechanisms. Use of units with safer design eliminates the risk of runaway heating by inclusion of features such as automatic over-temperature monitoring, on/off controls that are separate from the heating or stirring controls, and/or feedback loops. In addition, some designs reduce the issue of human errors by having lights that indicate when the surfaces are hot or incorporating hermetically sealed heating elements which eliminates an ignition source if used near flammable vapors. Researchers interested in replacing their existing hotplates with safer models, should look for these features when considering replacement equipment.

Some research institutions have implemented voluntary or mandatory hot plate replacement campaigns to remove error prone designs from use. While costly to implement, such programs offer the research organizations assurance that all hot plates in use meet a minimum standard for safety. The implementation of such a campaign will necessarily vary with the organization, however attributes of successful programs have included providing incentives to encourage replacement, obtaining reduced pricing with vendors on preferred models, establishing a vendor or manufacturer lead trade-in program, or a combination of approaches.

We note here that it is still possible to obtain hot plates that have the error-prone TRIAC design (without additional safety controls) so prospective buyers should confirm systems designs and safety features prior to making a purchase.

PREVENTING RUNAWAY HOT PLATES VIA ADMINISTRATIVE PRACTICES

In lieu of a program to eliminate failure prone hot plates, some institutions have opted to implement programs and policies to administratively control the hazard. While such administrative controls are by no means as effective as eliminating risk as engineering controls that eliminate the underlying problem, these may be selected as interim measures until a means to fund and execute a replacement campaign is available. Although this can be accomplished in a variety of ways, common policies include requiring attended operations during heating activities, and unplugging hot plates when not in use. It has been noted that even when an institution has made the effort to replace older hot plates, administrative policies and oversight may still be required to some extent to ensure that runaway prone hot plates do not re-enter use (through personnel moves or acquisition) and that requirements for proper use are disseminated to address issues not associated with equipment design.

Instructions and markings on hot plates listed to the UL 61010 series of standards inform the user to unplug the power cord when the hot plate is not in use. Many organizations remind employees to unplug hot plates when not in use. In many cases, the plug is accessible and can be removed from the supplying receptacle.

Situations frequently arise in which a hot plate's plug is not readily accessible. A typical reason for the power plug to be inaccessible is because the hot plate is inside a glove box, fume hood, or "hot cell" that has been sealed because the materials being studied or processed are particularly hazardous to persons, require a special atmosphere, or for similar reasons. Equipment (such as hot plates), glassware, chemicals, etc., are staged inside the glove box, fume hood or hot cell, and then the box, hood or cell will be sealed by various methods for the duration of the experiment or process. Operation of the hot plate controls is accomplished by utilizing gloves through the wall of a glove box, by remote mechanical manipulators, etc. In some cases, the receptacle supplying the hot plate is accessible after the equipment and materials are loaded in the glove box or fume hood and can be utilized to disable the hot plate remotely. But other times the glove box or fume hood contains materials in a configuration such that the receptacle cannot be reached and other (non-administrative) methods for controlling this hazard should be used.

Installation of a switched receptacle is a considered a good alternative to unplugging a hot plate, and this is encouraged when installing new glove boxes and fume hoods. However, modifying all of the existing glove boxes and fume hoods in use is expensive. In cases where older glove boxes or fume hoods are used to routinely handle radioactive or other hazardous materials, the cost of retrofitting switched receptacles could be prohibitive.

FIXING THE PROBLEM

While unplugging a hot plate when not in use is effective, the control is faulty. This approach was also irrelevant in some of the cases noted in this paper

Hot plates, both combination and heat-only varieties, are an omnipresent piece of equipment in most chemistry laboratories. As an integral part of many research activities, they are used with and near a variety of potentially hazardous materials and environments, and even when functioning normally, can pose a hazard to the researcher if not used properly. Most researchers are aware of these potential hazards. However, we have found that many researchers are unaware that hot plates with certain design features may heat unexpectedly or uncontrollably.

A multi-faceted approach is needed to remedy this issue and address potential issues of hot plates already in use as well as those still being manufactured and sold.

- Research institutions and organizations like the ACS Division of Chemical Health and Safety should improve guidance and awareness regarding the proper selection and safe use of hot plates.
- Responsible manufacturers and distributors should ensure that hot plates available on the market are not susceptible to failure that could create runaway or uncontrolled heating conditions.
- Trade and standards organizations should require that laboratory heating devices have integrated safety features rather than relying on administrative controls to prevent equipment failures and their consequences.

Publicity surrounding events that have caused injuries or significant damage to research facilities has encouraged many organizations to take action on the issue within their own domains. Additional effort is needed to increase awareness of the number of events that have occurred and the details surrounding the event. Actions of the American Chemical Society, the Pistoia Alliance, and University of California Center for Laboratory Safety to develop lessons learned databases to share this information can help with awareness. Researchers are encouraged to share their experiences when adverse events happen to make these awareness programs effective.

While informed institutions and individual researchers can take actions to eliminate or mitigate hazards associated with malfunctioning hot plates in their own laboratories, substantive actions taken by the manufacturers and distributors would have a significantly greater impact on educating the research community and preventing the propagation of failure-prone devices in the marketplace and the availability of devices with inherently safer designs. It is encouraging that many vendors are actively identifying product design features that improve safety, in addition to traditional focus on product specifications and performance. In addition, some vendors and distributors have participated in buyback or hot plate replacement programs.[18]

The actions of responsible vendors and distributors may be adversely affected if the initiatives are not adopted and sustained by the industry as a whole. The development or modification of standards that require safer designs for hot plates could have a significant impact in encouraging this result. To that end, in 2016 a request was made to the UL Standard Technical Panel for Standard 61010 which includes laboratory heating devices (specifically in respect to UL61010-2-010: *UL Standard for Safety Electrical Equipment For Measurement, Control, and Laboratory Use*) to consider adding a requirement to provide hot plates with a mechanical switching device (a switch, a contactor, etc.) that physically disconnects ac power to the heating element when the temperature control switch is turned to the "OFF" position. The issue was considered by the responsible committee in 2017, however no action was taken by the committee as they believed the standard adequately addressed the hazard.

CONCLUSION

In conducting research for this article, we have identified several reports of runaway hot plates, some with significant consequences. The failure of a solid-state "triac" component in some hot plates has been identified as the cause of many of these events. Hot plates based on this design are still in frequent use in research laboratories and can still be purchased through reputable vendors. Hot plates with inherently safer designs are available on the market, and while some organizations have made the effort to systematically replace the failure-prone design with the safer technology, many others remain unaware of the potential issue.

Efforts are being made, through this communication and through the work of organizations such as the ACS Division of Chemical Health and Safety, to increase researchers' awareness of this particular issue and to promulgate recommendations for safe use of heating devices. We note that manufacturers, distributors and standards organizations have the opportunity to have a major positive impact on the collective safety of their customers by eliminating the availability of hot plates susceptible to runaway heating and by supporting product standards that require more reliable safety features.

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