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Insights from a laboratory fire

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Fires are relatively common yet underreported occurrences in chemical laboratories, but their consequences can be devastating. Here we describe our first-hand experience of a savage laboratory fire, highlighting the detrimental effects that it had on the research group and the lessons learned.

Fires are one of the most common types of accidents in chemical laboratories[1], but fortunately responsible practice developed over the history of exploratory chemical research means that they are typically contained or extinguished quickly. Details of more serious laboratory fires are rarer, with very few accounts reported in the media over the last two decades[2–5]. For example, in our own faculty of chemistry at the University of Vienna, we are aware of only three notable fire incidents in almost 55 years, with the last one occurring in 1996.

One of the most common accidents, yet rarely big news? The premise screams of lucky breaks and near misses. Fires that broke out in the 'right' place, at the 'right' time with the right detection and extinguishing technology available. Such incidents are likely not widely reported because of the stigma surrounding laboratory fires and their tendency to expose embarrassing holes in supposedly watertight safety protocols, as well as the repercussions of highlighting responsible parties, all of which prevent chemists from discussing them openly and honestly.

We were unfortunate enough to experience the complete destruction of one of our chemistry laboratories by a fire ignited upon the failure of a laptop's lithium-ion battery. Thankfully, no one was hurt, but it led to ~€1.4-million-worth of equipment and infrastructure losses, hundreds of hours of additional labour, at least 10 months of research delays, the loss of entire projects, and immeasurable stress and pressure on many of our students and staff. Here we provide our account of what happened, and the lessons learned from the event and aftermath.

The fire

The phone rang just after 08:00 on the morning of Saturday 20 February 2021. It was the dean of the faculty of chemistry: "Your lab burned down. Get moving".

The fire had started in the early hours in one of our basement laboratories (K05, see Fig. 1a). The laboratory was fitted with smoke detectors and fire alarms, which went off at 01:42 but were neither noted by the central security service nor configured to be automatically forwarded to the Viennese fire brigade. The fire brigade was alerted at 02:00 by security personnel who smelled smoke during their routine patrol, and although they could not locate the fire, reported it nonetheless. The fire brigade arrived at 02:07. After locating the fire, firefighters broke ceiling-level basement windows from outside the building and extinguished the fire, flooding the laboratory with foam (Fig. 1b) to a height of ~1.2 m.

The fire started inside a cabinet at the rear centre of the tiled laboratory (Fig. 1a). It was localized to the bench area and a table adjacent to the ignition source was also burnt. Two sets of fume cabinets running at either end of the room continuously extracted hot smoke, causing the air extraction system to melt and collapse. The still-operational ventilation system resulted in massive smoke damage in neighbouring laboratories. Subsequent firefighting efforts also caused considerable water damage to everything submerged in the foam, which spread to the adjacent laboratory K04.

A forensic fire and arson investigator identified the ignition source as a battery inside a laptop, which was stored switched off and unplugged in a cabinet underneath a wooden laboratory bench (Box 1). Only two of the original six 18650 cells in the laptop battery pack were found in the ash and the laptop itself was completely thermally converted (Fig. 1c). The laptop was stored in the laboratory because it contained software necessary to operate an analysis instrument but had not been used for at least three years.

The immediate fallout from the fire was a loss of general and specialist equipment, samples, data and workspaces. Overnight, we lost access to five labs, representing ~60% of our laboratory footprint and associated equipment. Laboratory K05 (~15% of footprint) was completely destroyed by the fire and associated water damage caused during firefighting (Fig. 2). All furniture below bench level was swollen and warped beyond recovery. Ventilation, power and some (waste) water infrastructure were destroyed, and windows smashed. Most electrical equipment was damaged beyond repair, a fume cabinet was destroyed, and two others were salvaged after comprehensive professional cleaning and restoration of electronic systems. Hydraulic, pneumatic or mechanical processing equipment were affected to a much lesser degree, generally only requiring the replacement of their control units and hoses. Most hand tools and glassware survived relatively unscathed, requiring only general cleaning (Fig. 3).

Three adjacent laboratories (K03-01, ~40% of footprint) (Fig. 1a) were smoke damaged to varying degrees. K03 houses specialist equipment and was damaged by smoke such that the colour scheme of the laboratory ranged from black to dark yellow. Our general analytical services laboratories (K01/02) were also smoke damaged to a lesser degree because the door separating them from K03 was fortunately closed during the fire. K04 (~5% of footprint), directly adjacent to the burnt-out laboratory but not connected to the joint ventilation system, was subject only to minor water damage caused by firefighting efforts.

The damage and losses associated with the event were significant, but that was just the start: we also had to face the complexity of the investigation, documentation and recovery. Three independent fire investigations by the police, federal government and the insurance company were conducted in the fortnight following the fire. During this time, the laboratories had to remain untouched. In fact, equipment in the smoke-damaged laboratories started to corrode. Delays occurred as the university was understandably unwilling to allocate funding until the cause of the fire was determined and coverage by insurance guaranteed.

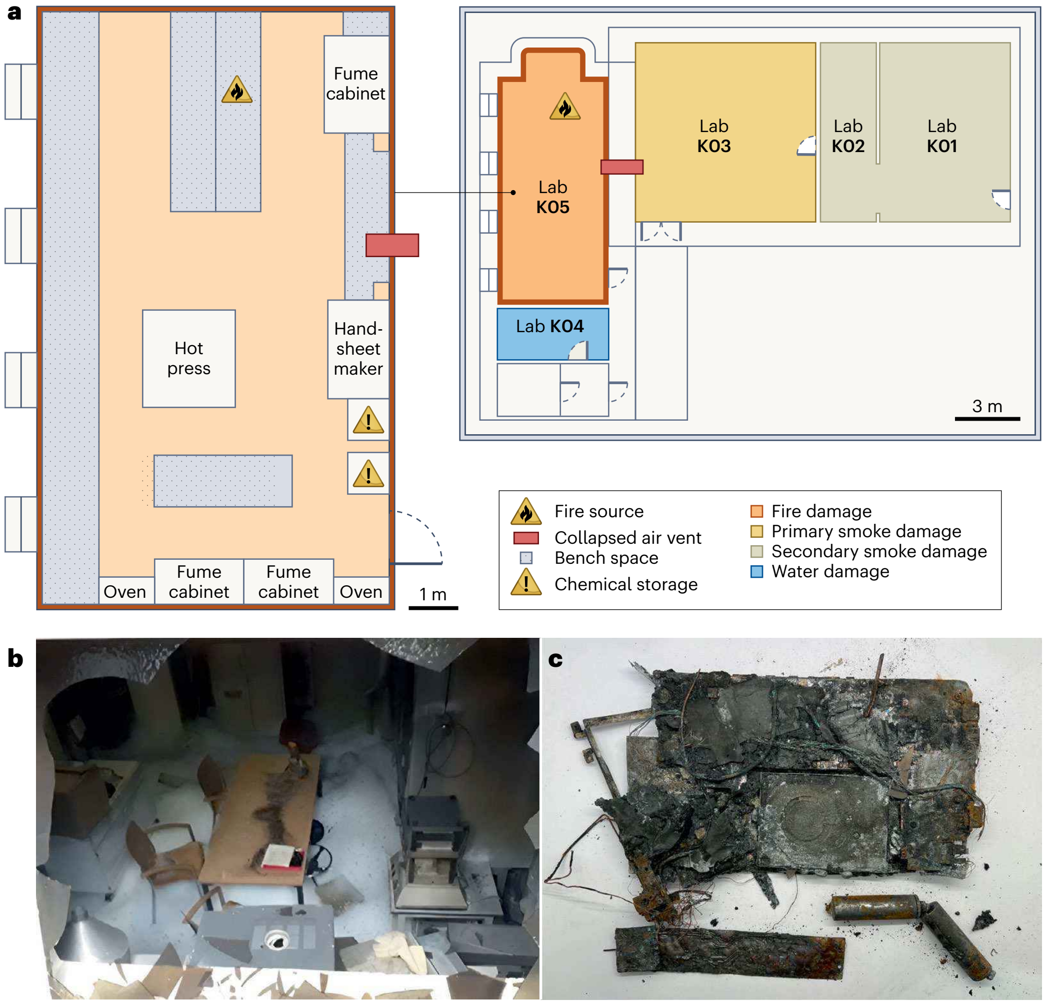

Fig. 1 | Laboratory floorplan and images of the fire aftermath. a, The floorplan shows the location of burnt laboratory K05 (orange) with the point of ignition marked; primary and secondary smoke-damaged laboratories (K03-K01) are marked in yellow and grey, respectively, and water-damaged laboratory K04 in blue. **b**,**c**, The foam-filled laboratory is photographed after firefighting through the broken window (**b**), as well as the remains of the laptop that caused the fire (**c**), later documented during the investigations. Credit: Robert T. Woodward (**a**); Andreas Mautner (**b**); Diana Bratilescu (**c**).

Human impact of the fire and the recovery

Less quantifiable consequences of the fire were the psychological factors associated with it, stress being one, and feelings of guilt another: "Was I responsible?"; "Did I shut down my experiment safely before leaving the laboratory?". 'Negligence', 'criminal liability' and the potential of insurers refusing to pay can be terrifying prospects. The stress was aggravated by the thoughts of interviews and investigations that would follow with the fire brigade, police, insurance agents and university representatives, but much of this stress was in fact unwarranted. The insurers did pay out and the investigations were not confrontational or accusative, but were instead professional, compassionate and supportive.

Only after the last investigator left did the full weight of reality set in. Our prized laboratory was now a useless, smelly, wet, burnt-out shell. We had lost equipment, ongoing and legacy samples, intermediates and written records such as laboratory books. It is one thing to think in terms of lost laboratory and research functionality, but we also suffered less tangible and quantifiable losses in creativity and innovation, competitive edge, funding potential and reputation due to delays in experimental work and publishing our research.

Time that should have been invested in science was now spent rebuilding. We took an inventory of what we thought was salvageable and recovered equipment from the burnt-out laboratory, packaging and shipping some of it to manufacturers for assessment: for five out of eight pieces, this was ultimately a waste of time and money because they were scrapped due to severe fire, heat, smoke and water damage. We got 45 quotes for replacement equipment and 38 for servicing and recalibration. For the major items that we bought, we had to negotiate prices, go through all the admin of ordering, and find space and resources for storage prior to the reopening of the laboratories. We were also faced with an often overlooked, exacerbating factor in the replacement of scientific instruments: what to do when attempting to service or replace equipment produced by companies no longer in business or that had changed ownership multiple times.

Fig. 2 | Photographs taken after the fire. a–d, Burnt-out laboratory K05 (**a**), collapsed air extraction system (**b**), destroyed fume cabinet (**c**) and the level of the firefighting foam indicated against a chemical cabinet (**d**). Credit: Christian Tisch.

BOX 1

Lithium-ion battery failure

Lithium-ion battery failure is rare. When stored under recommended conditions, lithium-ion batteries have an estimated failure rate between 1 in 1 million (ref. 7) and 1 in 40 million (ref. 8). That said, we have all heard stories of electric vehicles and smart phones destroyed by battery fires resulting from manufacturing defects, thermal and electrical mishandling or mechanical damage.

Undesirable exothermic chemical reactions within battery cells lead to thermal runaway, which increases the cell temperature and forms a mixture of flammable gases[9]. Pressure build-up due to gas formation leads to cell rupture, which can result in fire and/or explosion if the released gas mixture ignites, causing considerable property damage and serious risks to health and safety. Even lithium-ion batteries in a 0% state of charge can release considerable heat when ignited. Two charged Lenovo laptop battery packs each containing six cells exhibit an overall energy release of 3,470 kJ (ref. 10), equivalent to the complete combustion of approximately 100 ml of petrol[11].

If you are unlucky enough to encounter such an incident, note that lithium-ion battery fires are 'Class B' fires, meaning that standard 'ABC' fire extinguishers are sufficient to extinguish them. Once the fire is out, the battery should be removed and submerged in water as they can often spontaneously reignite. Approximately 3 l of water was shown to be sufficient for the initial extinguishing of a burning DELL XPS 15 laptop[12].

The burnt lab, K05, had to be cleaned and have essential services restored (power, light, water and ventilation), which only began one month after the fire. The laboratory was then painted, refurbished and reequipped. This resulted in downtime of almost 10 months prior to reopening, during which four Ph.D. students, two master thesis students, and a senior post-doctoral researcher were displaced and unable to perform experimental work in the lab.

Access to the smoke-damaged laboratories was restricted for 2 months while everything, including the ventilation system, was cleaned and restored by a disaster recovery and restoration company. When K01/02 reopened, we could still not access our instruments for an additional 2 months while they were all professionally cleaned, serviced and recalibrated. These closures considerably hindered the research and practical teaching of our entire team, totalling ~30 people. Fortunately, water damaged K04 only required drying and was functional again within a few weeks.

The research that was still possible was conducted under improvised conditions at reallocated workspaces in other laboratories and nearby universities. It was made more challenging by the social distancing measures enforced during COVID-19, but in this time of need, the solidarity both within the group and research community must be acknowledged, with offers of help coming from across Europe and as far as British Columbia. Indeed, many group members also suggested that group cohesion had improved, and this encouraging display of comradery was the one silver lining of the whole experience.

Whilst a triumph for the group spirit, the reopening of the laboratories only really represented a return to business as usual. Damage to student and staff progress could not be reversed. Four group members lost samples relevant to ongoing investigations in the fire. Two master students lost their thesis work (one in its entirety and the other almost completely save a few samples). Such a blow severely demoralized the students, heavily delaying the completion of their degrees and the start of their subsequent careers. Affected students described feelings of helplessness and exhibited slower progress in their research compared to prior to the fire.

Economic ramifications

For the cost of a new laptop, or an improved fire warning system, around €1.4-million-worth of damage might have been avoided.

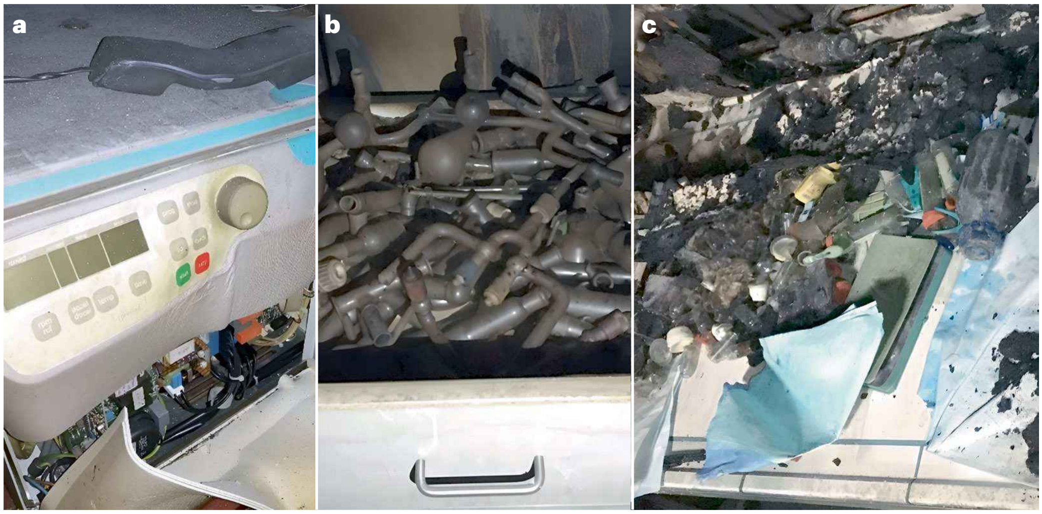

Fig. 3 | Photographs of objects found after the fire. a–c, Centrifuge (**a**), glassware (**b**) and research samples (**c**). Credit: Christian Tisch.

The greatest costs were associated with replacing damaged instruments and equipment (~25%), professional cleaning and laboratory restoration (for example, painting, essential services and similar (~20%)), a single piece of specialized equipment (a vacuum hot press, ~20%), hazardous waste disposal (~15%) and service and recalibration of equipment (~10%). Minor costs were associated with replacing laboratory furniture (~5%), new ventilation systems (~3%) and incidental costs for glassware, reinstallation of alarm systems, emergency lighting and similar.

Less obvious costs incurred during the restoration of the laboratories included the human resource costs associated with putting the laboratory back together — as a conservative estimate this represented around 1,000 working hours distributed across eleven staff, amounting to an additional €50,000 in labour not covered by insurance.

Silver linings

Obviously, there was a lot of bad that arose from the events surrounding the fire, however, there were also some benefits. We now possess a brand new fully furnished and equipped (to pre-fire specification) laboratory and are ready to take any future research challenge head on. The fire, whilst devastating, especially in terms of research time lost, can also be seen as an opportunity to update old equipment, service and recalibrate everything, and start from scratch.

The reconstruction effort was simplified by the consolidation of the rebuild project with a single contractor, whilst the insurance company and university provided necessary resources. When refurbishing a laboratory, one must accept its history (our laboratory is over 100 years old): its floorplan, its existing infrastructure, its quirks and weaknesses. One often inherits existing equipment and adopts associated laboratory protocols. Rebuilding provides the opportunity to address these weaknesses, enabling us to generate a more logical and practical layout, use space better and refine our protocols.

Although severely hindered, progress did not cease as evidenced by the graduation of six PhD students and the completion of a habilitation since the fire. Starting afresh is also a perfect opportunity to rethink and prioritize (hopefully) more fruitful research avenues.

Lessons learned and opportunities for fire education

Our fire yielded some stark conclusions that might not have otherwise been obvious, and can serve as learning opportunities for the scientific community. There are several things that we did do well, such as chemical storage in dedicated ventilated cabinets, whose safety systems worked. We also ensured that we never stored self-igniting chemicals in the laboratory, kept the laboratory clean, had all electrical devices and essential services regularly checked and maintained, and strictly adhered to appropriate waste management protocols, meaning that minimal chemical waste was present in the laboratory at the time of the fire. It was for these reasons that our laboratory fire did not become a chemical fire or cause explosions. Our fire, thankfully, never really had the potential to result in loss of life or health issues for our students or staff.

In hindsight, however, there are things that could have been done better. Starting with those that are outside the control of most laboratory users: fire alarm systems, security patrols and protocols, and the interface with the fire brigade, which are typically managed at a university or corporate level. In our case, the failure of a triggered alarm to rouse attention coupled with poor communication between security personnel and the fire brigade exacerbated the scale of the fire damage. The fire burned for 25 minutes from the triggering of the alarm despite a 7-minute response time from the fire brigade. Had the fire alarm been directly interfaced with the fire brigade, the scale of the damage could have been considerably reduced.

Of the things that were in our control, we would obviously advise not to store disused laptops or devices containing lithium-ion batteries in laboratories — if they must be, then batteries should be removed and safely disposed of. The laptop can still be used with mains power. Since most fires are caused by electrical defects, also regularly check relevant infrastructure and devices.

As a matter of good practice, all combustible material, be it paper towels, boxes or legacy samples, should be minimized and, where possible, stored in a separate designated storage room or archive. Unnecessary storage space in functioning laboratories, which is often misused and cluttered, should be minimized. Safety forms (often requested by the fire brigade), logs such as laboratory books, and experimental data should be digitized, and back-ups kept outside of laboratory spaces. These practices help reduce knowledge loss in case of fire.

We suggest that risk assessments are performed and experimental registration forms are completed, ensuring that laboratory work is carried out with minimal potential risk. Emergency switch locations for electricity, gas and water should be incorporated into staff training in addition to fire discovery, reporting, basic firefighting protocols and, if possible, basic firefighting training.

Keep an up-to-date laboratory and chemical inventory for insurance purposes in case of a serious incident and prevent unnecessary ordering and storage of excess chemicals. Accidents do happen. In the last seven years, we were plagued by two devastating accidents: a flood caused by the overnight (Friday–Saturday) failure of a water fixture in the teaching laboratory above and the fire we discuss here. Never dismiss these possibilities as unlikely and be prepared for them in case they occur. We have always been vigilant and maintained best practice in our labs and yet, as demonstrated, these measures were not sufficient to prevent major incidents and disruptions from occurring.

One thing that became apparent in the aftermath of the fire was how few resources and reference materials exist to assist those affected by such incidents, and how this slows recovery efforts. Discussions on laboratory safety are rife[6], yet primarily focused on prevention. Those unlucky enough to face a major incident are often unprepared and have nowhere to turn for guidance. To the best of our knowledge, literature dealing with laboratory fires that detail associated fiscal costs, human impact and the detrimental effect on research output do not exist. Laboratory fires are an important and devastating topic, and this dearth of relevant literature needs to be addressed. Similarly, it was a difficult period for all involved, and mental health resources were not made available to assist affected staff and students.

We hope that our story can inspire others to start a conversation about 'what if', and produce resources on how to deal with and recover from major destructive incidents, which are just as important as other laboratory safety resources.

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Competing interests

The authors declare no competing interests.