File ref. no: FRN17/1811-003
Doc. ref. no: D19/63139
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4 November 2019

FRNSW Response to Peer Review of FRNSW Smoke Alarm Studies prepared by Dr Vytenis Babrauskas (dated 28 January 2019 and received 20 June 2019) and amended version (dated and received 30 October 2019)

We thank Dr Babrauskas for taking the time to review the work conducted by Fire and Rescue NSW (FRNSW) on smoke alarm performance in 'real-world' fire scenarios. We also thank our valued research partners that have contributed to FRNSW's research and this response.

FRNSW's work is ongoing, so we value the advice and suggestions from respected experts in the field such as Dr Babrauskas to help FRNSW improve our methods and identify any gaps that need to be addressed.

We agree that FRNSW's research has limitations. We have not claimed to have exhaustively addressed all the issues and found all the answers; rather, the toxic tenability aspects of smoke alarm performance are one area FRNSW feels is important to share with the research community to help improve the current effectiveness of smoke alarms in real-world fires.

FRNSW reiterates our view that smoke alarms need to evolve beyond current technologies, since no single current technology was found to be significantly better performing than others in all real-world fire scenarios. FRNSW will continue to work with its research and industry partners to review new technologies and update standards to improve performance. Protection of human life will be greatly improved by all homes having interconnected, working smoke alarms in every bedroom, hallway and living space, providing the best warning for home occupants.

There are aspects of Dr Babrauskas's review that FRNSW believes are pertinent to address:

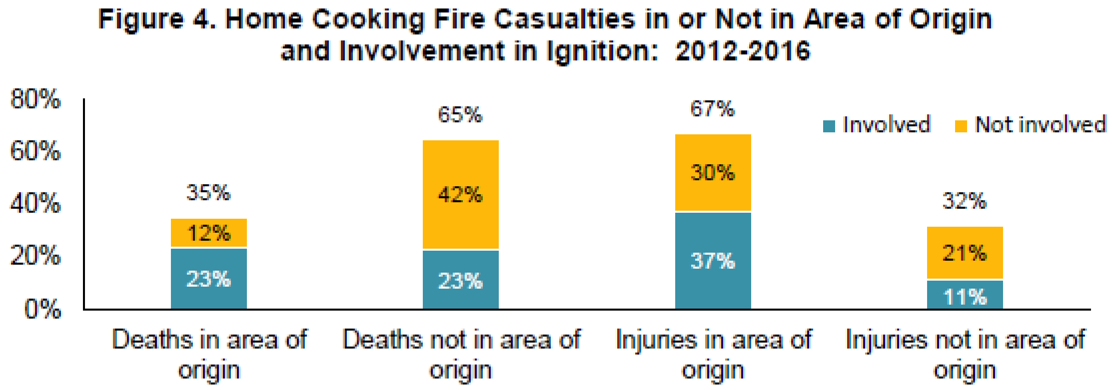
Background

- We note Dr Babrauskas's concern that "*A loud, noisy warning to an individual who is already aware of a hazard is an impediment*"; however, the risks posed by a home fire mean that the need for a warning appliance is acute in all circumstances.
- FRNSW agrees it is most important that smoke alarms alert occupants when they are asleep or not aware. Being awake and aware of the fire means faster action can be taken, sometimes before the smoke alarm sounds. Questions posed by our research were whether smoke alarms activated, and the occupant's potential level of incapacitation at the time they did.

- We note Dr Babrauskas's view that importance should be placed on "*what kinds of fires are more likely to benefit from a smoke alarm warning".* This was not the question FRNSW's research was posing, as our view remains that smoke alarms need to benefit occupants in ALL fires to help reduce loss and minimise risk. Toxic combustion gases are a direct risk to humans, but so is the fire, which is also a clear threat to property damage.
- FRNSW's 'real-world' fire research and the research of others (including UL) provides evidence that a fire in a room with modern furniture and furnishings can reach flashover and be untenable for human life within 2-4 minutes. This was not the case in 1963 (56 years ago) or in 1980 (39 years ago), when synthetic materials of higher flammability were less prevalent in homes. The focus on smouldering vs fast flaming fires is questionable as the time now taken for a fire to develop to the flaming stage is typically much, much less than it was in 1963.
- We note that Dr Babrauskas's provision of Ahrens's statistics on 'Major Causes of Home Structure Fire Deaths and Injuries 2007-2011' demonstrates that death and injury (and accompanying property damage) originates from numerous ignition sources. This supports FRNSW's approach of reviewing smoke alarm performance across a broad range of real-world fire scenarios.

<u>Smouldering vs flaming fires</u>

- FRNSW disagrees with Dr Babrauskas's opinion that *"It is entirely inappropriate to propose a smoke alarm strategy where warnings for smoldering and for flaming fires are valued equally. Instead, it is crucial to focus on obtaining an optimal warning for smoldering fires."* We do not claim that the incidence of flaming start vs smouldering start fires is equal or not equal, these figures are not directly available to us as fires are often devoid of a clearly identifiable smouldering stage after the fact. Additionally, depending on the length of time and amount of smoke produced during the smouldering stage, the air flow and ventilation conditions, and the distance from the nearest smoke alarm, the likely stage of development of a fire at which any smoke alarm or detector might be able to detect it is highly variable.
- Dr Babrauskas has used a raft of questionable assumptions and assertions in utilising various NFPA report statistics to deduce that "*of fires where smoke alarms can be viewed as germane, smoldering fire deaths comprise… 78%*."
- Dr Babrauskas attributes all fire deaths where the identified causes were due to "*heating equipment, electrical distribution, and smoking materials",* to have started from smouldering, drawing from a 2014 NFPA report (Ahrens, M. 2014. "*Characteristics of Home Fire Victims"*, National Fire Protection Association, Quincy, MA) to account for 54% of fire fatalities. Of the remaining 46%, which comprises of candles (4%), playing with heat source (3%), intentional (13%), cooking equipment (16%), and an unknown cause (10%), Dr Babrauskas omitted intentional fires and those in which the victim was "intimate with fire", and concluded that 15% of fatal fires are due to flaming sources. He states that for fatal fires involving cooking equipment "*about 50% are victims who were intimate with the fire, and these individuals cannot be protected by safety measures*", citing the 2018 NFPA report (Ahrens, M. 2018. *"Home Cooking Fires",* National Fire Protection Association, Quincy, MA). It is not clear how Dr Babrauskas came to this conclusion as the report indicates (Figure 4, pg. 3) that 35% of victims had died in the area of origin, with only 23% having been involved in the ignition. Our interpretation of this data is these 23% of victims were cooks who were "intimate with the fire", having been aware of it at the time and did not require alerting.



- Even if we ignore the fact that lives can be saved when other occupants are alerted to fires whether they are intentional, or accidental where someone else is "intimate with fire", then Dr Babrauskas's estimations still show that 22% of accidental fire deaths are caused by flaming ignitions. In our opinion, this certainly warrants consideration in any research to improve and optimise the performance of smoke alarms. In our view, smoke alarms must provide adequate warning to occupants for appropriate action in the case of any type of fire at any time of day.
- Fire results in human and economic loss and has many causes. It is therefore entirely appropriate to review smoke alarm performance across a broad range of real-world fire scenarios, as per FRNSW's research.
- We note Dr Babrauskas's advice for FRNSW to collaborate with Standards Australia on improving the standard for smoke alarms. FRNSW continues to collaborate closely with all stakeholders, including the Australian Building Codes Board, Standards Australia, AFAC, UL, CSIRO, Fire Protection Association Australia and key smoke alarm industry representatives to improve the performance of smoke alarms available in Australia.

Sensitivity testing

- Dr Babrauskas argues that the CSIRO test report is "skeletal and basically useless" as it doesn't directly compare the sensitivities of all alarms under one test. CSIRO's role within the wider FRNSW research project was to perform a pre-qualification of the commercial smoke alarm samples intended to be used during real-world, large-scale fire experiments. The project team identified that using off-the-shelf samples may introduce a potential for variability in alarm response behavior to impact overall project outcomes. To mitigate this risk, a series of tests were conducted to ensure that sensitivity of the collected smoke alarm samples selected did not vary unexpectedly in smoke or directional response.
- The test methods selected to pre-qualify the smoke alarm samples were drawn from the most current version of the Australian Standard for residential smoke alarms (AS 3786:2014). The tests selected from AS 3786 are mirrored by both the current International (ISO) and European standards for smoke alarms, ISO 12239 and EN 14604, respectively.
- The tunnel sensitivity test requires that each alarm sample is exposed to a well-controlled source of smoke-like particles under known airflow conditions until it registers an alarm response. The density of the synthetic smoke is continually monitored by instrumentation mounted within the test apparatus. Application of this test would therefore ensure that the later real-world fire test results from the pre-qualified smoke alarms would be comparable.

- To ensure uniformity when mounting in the test building, directional response was also assessed on a sample of each smoke alarm model in accordance with AS 3786:2014. The response of each alarm type was measured when positioned at eight different angles relative to the direction of airflow.
- It is highlighted that the prequalification tests applied by CSIRO were not intended to establish fire sensitivity of the chosen devices, noting that each was a commercially purchased smoke alarm complying with AS 3786. The selected tunnel sensitivity test is performed in a highly-controlled environment, where differences in sensitivity between alarm samples of the same design are considered reliable. CSIRO understands that the results were sufficient to demonstrate that no significant variation between alarm samples of each model was evident, including the identification of one alarm sample which was faulty and in constant alarm state.

Materials and Methods

- We note Dr Babrauskas rightly criticises the lack of dimensions given in the basic room layout. The initial intention was for the report to be read as a follow-on from the Stage 1 report. When the Stage 2 report was released without Stage 1, the detail regarding the missing information was overlooked. The methodology section contains details regarding the burn unit and furnishings, test scenarios, ignition, smoke alarms, instrumentation and analysis methods.
- We also note that Dr Babrauskas states that there is no description of the materials that form the soft goods. Although no analysis of the material content was performed, what was available from the labelling is presented in Appendix A of the report.
- We note Dr Babrauskas's suggestions regarding mass loss and smoke density measurements. We are in fact developing these capabilities in preparation for our Stage 3 work and would value his input in the design of the test program. For completeness, FRNSW will consider including measurements of mass loss in future testing, when appropriate. Smoke obscuration measurements in the next phase of testing will allow direct comparisons to be made of the alternate criteria. The absence of these measurements in previous testing, however, does not in any way invalidate the results and findings.

Surrogates for cigarettes

- We note Dr Babrauskas's opinion regarding the use of a soldering iron as a surrogate for a cigarette. We also note that comparisons between the tests showed very similar results and believe the method can be used to produce a consistent test that is indeed repeatable.
- It should also be noted that Australia now has reduced fire risk cigarettes because of national action led by FRNSW.

Dead zones

- We note Dr Babrauskas's comment that "the report implicitly accepts the Australian Building Codes Board's (ABCB) requirements for the avoidance of 'dead zones'". In reviewing real-world fires, FRNSW determined this was appropriate as it is the current policy/regulatory position in Australia.
- We note that an evaluation of dead zones was not a priority in this research and that further analysis of the data can be conducted if this is an area that needs addressing. FRNSW is keen to undertake further collaborative real-world fire research on the

performance of smoke alarms in dead zones. Anecdotally we did find that dead zone activations were common, but also inconsistent.

Reporting of results

- We note the inconsistency in time units, which was overlooked and will be amended in a revised version of the report.

Tenability analysis

- We note Dr Babrauskas's criticisms regarding the values used in the tenability calculations. These were what were available to FRNSW at the time and we would value his advice in developing the calculations for these and our updated gas libraries for future testing.
- From FRNSW's understanding, the US EPA's AEGL threshold values for acute exposure were appropriate to use for the Fractional Effective Concentration calculations. AEGL-2 was used in our calculations. This is the airborne concentration of a substance above which it is predicted the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape[1].
- The 10-minute threshold was used in our escape impairment FEC calculations, and represents the level below which adverse health effects are not likely to occur for up to 10 minutes of exposure (the initial period in which a person is likely to attempt escape from a fire). AEGL-3 was used in our calculations. This is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening adverse health effects or death[2]. The 30-minute threshold represents the level below which adverse health effects are not likely to occur for up to 30 minutes of exposure, which for the duration of the tests was appropriate. For carbon monoxide, the AEGL-2, 10-minute concentration of 420ppm was used for escape impairment FEC, and the AEGL-3, 30-minute concentration of 600ppm was used for incapacitation. For the fractional effective dose (FED) calculations, COHb of 30% was used.
- The explanation of AEGL used in the calculations applies to all gases. Dr Babrauskas has pointed out CO as an example only. The equations used in the calculations were presented in Stage 1 and were not repeated in Stage 2, which might have been a reason for the misunderstanding. The Stage 2 report was written as a follow-on from Stage 1, rather than a stand-alone report.

Lack of adequate burning

- We note Dr Babrauskas's comments on the small amount of damage resulting from the smouldering fires simulated in the tests. FRNSW agrees that the fires were relatively minor, but notes that they were comparable to the damage caused by cigarettes left to smoulder. We don't believe that the fuel amounts were "trivial" given that the cotton batting was placed on a full-sized bed with bedding materials common to modern households, or a two-seater sofa with cushions, etc. With regards to the comment about people not dying from combustion toxicity, we agree that this may be correct; however,

[1] https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/acute-exposure-guideline-levels-aegls.html
[2] ibid

Unclassified

the aim of the test was to scrutinise the smoke alarms during a smouldering fire scenario.

- FRNSW does not agree with Dr Babrauskas's comment about these fires being nuisance fires that do not result in casualties, as many fires start off as a smouldering fire that either continues or transitions to a flaming fire where people are either injured or killed. Note our test program also included electrical smouldering fires involving appliances and electrical cables. It should be noted that the smouldering fires were left to continue until all alarms had activated and/or the fire had self-extinguished.
- FRNSW's research scenarios focussed on smoke alarm performance based on real-world fires, primarily activation times and occupant tenability at time of activation. The amount of fuel consumed is arguably immaterial to our research as these two measurements do not require the fire to continue to consume any further fuel.

Poor choices in selecting the test scenarios

- We note Dr Babrauskas's opinion regarding the selection of scenarios and the need to focus on those where alarm activation is likely to prevent casualties. FRNSW believes that all fires have the potential to cause injury or death and that smoke alarms need to provide adequate warning for escape in all possible fire scenarios. There was no 'averaging' across the scenarios, as each was presented with their own results. What the research findings showed was that activation times varied across the different types of technology, but all were less than we would expect to allow for safe egress of occupants in the event of a fire.
- FRNSW's Stage 2 research was conducted to address the gaps identified in our Stage 1 testing by Novozhilov *et al*. (2015). We invite Dr Babrauskas to comment on future smoke alarm research planning by FRNSW.

Burning of cotton vs PUR foam

- We note Dr Babrauskas's comments regarding the use of cotton batting in our tests. FRNSW has found that modern furnishings involve a variety of covering and inner materials, including cotton, bamboo, polyester, polyurethane, nylon, and polypropylene. The purpose of this research was to evaluate smoke alarm performance in real-world fires. To ignite flaming fires, a butane lighter was used directly on the soft furnishings to initiate the tests with no cotton batting material. It was found that placing a cigarette or soldering iron directly on the bedding or sofa cover produced very little visible smoke and the base material melted away from the heat source until there was no contact, at which stage the smouldering ceased. The small amount of cotton batting was used in the smouldering tests to produce a sustained smoulder as the cotton continued to smoulder and heat the underlying synthetic material.
- Cotton material has been used in numerous other smoke alarm research projects overseas, including tests by the US National Institute of Standards and Technology (NIST). The independent peer review by Victoria University accepted the use of cotton batting.
- The design of the tests was to replicate real-world fires, and cotton covering on foam padding is very common in residential furniture and furnishings. The testing undertaken by FRNSW used readily available real furniture. As part of its testing, FRNSW did not test any scenario that included cotton batting on bare foam, but rather on covered mattresses, sofas, cushions and upholstered chairs. Consequently, the cotton batting was in addition to the standard covering materials, which were mainly polyester or polypropylene.

Comparison to other studies

- Dr Babrauskas opines that *"the reason for the more credible results from Stage 1 testing is that, for the tests that used PUR foam, tests were run in such a way as to allow a more extensive involvement of the foam. One factor contributing to this was evidently that, in the Stage 1 work, a cotton-batting wrapping was not adopted for use around the ignition source; this meant the fuel load to actually get fire involved more closely resembled what would happen in a real fire (which, for a lethal fire involving PUR foam-padded items, will be dominated by the burning of the PUR foam and not of cotton fabrics)."* In fact, cotton batting sheets were used in the smouldering tests in the Stage 1 research, also reviewed by Dr Babrauskas. This is detailed on page 45 of the report (Engelsman, 2015).
- In Dr Babrauskas's amended response, he has corrected his above statement regarding the Stage 1 testing as follows: "*I believe the reason for the more credible results from Stage 1 testing is that, for the tests that used PUR foam, tests were run in such a way as to allow a more extensive involvement of the foam."* The reasons for the more extensive involvement was the larger amount of heat energy transferred to the cotton batting and furnishings in using the cartridge heater in the Stage 1 tests, compared with that of the soldering iron in Stage 2. The Stage 1 method was criticised by Novozhilov *et al*. (2015) as being excessive compared with that from a burning cigarette. The method used in the Stage 2 testing was designed to provide a similar amount of heat energy to the substrate as a lit cigarette and was observed to result in a very similar amount and pattern of burning under similar conditions.
- FRNSW's research findings align with similar tests undertaken by UL in the development of UL 217 and UL 268 standards. The focus of improvement needs to be on the number, location and interconnection of smoke alarms. Devices should be compliant with a performance standard rather than mandating a specific type of technology over others.

Stage 2 flaming fire tests

- We note Dr Babrauskas's comments regarding the amount of fuel burnt during the flaming fire tests. FRNSW believes that a sufficient amount of fuel was burnt during the tests for activation of all available smoke alarms, which was a criterion for ending tests.

How the experiment design could have been improved

- We note Dr Babrauskas's suggestions on estimating the amount of fuel required to reach tenability limits within a compartment. We disagree that the amount of fuels available were insufficient. The test rooms were furnished as a basic modern home are and fires were allowed to progress until all or most smoke alarms had activated.

Dual-sensor devices

- We note Dr Babrauskas's comments regarding dual-sensor and multi-criteria alarms. The devices used in the testing were current off-the-shelf alarms that met the Australian Standard. The detail on how they were programmed or calibrated is not available to the consumer nor FRNSW.

The Milarcik Study

- We note Dr Babrauskas's criticisms of the Milarcik study. We do not agree that the statistical methods used by Milarcik *et al.* minimises or obscures any findings, but simply provides a means to statistically compare results.

Additional comments regarding Dr Babrauskas's amended response

- In Dr Babrauskas's latest amended response, he has added a Sidebar on fast flaming fires. In this section, he makes comments regarding UL research that relates to faster fire growth rates due to modern furnishings. Dr Babrauskas observes that the fire conditions are exacerbated by what he describes as unhabitable fuel loads arranged in a small room. Dr Babrauskas also argues that living room furniture has not changed since the 1960s and 1970s which also featured polyurethane foam, and that "*the furniture of today has somewhat reduced flammability compared to 1969 furniture, since during the late 1980s, manufacturers started inserting layers of polyester fiber batting beneath the surface upholstery fabric, effectively replacing a portion of the more flammable polyurethane".*

- In the section of his response commenting on "Burning of cotton versus PUR foam", Dr Babrauskas states that since the 1960s or early 1970s, cotton-batting has been replaced by polyester fibre "which does not smolder and thus is not germane to the smoldering process". These comments give rise to questions regarding why Dr Babrauskas has questioned the use of cotton in the smouldering furniture tests (which was to aid the smouldering process), but has not questioned why smouldering PUR testing should be included at all if he considers it not to be a realistic scenario, given the covering materials are "*not germane to the smoldering process*".