New Zealand Code of Practice for retail fireworks - Revision of the noise testing provisions: Experiences and findings

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ABSTRACT

Retail fireworks are sold in New Zealand (NZ) each year for a limited time after testing and approval by a qualified test certifier. In 2013, there were reports that some fireworks were excessively loud. Retail fireworks are regulated under the Hazardous Substances (Fireworks) Regulations 2001 which sets a level of 90 dB for fireworks with a percussive effect. However, as qualified test certifiers are generally not trained in noise measurement and may not understand many of the fundamental difficulties in making accurate noise measurements, they may be incorrectly measuring firework noise. This highlights the need to educate both test certifiers and importers about noise measurement. The NZ Environmental Protection Authority's Approved Code of Practice (COP) sets out requirements for the design, performance and testing of retail fireworks. This paper covers the process of revising the noise testing provisions of the COP, the public consultation process and the development of a new robust testing procedure. Using the new procedure, experimental findings unexpectedly demonstrated that wind effects and frequency-weighting selection have only a small effect on the measured noise levels of the percussive fireworks.

Keywords: fireworks noise measurement, noise descriptors, approved code-of-practice. I-INCE Classification of Subjects Number(s): 69.3, 81.1, 83

1. INTRODUCTION

Controls on the sale of retail fireworks have increased in many Western countries including New Zealand, due to public pressure about the fire risk to properties and harm to children and animals. The effects of loud fireworks on animals in were well documented in the 2003 RSPCA (United Kingdom) report titled "Quite Please - Loud Fireworks frighten animals" (1). In 2013 there were complaints from the public that some fireworks were excessively loud compared to previous years. This and the fact the COP was last revised in 2008, promoted the EPA in early 2014 to look at revising this document. The lead author of this paper was contacted by the EPA and asked to consult on the revision of the noise testing section of the COP. Retail fireworks are sold in New Zealand each year for a limited period after testing and approval by a qualified test certifier. These fireworks are regulated under the Hazardous Substances (Fireworks) Regulations 2001 (2) which sets a level of 90 dB for fireworks with a percussive effect. An 'Approved Code of Practice (HSNOCOP 18) - *Retail Fireworks: Design, Performance, Testing, Storage, Transport, Sale and Use*', was developed by the New Zealand government agency, the Environmental Protection Authority (EPA) specifically to address the design, performance and testing of retail fireworks by approved test certifiers. The current version of the code of practice [COP] (3) includes amendments from the Hazardous Substances (Fireworks) Amendment Regulations 2007 and 2008. The 2008 amendment clarified the intent of a *percussive effect* and specified the permitted noise level of a firework. This paper covers the process that was undertaken to revise the COP noise testing section.

2. REVISING THE CODE OF PRACTICE (COP) NOISE TESTING PROVISIONS

2.1 Review of the Noise Provisions

A review of the current section in the COP concerning noise testing was undertaken. The section

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copies verbatim the text from the Hazardous Substances (Fireworks) Amendment Regulations 2008, which states:

when used produce a percussive effect that—

(i) is not greater than necessary to achieve the visual effect of the fireworks; and

(ii) is a subsidiary effect only; and

when used produce a noise that is not more than 90 dB as measured—

(i) at a horizontal distance of 15 metres from, and at a height of 1 metre above, the location of the firework tested; and

(ii) by a sound measuring device that conforms with type 1 of BS EN 61672–1:2003, Electroacoustics. Sound level meters. Specifications.

This text makes it clear that the percussive effect is secondary only to creating the necessary visual effect. However in stating that the noise level should not exceed 90 dB, no noise descriptor is specified. In order to test the compliance of the fireworks to the noise requirements, the COP states:

(a) not less than 10 fireworks are selected at random from those fireworks of that type within the consignment, and each of the selected fireworks, when tested, complies with that regulation; or

(b) in a case where one of the fireworks selected under paragraph (a) does not comply with 1 or more of the requirements of regulation 11(1)(c), (f), (g), or (h), not less than 10 additional fireworks of the same type are selected at random from the same consignment, and each of the selected fireworks, when tested, complies with regulation 11

The above regulations and clauses are ambiguous and require assumptions to be made about what was the intended noise descriptor to use, and if one could keep selecting 10 additional fireworks to test until there is a pass.

As a practical starting point, it was decided the best approach was to find out from the current test certifiers how they went about applying the COP and making noise measurements. Fireworks test certifiers typically have pyrotechnics qualifications and experience but are not trained in noise measurement.

Both test certifiers followed a pragmatic process and had a good understanding of the basic components that affect noise measurements and the idea that there would be significant variation in noise levels across the fireworks. They used the maximum $L_{Aeq,\ 1s}$ (A-frequency weighted equivalent sound level with a 1-second integration time) as the noise descriptor to compare to the 90 dB limit and measured using a Class 1 logging sound level meter (SLM) with a current certificate from an accredited laboratory. Enquiring about use of field checks with a calibrator, as they typically would spend several days at a time making measurements; it was found that they performed checks at regular intervals. The measurement environment, acceptable weather conditions and in particular, wind effects, were all discussed to find out what was considered acceptable. They said that they measured cross-wind (SLM placed at 90 degrees to the prevailing wind) on the basis that this would minimize wind-transport effects. Another point of interest was whether or not they used any form of averaging of the noise measurements from the ten fireworks randomly selected from a batch. This proved to be a very interesting line of enquiry once it was clear they used an arithmetic average of the measurements as the value to compare to the 90 dB limit. The average was used in conjunction with an upper limit of 93 dB such that no more than two of the ten fireworks under test could have a measurement level in the range 90-93 dB. Also, the second part of the sampling compliance clause of the COP, which allowed a re-test of another random sample of ten fireworks from the batch if one of the fireworks failed any of the four specified sub-sections (which did <u>not</u> include the noise sub-section), was applied if one of the fireworks noise readings exceeded 93 dB. In this situation, the average for compliance was taken over the 20 readings while still keeping the 93 dB upper limit of just two readings from the new sample. This two-stage pragmatic approach seemed reasonable as it avoided the complexity of computing a standard-deviation as would normally be required when applying a statistical quality control approach.

2.2 Drafting the New Noise Testing Provisions

From the discussion with the two test certifiers and influenced by best practice in environmental noise measurement, a two page draft noise testing section was created and the revised after a few points of clarification from the EPA. Where possible everyday language was used and it was structured into six short sections: 1. Equipment; 2. Setup; 3. Basic measurement procedure; 4.

Processing and Interpretation; 5. On-going Monitoring Procedure and 6. Further Technical (4). The aim was to ensure that it was comprehensive and sufficiently detailed to be readily followed. The draft procedure departed in two ways from the practice of the two certifiers. Because of the percussive nature of the fireworks noise, it did not seem sensible to be using the maximum $L_{Aeq,\ 1s}$ descriptor. This is because it is designed to monitoring relatively continuous noise and not the type of impulsive noise produced by percussive fireworks. So the L_{AFmax} (the maximum A-frequency weighted, F-time weighted equivalent sound level) or the integrating meter equivalent (maximum $L_{Aeq,\ 125\ ms}$), was stipulated.

The second departure was to limit the maximum acceptable wind speed to 20 kph to minimize wind-induced noise and wind transport effects. All measurements were to be made with the SLM orientated cross-wind and angled at 30 degrees from vertical. The angle was based on an expected height of the aerial sounds (about 25 metres) at a measurement distance of 15 metres from the ignition point.

A point of contention was the use of averaging of the measurements in order to achieve compliance and an upper limit which in effect amounted to a tolerance. An in-house opinion was sought from the EPA to see if this was an acceptable interpretation of the regulations before moving forward with drafting the text. The opinion was that averaging was acceptable, along with an upper noise limit, so long as only a single retest of an additional sample of 10 fireworks was specified. Suitable text was developed, revised with input from the EPA, and incorporated into the draft revised COP.

2.3 First Field Measurements

While the draft revision of COP went out for public consultation, the first set of field measurements were undertaken to see what the effect the changes to procedure might have. The measurements focused on finding out the effect of SLM microphone angle, wind transport effects (cross-wind and down-wind) and the expected level of wind-induced noise. The only fireworks available at the time were a small sample from selection-box left over from the previous year. The three largest fireworks were selected for testing, all being a 6-shot design that sat on the ground. It was decided early on to record the actual sound of the fireworks to enabled flexible post-measurement analysis. The setup used a Zoom H4n (5) sound recorder configured to record four-channels at 48 ksps and 24 bits resolution, direct to an SD card. The two built-in microphones were used in conjunction with two external class 1 microphones that were calibrated in the field using a standard 94 dB @ 1 kHz calibrator. Figure 1 shows a picture of the setup with one external microphone vertical, the other at 45 degrees and the built-in microphones at 30 degrees and with wind shields in place.

Figure 1 – Recording setup for field measurements

The measurement environment was a large open green space on a clear day but with a strong northerly wind of 40 kph gusting to 55 kph. The wind speed was outside the range specified in the draft revision but it was considered acceptable to evaluate wind effects. The sound recordings were downloaded to a computer and analyzed in Audacity (ref) using a set of custom ‘analyse’ plugins. As expected, the level of wind-induced noise from a cross-wind was high, ranging from 50-65 dB L_{Aeq} with significantly lower down-wind levels, ranging from 42-52 dB L_{Aeq}. Also as expected, there was more wind-induced noise for the vertical microphone orientation compared to both the 45 and 30 degree orientation with the level being about 2.5 dB L_{Aeq} higher. Interestingly there was very little difference in the measured levels for the fireworks sound events between the three microphone orientations. The differences were typically 0.2 dB L_{Aeq}, 0.4 dB L_{AFmax} and 0.9 dB L_{peak} (unweighted peak level) measurements.

Subjectively these test fireworks were not loud so there was an expectation that they would be compliant with the noise testing provisions of revised COP. The ground launching shots (which lasted a mere 5 ms), measured typically 80 dB L_{Aeq}, 85 dB L_{AFmax} and 113 dB L_{peak}. The main aerial sound (which lasted about 600 ms at around 25 metres elevation) typically measured 85 dB L_{Aeq}, 90 dB L_{AFmax} and 111 dB L_{peak}. Over the full run-time of the fireworks (about 13 seconds) the level was 80 dB L_{Aeq} with a maximum $L_{Aeq,\ 1s}$ of 85 dB and L_{AFmax} of 90 dB. As this was a 6-shot firework, and given the stated durations above for the various sound events, only about three seconds of the total run-time contained fireworks noise. Based on this the expected reduction due to averaging with the background noise is around 6 dB L_{Aeq} and this is about what is measured (85 vs. 80 dB).

By having the flexibility to select a particular part of the sound waveform to measure the levels, it became clear that because the sound events were shorter in duration than the standard 1-second logging interval, and the measurement interval would be asynchronous to the sound events, there was going to be significant variation in $L_{Aeq,\ 1s}$ levels. Using a 1-second sliding window, the L_{Aeq} values varied by as much as 6 dB as the window was moved over a sound event. However the L_{AFmax} (and L_{peak}) values were unaffected by this, supporting its choice as a more robust noise descriptor.

2.4 Public Consultation

The industry feedback on the draft revision of the COP was interesting and generally showed a lack of understanding of sound measurement and instrumentation. Two respondents questioned the "*requirement for laboratory calibration and certification every two years since the noise meters that have been factory pre-calibrated and have a calibration certificate from the manufacturer*". They also questioned "*the need for a field calibrator for equipment that is pre-set at point of manufacture. Type 1 meters such as ours have an internal calibration adjustment mechanism facilitating simple field adjustment for 94 dB prior to testing*". They also questioned the "*rationale for pointing the microphone at 30 degrees from the vertical*".

At the industry consultation meeting there were clearly two groups, the major importer supported by their preferred test certifier and a range of small importers supported by their test certifiers and an external noise consultant via a cell phone. The first half of the meeting concerning the noise section of the revised COP and was largely spent educating the people about the common issues of noise measurement outdoors. There were a number of contentious points in the written feedback on the draft revision that were the focus of an at times heated discussion. First up was the use of the L_{AFmax} noise descriptor to which the author explained the rationale behind the choice of the descriptor. Then went on to say that results of recent field measurements had shown that this was a good choice, however because of the limited test set of fireworks, further measurements would be desirable. Both sides offered to supply fireworks for testing and both of the small importers stated that their own testing to the revised COP noise section had shown that most of their current fireworks would fail and this would be financial ruin. They also said with input from their remote external consultant via cell-phone that their fireworks were compliant with the BS-EN standard that used a limit of 120 dB L_{AImax} and this is what should be used in the COP. The author responded that he was surprised by the use of the 'I' or Impulse time-weighing because it had been obsoleted for 15 years or more after research showed the it was a poor indicator of perceived noise level for impulsive sound events (6-7).

The specified allowable wind speed for making measurements was discussed and that it was considered too low for practical reasons as certification occurred in late autumn when wind speeds were typically much higher than 20 kph. The results from the first round of testing had already shown that measurement could be made reliably in wind speeds up to 40 kph and so it was agreed that the revision of the public draft would include this change.

Next up was the issue of the need to record a time-history of the measurements rather than reading directly off the SLM. This discussion largely involved augments of extra cost and time but was it nicely curtailed (and then accepted) when the author asked a question concerning an audit trail. The longest serving test certified answered this by saying he had been audited twice and because he had detailed time-history information for all his testing, he passed the audits.

The last significant issue for discussion concerned the more complicated way in which a pass/fail was to be determined for a batch of fireworks. One of the smaller importers had obtained a legal opinion that clearly indicated that a 90 dB limit for all meant exactly that, no averaging and no upper limits. It was explained that having this more complicated scheme was to their advantage in more fairly allowing for the variation in the fireworks but that we were happy to consider going back to the simpler approach if further fireworks testing supported this.

2.5 Other Fireworks Standards

While waiting for the test fireworks from three suppliers to arrive, the author was able to confirm that in the United Kingdom, 'The Fireworks (Amendment) Regulations 2004' specifically refers to the harmonized BS EN 14035 standard series (8) which is in multiple parts covering specific types of fireworks. The noise limit of 120 dB L_{AImax} for compliance of category 3 (the largest and most powerful fireworks available to consumers) fireworks is unchanged from its predecessor, 'BS 7114: Part 3:1988-Fireworks. Methods of test for fireworks'. However neither standard explicitly states the measurement time, and so is likely to result in different interpretation of the limit. Closer a field in Australia, the Northern Territory Government (the only jurisdiction in Australia where it is legal for members of the public to purchase and use fireworks) choose to use the L_{CFmax} noise descriptor with a limit 100 dB (9). The stated rational was that "*The C type weighting is designed to give a response similar to human perception at higher noise levels*" and that "*The 'Max' measurement type is to give the best measurement that equates to a bystanders perception of the noise level*". It also goes on to state that "*'Peak' noise is not to be used as it is highly affected by wind and deemed to be not as accurately a measurement of human noise perception for fireworks*." Following this rational it would be expected that the L_{CFmax} noise descriptor will be more susceptible to wind-induced noise effects than the L_{AFmax} noise descriptor used in the draft of the revised COP but that the limit would need to be raised from the current 90 dB value to probably 100 dB otherwise many of the currently sold fireworks would not pass.

2.6 Second Field Measurements

First sample of high-power fireworks from one of the small importers arrived. With names like 'Decibel breaker' and 'Devastation' it was clear that these fireworks were probably aiming for a high noise level and this was born out both subjectively and by measurement. This second round of fireworks measurements focused on further quantifying wind effects and the maximum practical measurement wind speed by using a pair of microphones angle at 45 degrees from vertical, one cross-wind and one down-wind at 15 metres from the ignition point. After the first three samples were let-off, the data downloaded for inspection. It was found that there was a significant overload issue above 115 dB L_{peak} and testing was abandoned. Back in the laboratory it was determined that the built-in attenuator in the Zoom H4n recorder could not handle linearly the large signal levels from the external microphones. To resolve this issue in-line -30 dB passive attenuator cables were designed and built and then tested using dual-level calibration at 94 dB and 114 dB @ 1kHz. This clearly showed there were no signs of the nonlinearity and range compression previously experienced in the recordings. The new setup had a theoretical maximum limit of 145 dB L_{peak} and the class-1 microphones were rated to 142 dB.

Testing resumed a few days later with a strong northerly wind of 30 kph gusting to 45 kph. The summarized results for two of the four fireworks are shown in table 1. Unfortunately due to noise complaints from the public and the subsequent arrival of a policeman, the measurement session had to be cut short and a new test venue located. However, the results clearly confirmed that in comparison to the previous fireworks, these fireworks were much louder with the maximum $L_{Aeq,\ 1s}$ reaching 105 dB and the maximum $L_{Cpeak,\ 1s}$ 142 dB. Even the L_{Aeq} for the total run-time of the fireworks (which included substantial quiet time), significantly exceeded the 90 dB limit of the current COP. The difference between the minimum and maximum values (9-10 dB) for each of these noise descriptors for the loudest noise events (the sky-blast) indicates the wide variation between sound levels for each of the six shots from these fireworks and across individual fireworks.

Table 1 – Results of the second field measurements (all values in dB)

	max($L_{Aeq,\ 1s}$)		**max($L_{Cpeak,\ 1s}$)**		**$L_{Aeq,\ run\text{-}time}$**
Fireworks Name	max	min	max	min	
Freakshow Candle	104	95	137	127	96
Decibel Breaker	105	96	142	132	98

The comparison of the measurements between the cross-wind and down-wind microphones showed that wind-induced noise was consistently 2-3 dB L_{Aeq} higher in the cross-wind direction over the range of wind speeds on the day (30-45 kph). Wind transport effects on the measured levels over the wind speed range were fairly small. Down-wind levels were typically less than 3 dB L_{Aeq} higher for the launch shots (that occur at ground level) and less than 2 dB L_{Aeq} higher for the aerial sounds, compared to the cross-wind values.

The effect of frequency weighting on all the measured sound pressures for these fireworks was small, with values reducing by less than 2 dB going from un-weighted to A-frequency weighted. This is because most of the sound energy from the fireworks was in the sky-blasts for which the power spectrum is fairly narrow, peaking at about 600 Hz and then falling at -2 dB/octave below this frequency and -8 dB/octave above this frequency.

2.7 Third Field Measurements

In an effort to avoid the police receiving further complaints in the course of this research, the third field measurements were made at a rifle range just outside an Army camp. The weather conditions on the day were ideal with a clear sky, minimal wind and soft wet ground under foot. Two 01dB Solo class 1 SLMs were set up at right angles to each other at a 15 m radius from the ignition point. They were configured to record a comprehensive suite of noise descriptors at 1-second intervals. Over the course of about 90 minutes, 48 fireworks were discharged, consisting of three duplicates of 16 different (ground launch) types. From the readings and based on the subjective experience on the day, this suite of fireworks were slightly quieter than the ones tested in section 2.6. Mechanical stability issues were identified during this session, with a number of the thin and tall multi-shot radial fireworks falling over and shooting in all directions resulting in some near misses for our assistants. These would certainly not be safe at the recommended 5 m operating distance.

Table 2 – Summary results of the third field measurements (all values in dB)

#	Fireworks Name	Average max($L_{Aeq, 1s}$) (SD)	Average ($L_{Aeq, run\text{-}time}$)	Average max($L_{AFmax, 1s}$) (SD)	Average max($L_{Cpeak, 1s}$)
1	Frantic	84 (1.0)	79	91 (0.1)	122
2	Typhoon	90 (2.4)	85	100 (0.7)	128
3	Diamond Black	94 (0.3)	86	104 (0.4)	131
4	Ricochet	89 (0.4)	85	97 (1.3)	125
5	Charger	90 (0.2)	84	100 (1.7)	128
6	Alpha #1	92 (0.7)	84	101 (0.8)	128
7	Night Rocket	93 (1.8)	88	102 (3.2)	129
8	Bling Bling	87 (1.1)	80	95 (1.0)	123
9	Lazer War	94 (1.2)	88	98 (0.9)	126
10	Aladins Cave	95 (4.4)	87	102 (3.4)	130
11	Patriot #3	89 (0.5)	81	95 (0.3)	125
12	Commando	94 (1.1)	86	102 (1.6)	129
13	Hazard	92 (0.3)	84	101 (0.2)	131
14	Blazer	92 (0.3)	84	101 (0.3)	130
15	Arganaut	93 (0.9)	85	102 (0.9)	132
16	Smash	94 (0.7)	89	103 (0.5)	133

The average values shown in Table 2 were calculated over the three duplicate firework discharges, as measure by the SLM that held a current laboratory certification. Although the second SLM did not hold a current certificate, the difference between the two SLMs readings over all of the measurements, was low at about 1.4 dB. If the max($L_{Aeq, 1s}$) descriptor (column 3 of the table) is considered the key one for compliance, 10 of the 15 fireworks would fail, with 7 of these averaging 3-4 dB about the 90 dB limit. The second set of figures in the brackets for both column 3 and 5 of the table are the standard deviation (SD) of the measurements and give an indication of the variability of the fireworks across the three duplicate discharges.

The max($L_{AFmax, 1s}$) values (column 5) are 8-9 dB higher than the max($L_{Aeq, 1s}$) values and generally have less variability as indicated by the smaller SD values. Although the max($L_{AFmax, 1s}$) descriptor provides a better indication of the loudness of the fireworks, the current limit of 90 dB would have to be raised, possibly to 100 dB to be equivalent to the measured max($L_{Aeq,\ 1s}$) values.

The average L_{Aeq} values over the run-time of the fireworks (first-to-last bang) are shown in column 4 of table 2. While these are all less than 90 dB and typically 5-7 dB lower than the average max($L_{Aeq,\ 1s}$) values due to the effect of including the quiet time between noise events, to get these values required careful editing of the time-histories to mark the start and end time and then calculate the effective level in between, something a certifier is unlikely to do.

Although not included in Table 2, measurements verified that all of these fireworks were compliant with the BS EN 14035 standard noise limit of 120 dB L_{AImax} if it was assumed to be the maximum value over the run-time. There was almost no difference between these values and the alternative interpretation of the descriptor as the max($L_{AImax,\ 1s}$) due to the long decay time of the I-time weighting.

3. CURRENT STATE OF THE COP REVISION

With the noise measurements of the fireworks from all the suppliers completed and additional feedback received from industry on the public draft of the revised COP, a meeting will be arranged with the lead author and the EPA to work through finalizing the noise provisions of the revised COP which will not come into effect until 2015 at the earliest.

4. CONCLUSIONS

This paper highlights some of the difficulties that can result from the interpretation of poorly drafted regulations for noise testing, particularly when the noise testers are not specifically trained in this area. Experimental findings unexpectedly demonstrated that wind effects and frequency-weighting selection have only a small effect on the measured noise levels of the percussive fireworks.

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