Paper 7C

THE AS3959 EXPERIMENT

The Bushfire Management Overlay (BMO) is an amalgamation of two planning instruments. The two original planning instruments WMO and AS3959 were based on distance of the house site from nearest vegetation (Leonard et al 2009). The key features of AS3959 are analysed below, and Paper 7B analyses WMO.

Whereas the WMO process required a formal statement that was in three parts (see Paper 7B), the AS3959 process excludes parts 1 and 2 and implements some of part 3. It simply measures distance to nearest vegetation and calculates BAL accordingly.

- Site assessment process
  - Identify nearest vegetation type within 100m and calculate BAL according to wall of flame in vegetation type
  - No inner and outer zones or requirements for water supply and access

This Paper focuses on the core features of the site assessment process. We firstly outline the core features and then assess them for merit.

CORE FEATURES

The AS3959 narrative

The AS3959 method applies within a Bushfire Prone Area if vegetation is nearby, ie, within 100m of the house site. The vegetation is deemed to be at maximum fuel load so they can calculate a wall of flame with maximum flame height. The actual condition of the vegetation is not relevant for the AS3959 process.

The AS3959 narrative is as follows – a wall of flame advances in any direction through the nearby vegetation as a high intensity fire. The flame stops where the vegetation stops, eg, if the vegetation is 40m from the house site, the wall of flame stops at 40m.

The wall of flame is the only source of danger, and it generates flame contact, radiation and throws embers onto the house. The wall of flame is assumed to be 100m wide and its height is calculated by equations. The surface area of the wall of flame and the separation distance are used to calculate the incident radiation on the house wall. AS3959 protects the house with fire resistant building materials and design, whose resistance increases in proportion to incident radiation.

There are no defendable space specifications, but AS3959 assumes the gap between the wall of flame and the house site is heavily managed, and therefore will stop the wall of flame advancing (Douglas (2011).

Stated aim of AS3959 – 2009

The objective is to "prescribe particular construction standards for buildings to reduce the risk of ignition from a bushfire while the fire front passes". It also aims to reduce vulnerability of the building to bushfire attack, thus protecting the occupants (until the fire front passes) and the building itself.

The original AS3959 of 1991 sought "to improve the performance of buildings subjected primarily to burning debris (= ember attack) and not to radiant heat or direct flame contact". Its construction measures prevented ember entry by minimum gap sizes, prevent ignition on exterior walls where embers accumulate, allow sub floor access to extinguish embers. (Leonard 2009). The source of embers was not specified.

The 1999 update (AS3959-1999) and two amendments (2001 and 2002) added protection measures "to improve their performance when subjected to burning debris, radiant heat or flame contact generated from a bushfire". Four bushfire attack categories were defined, using distance to and type of nearest vegetation within 100m radius, with a rudimentary slope adjustment. The assumption was that risk of ember attack from beyond this distance was relatively low (Leonard, 2009). Specifications for external cladding increased in fire resistance level in proportion to higher radiation from advancing fire front and flame contact from a very close fire front.

The 2009 update (AS3959-2009) defined six categories of bushfire attack level based on calculated incident radiation levels from nearest vegetation. It varied other provisions, but the "CSIRO considers that the Australian Standard 3959-2009 is, on balance, less effective overall than previous versions to address the survival of buildings and the safety of the occupants during bushfires" (Leonard 2009)

Site assessment process to calculate Bushfire Attack Level (BAL)

First, AS3959 identifies the vegetation type (by ecological vegetation classes) within 100m of the house site, and prescribes it with maximum fuel loads (no matter what its actual condition is) and worst case weather conditions (FDI 100).
Next it calculates rate of spread using different equations for different vegetation types.
For forest and woodland, it uses equations derived from McArthur Meter to calculate rate of spread and then flame length.
For shrub and scrub, rate of spread and fuel load calculates Byram's Fireline Intensity and Byram's intensity calculates flame length.
Then, flame length is used to calculate incident radiation at the house site from 100m wide flame front using 100 kW / sq m emission.
Then, using calculated incident radiation, a BAL rating is assigned.
Finally, AS3959 lists the construction requirements for each BAL level.

Specifications for defendable space Not envisaged. AS3959-2009 assumes the gap between vegetation and house site is highly managed, eg, park like environment or well designed garden beds and some trees (Douglas 2011)

AS3959 specifications

- **House construction standard**

The bulk of the AS3959 Standard comprises detailed specifications for the construction design and materials for each BAL exposure.

Protection against ember attack
This paper examines protection against ember attack falls in two indicative categories, entry of embers into a building and ember collection in corners. Entry by embers into building is managed by maximum gap size. Ignition by ember accumulation in corners is done by specifying fire resistant timber or non combustible material, eg, window sill or the base of a wall or base of a door, or decking.

Protection against radiation
This paper examines protection against radiation falls in two indicative categories, heat damage on glass and ignition of wood. Heat damage on glass is managed by glass thickness. Ignition by radiation on a surface is managed by specifying fire resistant timber or non combustible material.

ANALYSIS

Is the AS3959 narrative realistic?

The narrative proposes an image of a house site in the middle of dangerous, high fuel load vegetation, and the wall of flame within it makes a beeline for the house. Whether a wall of flame marches across the landscape depends on wind direction, topography and fuel bed continuity. It assumes the vegetation is close to the house, upwind of the house and the wall of flame is the only source of danger (for flame contact, radiation and embers). This scenario may indeed occur in a few areas.

The more common landscape is a mixture of vegetation patches, dispersed among paddocks with scattered trees. The house site may be among scattered houses or within urban housing clusters. The more common worst-case bushfire scenario in a mixed landscape is multiple leapfrog spot fires, as the Royal Commission evidence (VRBC, 2011) described and as the author personally observed in Black Saturday. In these cases, the fire front does not come close to the house, and embers are the sole threat.

AS3959 narrative is a little confused. It clearly visualises the danger period as "while the fire front passes", which is when heat and embers are at highest intensity. But the only fire front it envisages is the wall of flame in the nearest vegetation patch, which radiates from a set distance. In other words, AS3959 believes the fire front stops at the edge of the vegetation patch, and therefore cannot pass over the house site.

Conclusion: The AS3959 narrative image addresses few of the range of bushfire attack possibilities. It does not address the most common worst-case bushfire scenario. It has an unrealistic view of a bushfire attack.

The concept of BAL

The BAL concept is aimed at preventing piloted ignition by embers during the passage of the fire front. The concept is useful and readily understood by the public, but its derivation mechanism usually results in higher levels than needed. BAL is not based on actual threat from either urban flame or upwind fire front. BAL is based on distance to a vegetation patch which may or may not be a source of the bushfire's threats.

If the vegetation is not a threat, BAL levels are higher than they need to be.

If vegetation is one of the threats, BAL level is calculated on radiation from an artificially inflated flame height. It assumes the vegetation will not be managed by the owner. Again, BAL levels may be higher than they need to be.

On the other hand, if the vegetation / wall of flame is not close, BAL remains low. If there is high risk of intense ember attack, the BAL specifications will probably be lower than needed.

The BAL specifications increase resistance to ignition according to increasing radiation levels. Thus the BAL mechanism is designed for one specific bushfire scenario –the nearest vegetation is the major threat, it carries high fuel load, and it is close to the house. BAL in this case will be high, and assuming BAL specifications are effective, the house should be well protected if at least two other assumptions apply, (1) the wall of flame stops at the edge of the vegetation (ie, there is a fuel free gap) and (2) there is no flammable fuel on, under or near the house. If the assumptions are not met, the BAL mechanism probably fails.

Conclusion: The BAL concept is based on an artificial bushfire scenario, and the resulting building specifications are either higher than needed or are not suitable for the protection needed.

In essence, how does AS3959 believe it will protect the house?

Fire resistant materials and construction design standards protect the house from ignition. The level of resistance increases with increasing incident radiation levels.

Are the AS3959 beliefs meaningful?

The house is protected from ignition only when flammable sites have been eliminated thereon. AS3959 assumes the specifications achieve this. This may be possible on most of the external structure of a new building, but it does not allow for the wear and tear and splits or damage through the years. Nor does it allow for ignition potential of debris adjacent to the building, eg, leaves in gutter, mulch in the garden.

AS3959 assumes fire resistant timber is also ignition resistant. Flammability tests are done in no-wind laboratories, yet severe weather conditions feature very strong hot winds. Research suggests (eg, Babrauskas, 2001) that the impact of air flow plus radiation on a flame is much greater than radiation without wind. The Royal Commission said "it is vital that the testing standards also be reliable predictors of the performance of building components under bushfire conditions. The Commission therefore considers that a review of both testing standards is warranted" (VBRC 2010)

Timber resistance specifications increase only when radiation levels increase, which assumes that the flame front is close. Yet in severe bushfires, the major cause of ignition is embers when the flame front is distant. "The Commission urges that ember protection measures at lower Bushfire Attack Levels also need to be pursued as a priority" (VBRC 2010)

Calculated radiation assumes the flame stops at the edge of vegetation, but no measures are put in place to achieve a fuel free gap.

Conclusion: Beliefs are not meaningful because they rely upon elimination of all ignition sites, on fire resistance tests that are not related to bushfire conditions and on the flame magically stopping at the edge of the nearby vegetation. The AS3959 wall of flame scenario covers few of the range of possible bushfire scenarios.

What fire behaviour changes to vegetation will the building specifications deliver?

None

Will the specifications achieve the AS3959 aim? NO

The specifications may work on the house components they are designed for, provided fire resistance equates to ignition resistance. But because specifications cannot cover all potential ignition sites and all potential bushfire attack scenarios, the AS3959 aims cannot be guaranteed.

Equations used for calculating radiation levels

As done in the Paper 7B, this article now examines the calculation process and equations in detail for two reasons, to understand the thinking behind the calculations and because the equations have been incorporated into the BMO.

Steps

1 Identify the vegetation type by AS3959's ecological vegetation classes within 100m of the house site.

2A For forest and woodland, calculate rate of spread with **R = 0.0012 *FDI*W**,

2B Adjust rate of spread for slope with **Rslope = R X exp (0.069 x slope)**

2C Calculate flame length with Z = **(13 x Rslope + 0.24 x W) / 2**

3A For shrub and scrub, rate of spread **R = 0.023 x wind^1.21 x veg height^0.54**
3B Adjust rate of spread for slope with **Rslope = R X exp (0.069 x slope)**
3C Calculate Byram's Fireline Intensity - **BFI = H x fuel load x Rslope**
3D Calculate flame length with **Lf = 0.0775 x BFI^0.46**

4 Calculate radiation from flame length or height using View Factor equations
AS3959 assumes 100m wide flame front radiating for 2 minutes at 100 kW / sq m
(WMO assumed wide front radiating at 120 kW / sq m).

Calculation process for flame length in the wall of flame in closest vegetation
AS3959 uses a convoluted approach to determine flame height in the nearby vegetation. It begins with calculation of rate of spread and uses a range of formulae to eventually derive flame height. The calculation process essentially estimates flame height from rate of spread. Paper 7B discusses how unreliable and non-scientific this process is because there is no causal link between the two. The AS3959 architects were clearly seeking to arrive at a justifiable peak flame height in an objective way, but, like the WMO, their choice of equations ignores basic scientific principles like design criteria and design purpose, which denies them relevance and validity.

Calculations for forest and woodland
AS3959 uses the Noble et al (1980) equation **Rslope = 0.0012 *FDI*W*exp (0.069 slope)**. As discussed in Paper 7B, the equation is derived from McArthur's chart, which was designed for a tall forest with litter bed and light understorey. McArthur's chart peaks at FDI 100, fuel load 25 t / ha and flame height 14m.

Like WMO, AS3959 uses maximum fine fuel load as an input. Paper 7B points out the scientific invalidity of including dense shrub fuel load in the rate of spread calculation because it extrapolates beyond McArthur's original work. It can be deduced that the W figure used by AS3959 will overestimate rate of spread in forest by 2.5 to 5 times and woodland by 1.5 to 3 times.

Paper 7B also explains how this equation has been disproven since Project Vesta confirmed that rate of spread is independent of fuel load, and that only the top layer of litter bed is consumed when wind pushes the flame. Thus the Noble et al (1980) equation is superseded and now technically invalid and not suitable for use in government policy.

Slope and flame height / length AS3959 uses McArthur's slope adjustment to re-calculate rate of spread. This was foreseen as reasonable by McArthur, and his chart table reflects this. But AS3959 then commits a scientific error and applies the re-calculated rate of spread to calculate flame length. This is a serious misapplication of his research.
In the first place, McArthur's chart calculates flame height, not flame length.
Secondly, McArthur's chart peaks at 14m for a good reason. It derives predominantly from surface fuel bed. The McArthur forest model was 30m tall. He assumed if litter and shrub fuel was sufficient to lift flame height to 13 - 14m, the slightest extra trigger would readily ignite the crown base and thus produce a crown fire. He would have known a crown fire could flash upwards rapidly but briefly to the top of the crown or beyond, and then resume to the 13 - 14m base level. McArthur did not research the prediction of crown flame height from fuel load in upper layers or canopy. To use his work to justify flame height in upper levels of a forest fire is seriously invalid and dishonest. His work was more focused on managing fuel load to reduce flame height. McArthur's work does not account for or authorise fuel loads from multiple layers or flammable bark or crown to be added up and applied to estimation of flame height beyond 13 – 14m.

Thirdly, if AS3959 used the slope adjusted rate of spread in Noble et al's original flame height equation **Z = 13 x Rslope + 0.24 x W – 2**, it would assume a linear correlation between slope and flame height. There is no scientific support for this (see next point). Science has found that doubling rate of spread can double flame depth. Whilst this may increase flame height a little in a surface fuel bed, increases in flame height in multi layer fuel beds like a forest have more complexity, and cannot be explained by a simplistic slope equation. Moreover, the doubling of flame height with each 10 degree slope increase does not explain common fire behaviour observations. Eg, if the flame has already reached into the crown of a eucalypt forest it is passively crowning and the flame is vertical. If the slope suddenly increases by 10 degrees, but nothing else changes, what extra fuel becomes available to power a doubling of flame height. Another example is trenching, which the author has observed on a tree covered steep slope. The flame remained a surface flame, not flashing up as a crown fire until it reached the ridge top. The flame may have increased in length as slope increased, it is not known if it doubled with each 10 degree slope.
Fourth, linking slope to flame length to rate of spread is devoid of scientific backing. Douglas's (2011) Table 8 says rate of spread doubles as slope increases by 10 degrees, therefore flame length also doubles. This has no relation to McArthur's Meter, which makes allowance for only rate of spread to double. It bears no relationship to McArthur's research, which found a complex correlation between rate of spread and flame height, eg, Figure 6.15 in Luke and McArthur (1978) clearly shows it was not linear. They said "although rates of spread are greatly increased with wind speed, flame heights are correspondingly reduced". Thus they mean the higher FDI, the lower is the flame height. This observation has not been incorporated into AS3959 equations. Selectively quoting from the researchers is one source of junk science.
Fifthly, AS3959 uses this equation for flame length **Lf = (13 x Rslope + 0.24 x W) / 2**
The RFS (RFS, 2001) devised this equation and called it "a modified McArthur Mark V formula". This is very dishonest for two reasons. It is Noble et al's (1980) formula, not McArthur's. It has no connection with McArthur's research. It is very close in format to Noble et al's original equation, which was **Z = 13 x R + 0.24 x W - 2.** In the revised equation, "minus 2" has become "divided by 2". **Z = (13 x R + 0.24 x W) / 2.** AS3959 quotes NSW fire authority (RFS 2001) as the source of the new equation. AS3959 includes this commentary (CB7): "Flame length (Lf) is taken as the sustained flame length, which adjusts the standard flame length equation for forest type vegetation (Ref. 6)". Reference 6 is listed as Noble et al (1980) and their equation is for flame height, not flame length. CB7 admits the bushfire equations have been extrapolated beyond original intention.

> CB7 The bushfire behaviour equations … may not be accurate in all situations due to (a) their empirical nature and (b) the extrapolation of them beyond the original conditions under which they were developed.
> Flame length (Lf) is taken as the sustained flame length, which adjusts the standard flame length equation for forest type vegetation (Ref. 6) reducing it by half, which takes into account flame discontinuity and adjusting for lower flame temperatures and flame geometry. AS3959

RFS (2001) distinguishes "sustained" flame length ("the sustained flame length was calculated (see Table A3.2) using a modified McArthur Mark V formula of **H = 13R + 0.24W / 2** for forest fires") from "maximum" flame length ("Maximum flame length for forest fires are approximately twice that provided in Table A3.2"). This suggests they believe Noble et al's original equation calculated maximum flame length and they reasoned when they removed the flame flickering and fluctuations, the sustained flame length is half the maximum. But, the change in equation has no scientific basis because the McArthur Meter estimated flame height, not flame length, and Noble et al (1980) did not specify whether flame height was maximum or average or at the top of the solid part.

To summarise, it appears that AS3959 is accepting this reinvention and is applying equations in absence of either empirical or theoretical evidence. It has no connection to McArthur's Meter or his research findings. Unfortunately, there is no law against mutilating science. The tragedy however, is this. AS3959 and fire authorities use junk science as a basis for government policy.

Calculations If we accept this equation for this discussion, AS3959 calculates flame length on flat ground in forest at 24m and woodland at 15m. The relevance of flame length becomes confusing because Douglas (2011) says AS3959 uses flame height for radiation calculations, done by adjusting flame length by the angle of tilt. However for zero slope, flame height equals flame length. Appendix 1 of this Paper uses AS3959 criteria (100m wide flame, 100 kW / sq m emission) to assess radiation from the wall of flame at a distance of 50m. Incident radiation from the AS3959 prescribed forest and woodland flames is 18 and 10 kW / sq m respectively.

AS3959 prescribes 35t/ha for forest and 25 t/ha for woodland to calculate flame height. It adds 10 t/ha for the canopy fuel load, and assumes the entire canopy will flame up. Measured canopy foliage loads for forests have been measured between 5 -10 t / ha, and woodlands can be down to 2 t / ha (literature summarised in O'Bryan, 2005).

Are these prescribed flame lengths and radiation loadings reasonable? No, because rate of spread and flame height equations assume these fuel types are uniform, varying only by fuel load. Yet AS3959 has diagrams of four vegetation structures for forest and five for woodland. The range of fuel loadings and fuel bed structure is wide. For example, an AS3959 "forest" can be over 30m tall or 10 to 30m tall, its canopy cover can be 30–70% foliage cover and its understorey may include understorey of sclerophyllous shrubs or grass. AS3959's prescribed uniformity contradicts abundant fire behaviour studies that find flame behaviour is site specific, fuel structure specific and fuel bed and fuel particle specific.

To illustrate the variability, Appendix 1 of this Paper compares calculated flame lengths / heights for AS3959 forest and woodland with actual flame heights for each AS3959 vegetation diagram. AS3959 generally overestimates flame height and thickness and therefore radiation by a variable and inconsistent margin. It can be equivalent to an inbuilt safety factor of up to 18 times.

The other part of the radiation damage equation is duration of exposure. AS3959 deems the duration is 2 minutes. The tall flame in a bushfire is the flash flame, and ample evidence exists that the maximum duration of the flash flame on a given site is 30 seconds (eg, Project Vesta, 2007). Theoretically, this is an additional safety factor of four times. However in practice, piloted ignition in 30 seconds requires radiation level of 40kW / sq m (Fig 4, Paper 3A).

If these safety factors are multiplied together, the undisclosed built in safety factor of AS3959 can be as high as 50 to 100 times actual (see Appendix 1 of this Paper). The safety factor seems excessive and unnecessary when we remember that radiation is a minor cause of house loss in severe bushfires. Leicester (1987) said "there is little evidence that these flames (from the fire front) cause significant damage to buildings either through direct flame contact, convective heat transfer or radiation. The main attack on a building from a bushfire comes in the form of a shower of burning embers that commence to arrive up to half an hour before the flame front".

Calculations for Shrub and Scrub
Flame height is calculated using a grab-bag of equations from various sources. There is no fire behaviour science that supports the use of these equations in shrub or scrub fuel beds. AS3959 gives the impression of "any formula will do" or "find a formula and make it fit".

Firstly, Rate of spread is calculated from the Catchpole et al. equation from their 1998 article:
R = 0.023 x wind^1.21 x veg height^0.54
AS3959 requires us to use veg height of 1.5m for shrub and 3m for scrub and authorities require us to use 45 kph wind speed. Deemed flame heights calculate to 6m and 12m respectively.

This equation was changed slightly in Catchpole et al (1999), but essentially, it derives from a composite of heath fire observations throughout Australia and New Zealand. It does not have the credibility of a site specific or vegetation specific study, and is difficult to justify its application in government policy. The author is not aware of this equation being used elsewhere. In essence, it says that the rate of spread is 2 – 5% of wind speed at 10m level, and the range is due to vegetation height, but the influence of vegetation height is not explained. Nevertheless, this estimate is reasonable close to the author's independent estimate (O'Bryan, 2005), where the likely rate of spread on a worst case day is 4-5% of 10m wind speed.

Secondly, rate of spread is then adjusted for slope using Noble et al's equation designed for litter bed, even though the Catchpole et al (1999) said provided a specific slope equation, saying that slope had less influence on rate of spread in heath than in litter bed
Rslope = R x exp (0.035 x slope) vs. Noble et al's **Rslope = R x exp (0.069 x slope)**.

Thirdly, flame length is then calculated in a two step process using both of Byram's (1959) equations. Byram's fire line intensity (**BFI = H x fuel load x Rslope)** for shrub and scrub calculates respectively to 22,200 and 53,800 kW / sq m, using deemed fuel loads of 15 and 25 t / ha. These figures are then plugged into Byram's flame height equation to calculate flame lengths **Lf = 0.0775 x BFI^0.46.** Flame heights calculate to 8m and 12m respectively.

The process of determining flame height from rate of spread using Byram's equations assumes they are scientifically appropriate and were developed for this purpose. But they are not. Byram's flame height equation was developed for flame height in a litter bed fire in a pine forest in central USA. Byram specifically stated that it was not suitable for high intensity fires and crown fires (Byram, 1959). Flame heights using these equations are not authentic. They are invalid. This is junk science.

Concerns about the calculation process
The process relies on the equations being accurate and relevant for the vegetation type. They are not, but they are presented as legitimate mathematical truths.

Application of one deemed flame height for each vegetation type implies that vegetation and danger and flame height are synonymous, that neither can be managed, and that the actual condition of vegetation is irrelevant. Yet AS3959 has diagrams for four types of shrub structures and three of scrub. It is curious why it presents so many possibilities and yet prescribes one to be applied to each vegetation type.

AS3959 seems to assume that bushfire is a natural disaster and that the owner of the vegetation has no desire or ability or obligation to reduce hazard.

AS3959 gives the impression that this vegetation patch is the only danger and that the BAL specifications will reduce the danger. People pay for fortification on this basis.

Appendix 1 of this Paper compares calculated flame lengths / heights for AS3959 vegetation types with actual flame heights for each AS3959 vegetation diagram. It shows that AS3959's peak standard flames generally overestimate flame height and thickness and therefore radiation by a variable and inconsistent margin.

AS3959 is probably attempting to build in a safety margin to protect people from what they perceive is dangerous and unmanageable. What is the safety margin? It is not known.
If it is reasonable – fine.
If it is excessive – why so? It should be reduced to cut unnecessary fortification costs.
Another option is possible. It is possible to estimate flame height, duration and width and calculate precise radiation loads and add a known safety factor.

Which causal threat agents are treated?

Paper 3A specifies the two types of causal threat agents in severe bushfires – primary (flame and embers from the fire front) and secondary (flame and embers from the urban flame). AS3959 sees the wall of flame as the fire front, and is the source of the flame, radiation and embers. Thus, AS3959 addresses only the primary causal agents. The secondary causals are not addressed. Eg, a cultivated garden is excluded as a vegetation type.

How does AS3959 mitigate primary threat agents?

A Flame and Embers

Flame front - flame contact and radiation

AS3959 regards the wall of flame in the adjacent vegetation as the fire front and the sole source of danger to the house, ie, flame contact, radiation and ember attack. Radiation from the wall of flame to the house is calculated by View Factor and registers as BAL. Flame contact from the wall of flame is accounted for as bushfire attack level called "flame zone" (BAL-flame zone). AS3959 deems the wall of flame is 100m wide and has duration of two minutes.

Flame front - embers

AS3959 assumes the embers originate from the wall of flame. If the wall of flame is close, BAL is high, and building specifications incorporate increased levels of ember resistance.

B Building design provisions

Building design provisions - ignition by radiant heat and flame contact

AS3959 claims to prevent ignition on timber surfaces, but surprisingly provides no ignition index for any timbers. Instead it prescribes thermally thick timber tested **after** ignition for structural strength grading under heat. Appendix E timbers are based on wood density. Appendix F timbers are based on burning rate of ignited timber under 10 minutes exposure to a heat load of 25 kW / sq m without wind. FRL rating timber is based on a referenced standard where structural strength is tested under heat load.

It is of interest that CSIRO is not aware of research that has shown that **timber density** is a definitive indicator of appropriate fire performance in bushfires (Leonard, 2009). Paper 3A suggests density has a marginal influence on time to ignition.

Nevertheless, the absence of ignitability classifications may not be of major concern because the AS3959 model envisages the fire front gets closer, and when incident radiation exceeds 29 kW / sq m, timber surfaces are not permitted on external walls. Above 40 kW / sq m requires non-combustible surfaces for walls and shutters. The construction grade requirement continues for BAL FZ, where shutters have to comply with another test AS 1530.8.2, and walls have to be non-combustible and at least 90 mm thick.

In summary, AS3959 clearly believes that prescribed timbers have low apparent flammability, but it does not provide evidence to link fire resistance to ignitability. Moreover, the tests for ignitability and resistance are very different, and neither includes wind as an input. Therefore, a definitive answer to the question is not possible.

Building design provisions - ignition by embers
AS3959 regards the wall of flame as the source of embers. The construction standards for each BAL include ember protection. The inference can be drawn that if they withstand embers from short distance spotting, they withstand longer distance embers.

There are two types of ember ignition – cold and hot ignition. Cold ignition occurs when wall of flame is distant and has minimal influence on ignition. Hot ignition occurs when the wall of flame is close and has pr-heated the timber surface, and heat remains after ignition. Paper 3A confirms ignition can occur on cold surface solid timber by flame contact, but flame is not sustainable when heat is removed. Ignition occurs more readily on a hot solid timber surface when a pilot flame ignites pyrolysis gases, and flame is sustained by ongoing heat.

The AS3959 scenarios that deal with cold ignition are the lower BAL's, and the higher BAL's deal with hot ignition. For example, the lower BAL's deal with cold and warm ember attack by specifying maximum gap and vent widths, eg 2 – 3mm, and requiring the lower 400mm of the walls to be fire resistant timbers (BAL < 19). The higher BAL's deal with hotter ember attack by the same gap specifications and requiring the entire wall (BAL 29) to be fire resistant timbers. They deal with hottest ember attack (BAL 40) by requiring external surfaces to be non combustible, ie, non timber.

To cause damage, embers have to ignite the exposed timber on the house or penetrate cracks and the flame has to sustain and spread. Ignitability is influenced by many factors other than AS3959 test criteria, eg, surface roughness, cracks or splits in timber surfaces, uneven joins between timber boards, gaps caused by distorted drying, temporarily damaged surfaces, flammable paint, and adjacent debris accumulation. Such sites can provide unforeseen entry or foothold points for embers. Such sites can allow ember entry if the surface is non-timber. Hot weather winds may fan them to ignition and spread. They can ignite if fire front is close or distant.

Furthermore, AS3959 may have a systemic weakness in the cold ember attack scenario because at low BAL, parts of the walls are not fortified. Eg, fortifying the bottom 400mm of a wall assumes the embers hit the wall and fall down to collect at the bottom. It does not cover the possibility that embers stay attached to the upper wall and cause ignitions in the hot dry wind.

Conclusion: Whilst AS3959 covers some ember ignition possibilities, there are many sites and scenarios on and near the house that it does not cover.

How does AS3959 mitigate secondary threat agents?

A Flame and Embers

Urban flame - flame contact and radiation

In short, the urban flame is not contemplated by AS3959. There are no specifications for the fuel bed in proximity to the house. It is assumed to be highly managed, which implies non flammable or low fire intensity (Douglas, 2011). Because grass or litter or shrub or any flammable material is permitted (ie, not prevented), flame contact can occur at the house. The source of the flame is ember attack. If the wall of flame is distant, BAL level is low. Flame radiation emitted by urban flame is 100 kW / sq m, which means the house is exposed to (ie, not protected from) excessive radiation load. Thus, flame contact and excessive radiation from urban flames can readily occur on a low BAL house.

It is also assumed by AS3959 that the wall of flame does not extend beyond the vegetation edge. However, the wall of flame will move through the gap toward the house if the fuel bed is flammable and continuous.

Urban flame - embers
Ignition by urban embers is not contemplated by BMO. If flame from a garden or shed is close to the house, radiation loading will be very high. If embers are thrown from these flames onto the house, piloted ignition occurs under very high radiation. Ignition will be rapid. AS3959 does not contemplate heat or embers from urban flame.

B Building design provisions

Building design provisions - ignition by radiant heat and flame contact
If the fire front is distant, BAL is calculated as low, and the building specifications have low fire resistance. If embers ignite flammable urban fuel near the house, the flame may contact the walls or the radiation may damage the house because it is not fortified.

Building design provisions - ignition by embers
These urban flames can generate embers and the house will be showered with live embers. As before, the house has been classified low BAL, and again, it is unfortified and therefore vulnerable.

CONCLUSION

AS3959 claims to reduce the chance of ignition from the wall of flame in the closest vegetation by reducing the impact of flame contact, excessive radiation and ember attack.

AS3959 Score card for fire front flame	**AS3959 Score card for urban flame**
Flame contact - unknown Radiation – unknown Ember attack - fail	Flame contact - fail Radiation – fail Ember attack - fail

VERDICT ON AS3959

Performance of AS39959 during Black Saturday
In regard to house loss, the Royal Commission asked the Building Commission for evidence of its effectiveness. The Building Commission was unable to draw any conclusions about the effectiveness of construction standards in preventing house loss. However, evidence presented to the Royal Commission shows that AS3959 approved houses **had no impact on reducing life loss or house loss** during Black Saturday.

We quote from Paper 6B:
Building Commission figures found that 2006 destroyed houses had known construction dates. After removing unknowns, they found 177 destroyed houses were built under AS3959. "Thus, 9% of destroyed houses were AS3959 compliant. We estimate from Buxton et al (2009) and (Leonard et al, 2009) that, of total houses exposed to the fires, the likely proportion of AS3959 compliant houses was 8 – 12%. This suggests that AS3959 compliance made no significant difference to house loss rate."

"In regard to protection of life, AS3959 compliant houses averaged just over two bodies per house, which is very close to non AS3959 houses. Thus, AS3959 provides no evidence of improvement in protection level.

"This next statistic is very disturbing because AS3959 houses aim to provide protection to people while the fire front passes over:
Of destroyed houses with known construction date, 2.5% had dead bodies inside
Of destroyed houses built to AS3959 or WMO compliance, 7.3% had bodies inside.
Thus, AS3959 houses had three times as many dead bodies as non AS3959 houses."

Royal Commission's comments about AS3959

The Royal Commission (VBRC, 2010) was rather critical of the AS3959.
"The Commission notes that building standards do not and cannot guarantee a home will not burn down".
It said "even if a house is built to the relevant building standard, this standard is not designed to ensure survivability without active defence".

The RC requested that "the relevant performance requirements in the Building Code of Australia and the objective of AS 3959-2009 should be amended to incorporate resistance to ember attack. This will assist in ensuring that ember protection measures remain a focus of future work on development of appropriate standards and regulatory measures."

RC said – "ember attack is the predominant bushfire attack mechanism, and measures to protect buildings from the risk of ignition by embers are essential. The significance of protecting a building against ignition by embers is not, however, specifically reflected in the objective of AS 3959-2009."
It said – " the performance requirement in the bushfire safety provisions of the Building Code of Australia is that a building constructed in a designated Bushfire-prone Area must be 'designed and constructed to reduce the risk of ignition from a bushfire while the fire front passes'. As noted, the evidence before the Commission suggests that most houses that are burnt in bushfires are burnt because of ember attack. Although buildings' resistance to radiant heat and direct flame contact is important in the areas of highest risk, resistance to ignition by embers is crucial to the survival of all buildings in bushfire-prone areas."

The RC criticised the administration of the AS3959

Despite this standard being crucial to providing effective guidance on construction of buildings in bushfire-prone areas, the process for revising, producing and publishing this guidance has been fraught with difficulty. It has not delivered timely regulation.
And again
The lengthy history of the revision of AS 3959-1999 and the eventual publication of AS 3959-2009 reflect poorly on both Standards Australia and building regulators, in particular the ABCB. It is unfortunate that regulation of a matter of public safety should have been allowed to drift for nearly eight years—and for five years after the 2004 COAG Inquiry recommended that it be completed as a matter of priority. Resolution of difficult and important policy matters such as the level of stringency required of the standard and whether deemed-to-satisfy solutions should be prescribed for the Flame Zone should not be left to a technical committee consisting of volunteers who must try to reach consensus and are not accountable for the timeliness of their decision making. While there has been some recognition of these problems, there is currently no clear commitment to adopting a more efficient process.

The RC was concerned with testing standards do not match bushfire condition

> On the evidence before the Commission, testing standards AS 1530.8.1 and AS 1530.8.2 do allow for repeatable tests for comparing and ranking the performance of building components subjected to radiant heat and direct flame contact in a bushfire. This is necessary. But, because AS 3959-2009 prescribes compliance with these tests as deemed-to-satisfy solutions for construction at higher bushfire attack levels, it is vital that the testing standards also be reliable predictors of the performance of building components under bushfire conditions. The Commission therefore considers that a review of both testing standards is warranted.

Expectations and disclaimers

We can deduce that the adoption of the Standard by governments within regulations and statutory rules implies that the government accepts that a bushfire design specification will protect a house from a worst case bushfire attack at each respective BAL level. For example, implementing a BAL 19 design **will** protect the house from damage or destruction by ember attack, heat and flame contact up to a radiation level of 19 kW / sq m. Furthermore, we can deduce that the government accepts that people living in a BAL 12.5 area are entitled to believe that if they design a house to BAL 29 standard, it will have a substantial safety factor. This is a reasonable expectation of a design standard.

But AS3959 includes serious disclaimers that seem to weaken its credibility:
The first disclaimer appears in the Forward and the Scope 1.1:
"It should be borne in mind that the measures contained in this Standard cannot guarantee that a building will survive a bushfire event on every occasion. This is substantially due to the degree of vegetation management, the unpredictable nature and behaviour of fire, and extreme weather conditions."

This is an unusual statement because (1) the BAL specifications are for extreme weather conditions that logically include the impact of fire behaviour and (2) the BAL calculations refer to vegetation with very high fuel loads, ie, vegetation in an unmanaged condition.

The second disclaimer is that the Standard … "is but one of several measures available to property owners to address damage during bushfires" "This Standard is part of a process" Other measures include … "planning, subdivision, siting, landscaping and maintenance".

Thus, we wonder if the government's belief in AS3959 is misplaced.

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APPENDIX 1

FLAME HEIGHT IN AS3959 VEGETATION TYPES
Actual vs. Deemed

INTRODUCTION

AS3959 nominates generic vegetation types (eg, forest, woodland, shrub, scrub) and presents up to five of Specht's ecological structure diagrams as sub types within each vegetation type. The first things to notice in the diagrams are the range of tree heights and the range of height and density of understorey. The next thing to understand is that the diagrams are in 3D. They represent a vertical slice through the vegetation. The darkened features are the foreground and the greyed features are in the background. This means the flame height at the sliced edge of the vegetation can only be produced by the darkened areas. This raises the issue of ladder fuel, meaning how does the flame rise from the ground to the crowns? The common method is via flammable tree trunks and layers that are close together. Many of the diagrams show large fuel free gaps between ground and crowns that will not support a tall flame, and if the tree trunks are non flammable, the flame cannot rise up.

Each generic AS3959 vegetation type has a predetermined or deemed flame height / length. It seems likely that the rationale is to ensure the house site is protected by a built-in safety margin. But as this Appendix shows, some sub types have a higher actual flame height / length than the deemed, and some have negligible flame height / length. The safety margin is inconsistent and often excessive. The deemed flame heights and radiation loadings for four generic vegetation types are now examined.

This Appendix uses flame height to calculate radiation. Douglas (2011) explained that flame length has to be adjusted for tilt angle to determine the effective flame height at the base of the flame. To minimise confusion, slope will be deemed to be flat. The house site will be 50m from the wall of flame.

To calculate radiation loading, AS3959 assumes the wall of flame is a solid face. Note CB10.2 explains that AS3959 applies emissivity of 0.95 to the radiation equation.

> CB10.2 A nominal flame emissivity of 0.95 is considered to be justified as the bushfire flames under design fire weather scenarios are generally optically thick ($\varepsilon \approx 1$). AS3959

Yet the vegetation structure diagrams it relies upon clearly show that the wall of flame at the sliced edge of the vegetation can only be produced by the darkened areas. Thus, we can see that the wall of flame cannot be a solid face. It is intermittent and scattered, which would render the emissivity low, eg, 0.4. Douglas (2011) seems to agree – "forest flames have significant discontinuities, and have highly variable flame temperatures across the fire face. This is exaggerated when flame geometry is based on tree canopy in addition to litter/understorey fuels". Thus, by specifying a solid wall of flame in nearby forest, AS3959 effectively has a substantial built-in safety factor of at least two-fold.

AS3959 deems the duration of the wall of flame is 2 minutes. We can quote Vesta (Project Vesta, 2007) which found the duration of the flash flame on a given forest site was less than 30 sec. This suggests a theoretical built-in safety factor of four-fold. These figures are relevant to a scenario where the flash flame occurs in isolation, which is consistent with the many occasions when the fire front does not reach the house.

However, the AS3959 narrative assumes the fire front passes over the house site. We can quote Royal Commission comments that normal duration is 15 minutes, but Black Saturday took much longer. The concept of the fire front passing over refers to the duration of elevated heat on the house site. In the AS3959 scenario, 2 minutes seems rather short. Whether piloted ignition occurs or not depends on radiation load. Eg, Paper 3A shows indicative piloted ignition of thermally thick timber under 40 kW / sq m (in calm lab conditions) occurs in 30 sec, 29 kW / sq m irradiation occurs in one minute, but if incident radiation is less than 20 kW / sq m, thermally thick timber will take several minutes. Thus, if we persist with the AS3959 narrative and its deemed 2 minute duration, piloted ignition will occur if radiation load exceeds 25 kW / sq m, but will not occur when less than the high teens. Does AS3959 realise that its specifications will fail within its own narrative?

But this is not the end of it. This data is for calm lab conditions on thermally thick timber. In hot windy bushfire conditions, piloted ignition occurs much quicker. It also occurs even faster on thermally thin timbers. These ignitions can then ignite the thicker timbers. AS3959 does not account for these variations, but they determine its success or failure as a system.

AS3959 VEGETATION TYPE BASICS - SYSTEMIC CONTRADICTIONS

For vegetation to be a danger to a house site (excluding adjacent vegetation), fire behaviour science says it has to be either up wind or down slope from the house site. But AS3959 defines the only danger to a new house is the vegetation patch within 100m wherever it is, including down wind and up slope.

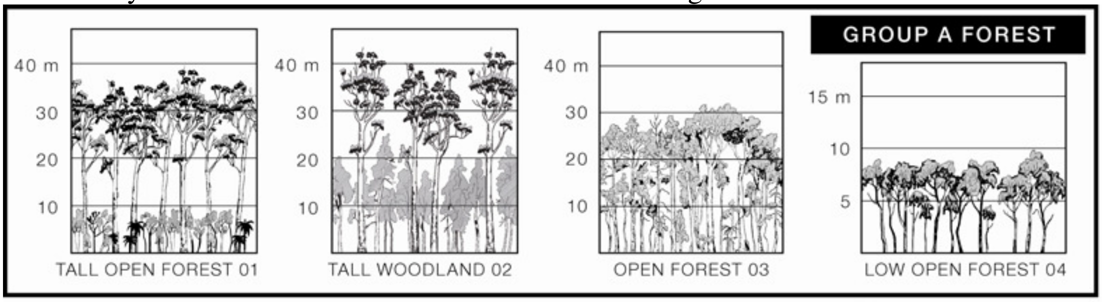
AS3959 lists a number of generic vegetation types and uses ecological not fire behaviour definitions to define each. Eg, forest and woodland are defined by percentage of canopy cover, and shrub and scrub are defined by minimum height and foliage cover. Bushfire behaviour science says that canopy cover is relevant to fire behaviour because denser cover reduces wind speed on the ground level, which moderates flame height and rate of spread. Thus, higher canopy cover tends to reduce fire intensity at ground level. However, in AS3959, forests (with 30 – 70% cover) are regarded as highest risk.

The rationale for the AS3959 process and equations is obscure. AS3959 shows up to five very detailed ecological vegetation structure diagrams within each generic vegetation type, giving the impression that they are somehow relevant, but then imposes an artificial wall of flame of predetermined height for each generic vegetation type. AS3959 prescribes the process and the equations to calculate flame length and radiation loadings. In almost all cases, the artificial wall of flame of the generic has no connection to the actual in a worst case bushfire.

Fire behaviour science says the rate of spread and flame height equations for a given vegetation structure is site specific - fuel structure specific and fuel bed and fuel particle specific. Fire behaviour is dependent on vegetation structure specifics, eg, litter bed fuel, vertical layers – their depth, their spacing, their fuel loading, their density, the % of dead fine fuel in each layer, the horizontal continuity (% cover) of each layer, their vertical continuity and the flammability of tree trunks, which can provide ladder fuel. But AS3959 applies rate of spread and flame height equations to each generic vegetation type as if it were uniform, varying only by fuel load. Eg, forest vegetation type lists five sub types, but AS3959 prescribes forest fuel type with a maximum fuel load of 35 t / ha.

FOREST VEGETATION TYPE

AS3959 lists five sub types of forest, but only the four eucalypt forests have diagrams (01 to 04). The fifth is pine plantation. Even though pine plantations have at least five distinct fuel types during their 25-30 year life span, AS3959 recognises only one, the deemed generic one for a flammable eucalypt forest. One very significant forest sub-type is not included on the AS3959 list. It includes a missing forest structure, tall forest with litter bed and scattered understorey. This is the McArthur forest for which he designed the McArthur Meter.



AS3959 flame height calculations

AS3959 equations for Forest, Woodland, Rainforest or other forest forms:
Step 1 Rate of spread
R = 0.0012 * FDI * w
AS3959 requires us to use FDI = 100, and w = 25 t / ha for forest
This makes R = 0.0012 x 100 x 25 = 3 kph

Step 2 Adjustment for slope – flat or upslope
Rslope = R * exp (-0.069 x slope)
Assume slope is zero
Rslope = R

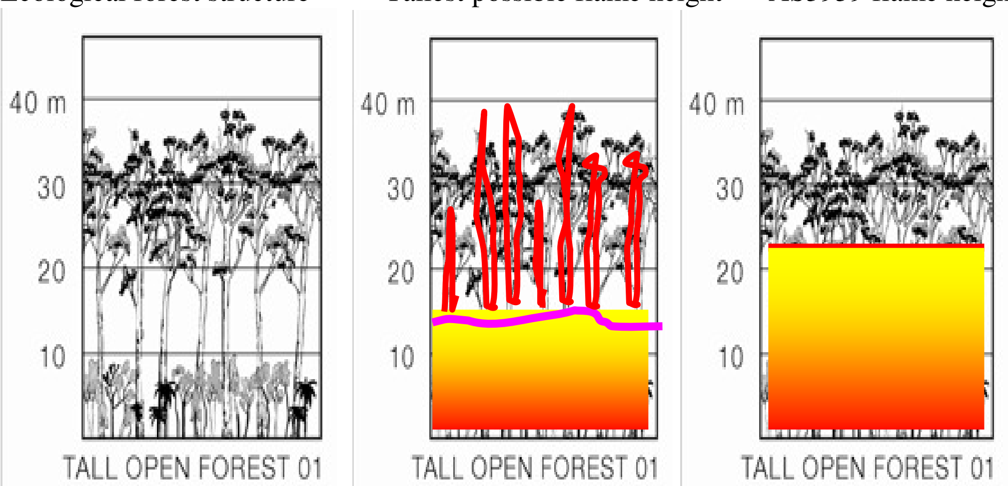
Step 3 Flame height calculation
Lf = [13 Rslope + 0.24W] / 2
AS3959 requires us to use W = 35 t / ha for forest
Therefore, Lf = (39 + 8.4) / 2 = 23.7m

AS3959 radiation calculations

Using view factor analysis, as required by AS3959, a 100m wide, 24m wall of flame emits 100 kW / sq m from this vegetation for 2 minutes.
Incident radiation at 50m distance = 18 kW / sq m

Forest sub type 01

Ecological forest structure Tallest possible flame height AS3959 flame height



If wind in open is 45 kph, wind speed below dense tall forest canopy is 10 - 12 kph.
Litter bed flame height = 3 - 5m, assumes low understorey exists and has added to flame height
Maximum flame height above elevated shrubs is approx equal to depth of shrub foliage
Pink line represents flame height if upper trunks are non flammable bark. Crown cannot burn, but it may be killed by heat scorch
Red lines represent flame height if upper trunks are flammable. Flame spikes up trunks into canopy

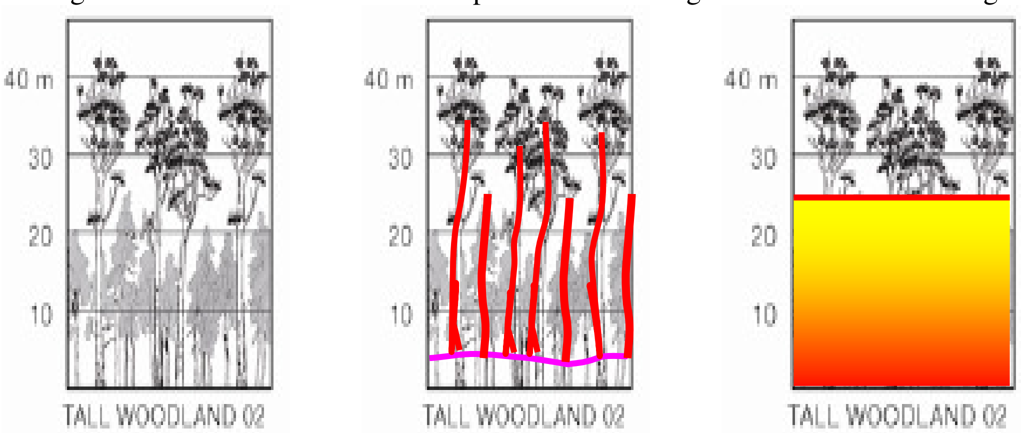
Duration of flashy flame in litter bed is 30 sec.
Maximum duration of flame in shrubs is 15 seconds
Duration of low smoulder flame in litter bed is many minutes

Equivalent height of continuous solid flame = 20m
(Equivalent flame height means flame height for the equivalent of a solid wall of flame whose emissivity = approx 1)
Assume 100m flame width
Incident radiation at 50m distance = 14 kW / sq m

Forest sub type Missing - tall forest with litter bed and scattered understorey. This is the McArthur forest that his Meter was designed for.
See table summary below for results.

Forest sub type 02

Ecological forest structure   Tallest possible flame height   AS3959 flame height

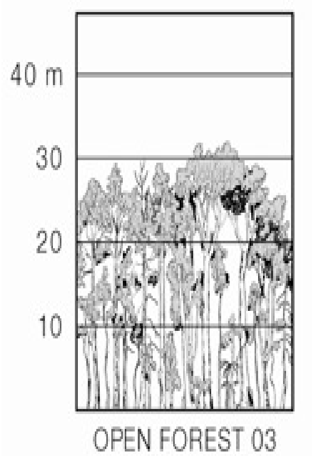


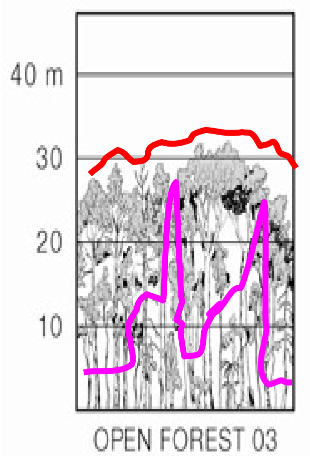
If wind in open is 45 kph, wind speed below dense tall shrubs canopy is less than 10 kph.
Litter bed flame height = 3 - 5m, assumes low understorey exists and has to added flame height
Pink line represents flame height if shrub and tree trunks are non flammable bark. Shrubs cannot burn, but may be killed by heat scorch
Red lines represent flame height if shrub bark and upper tee trunks are flammable. Flames spike up trunks into tall shrubs and canopy
Flame height rises only a little way above elevated shrubs because the only source of ignition is their flammable trunks.

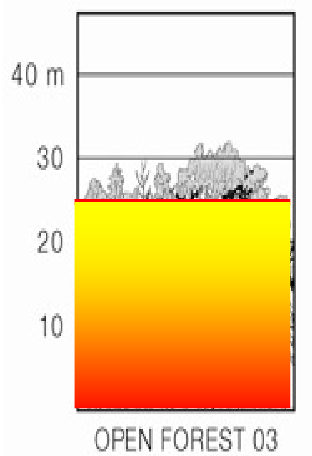
Duration of tall flame in litter bed is 30 sec,
Maximum duration of flame in shrubs and canopy is 15 seconds
Duration of low smoulder flame in litter bed is many minutes
Equivalent height for continuous flame = 15m
AS3959 Incident radiation at 50m distance = 11 kW / sq m

Forest sub type 03

Ecological forest structure Tallest possible flame height AS3959 flame height







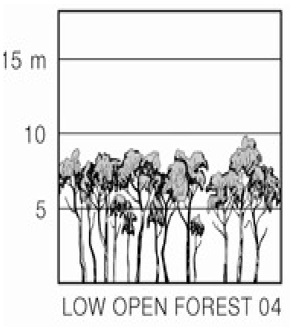
If wind in open is 45 kph, wind speed below dense tall forest canopy is 10 - 12 kph.
Litter bed flame height = 3 - 5m, assumes low understorey exists and adds to flame height
Maximum flame height above elevated shrubs is approx equal to depth of shrub foliage
Pink line represents flame height if upper trunks are non flammable bark. Occasional flame spikes into canopy. Crown cannot burn, but it may be killed by heat scorch
Red line represents flame height if upper trunks are flammable. Maximum flame height above canopy is approx equal to depth of canopy foliage.

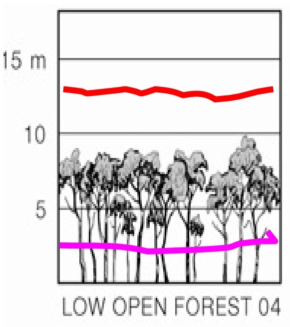
Duration of tall flame in litter bed is 30 sec.
Maximum duration of flame in shrubs is 15 seconds
Maximum duration of flame in canopy is 10 seconds
Duration of low smoulder flame in litter bed is many minutes

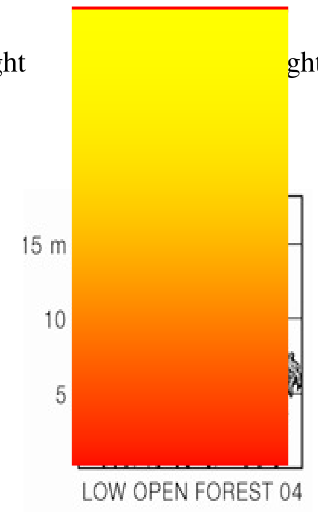
	For non flammable upper trunks	***For flammable upper trunks:***
Equivalent height for continuous flame	15m	30m
Assume 100m flame width	Assume 100m flame width	Assume 100m flame width
AS3959 Incident radiation at 50m distance	11 kW / sq m	20 kW / sq m

Forest sub type 04

Ecological forest structure Tallest possible flame height ght







If wind in open is 45 kph, wind speed below dense tall forest canopy is 10 - 12 kph.
Litter bed flame height = 3 - 5m, assumes low understorey exists and has added to flame height
Maximum flame height above elevated shrubs is approx equal to depth of shrub foliage
Pink line represents flame height if upper trunks are non flammable bark. Crown cannot burn, but it may be killed by heat scorch
Red line represents flame height if upper trunks are flammable. Maximum flame height above canopy is approx equal to depth of canopy foliage

Duration of tall flame in litter bed is 30 sec.
Maximum duration of flame in shrubs is 15 seconds
Maximum duration of flame in canopy is 10 seconds
Duration of low smoulder flame in litter bed is many minutes

For non flammable upper trunks:
Equivalent height for continuous flame = 3m
Assume 100m flame width
AS3959 Incident radiation at 50m distance = 1 kW / sq m

For flammable upper trunks:
Equivalent height for continuous flame = 13m
Assume 100m flame width
AS3959 Incident radiation at 50m distance = 10 kW / sq m

Summary

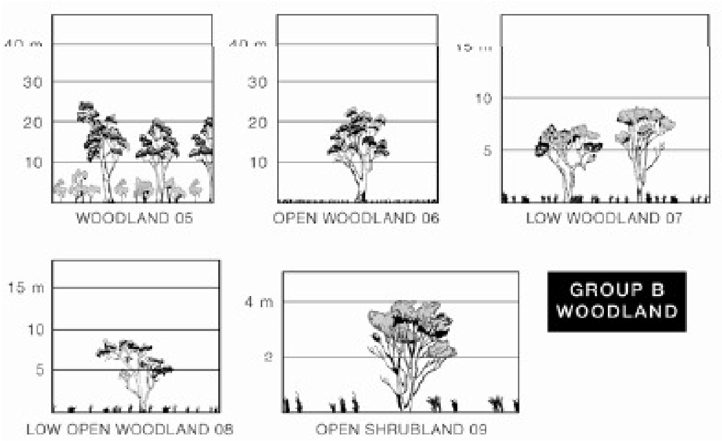
The flame height of the deemed wall of flame for the AS3959 forest fuel type matches actual flame height in none out of four cases. If AS3959 included the missing forest structure - tall forest with scattered understorey, the tally would be none out of five cases. However, deemed flame height overestimates in one case and comes close in another case, but only if the upper tree trunks are flammable.

AS3959 forest sub type	Equivalent* flame height (m)	AS3959 flame height (m)	Actual incident radiation** kW / sq m	AS3959 incident radiation* kW / sq m
01	20	24m	14	18
02	15	24m	11	18
03 upper bark non flammable	15	24m	11	18
upper bark flammable	30		20	
04 upper bark non flammable	3	24m	1	18
upper bark flammable	13		10	
Missing vegetation structure, tall forest, scattered understorey				
upper bark non flammable	3	24m	1	18
upper bark flammable	5		3	

* Equivalent flame height is flame height for a solid wall of flame, where emissivity =approx 1
**Radiation calculations based on 100m wide flame at 50m separation distance.

Deemed wall of flame overestimates radiation loading by a factor of 1.5 to 18 times. That assumes a solid thick flame. If incident radiation is from a thin patchy flame, which is the expected norm, is overestimated by tens of times.

WOODLAND VEGETATION TYPE



AS3959 / Table 1 Flame height calculations

AS3959 equations for Forest, Woodland, Rainforest or other forest forms:
Step 1 Rate of spread
R = 0.0012 * FDI * w
AS3959 requires us to use FDI = 100, and w = 15 t / ha for woodland,
This makes R = 0.0012 x 100 x 15 = 1.8 kph

Step 2 Adjustment for slope – flat or upslope
Rslope = R * exp (-0.069 x slope)
Assume slope is zero
Rslope = R

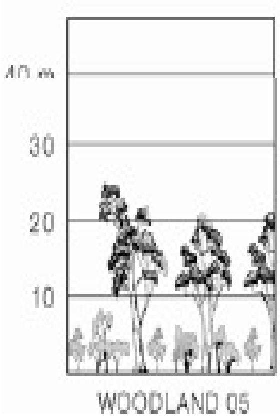
Step 3 Flame height calculation
Lf = [13 Rslope + 0.24W] / 2
AS3959 requires us to use W = 25 t / ha for woodland
AS3959 Therefore, Lf = (23.4 + 6) / 2 = 15 m

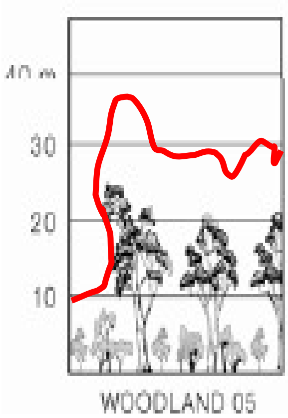
AS3959 radiation calculations

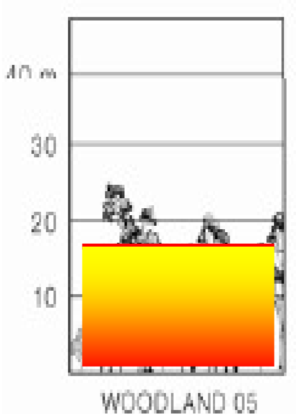
Using view factor analysis, as required by AS3959, a 100m wide 15m tall wall of flame emits 100 kW / sq m from this vegetation for 2 minutes.
Incident radiation at 50m distance = 10 kW / sq m

Woodland sub type 05

Ecological woodland structure Tallest possible flame height AS3959 flame height







If wind in open is 45 kph, wind speed below woodland canopy is 20-25 kph.

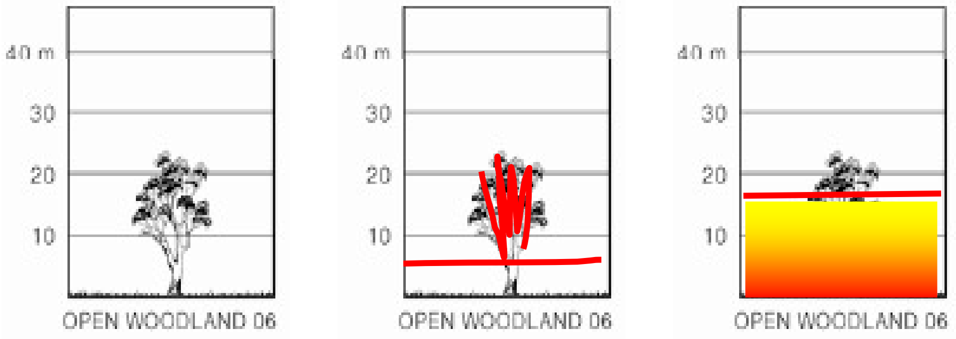
Litter bed and shrub flame height = 5 – 10 m,
Maximum flame height above elevated shrubs is approx equal to depth of shrub foliage
Red line represents flame height **if upper trunks are flammable**
Maximum flame height above canopy is approx equal to depth of canopy foliage

Duration of tall flame in litter / shrub bed is 20 - 30 sec.
Maximum duration of flame in canopy is 10 – 20 seconds
Duration of low smoulder flame in litter bed is a minute or two.

Equivalent height for continuous flame = 25m
Assume 100m flame width,
Incident radiation at 50m distance = 18 kW / sq m

Woodland sub type 06

Ecological woodland structure Tallest possible flame height AS3959 flame height



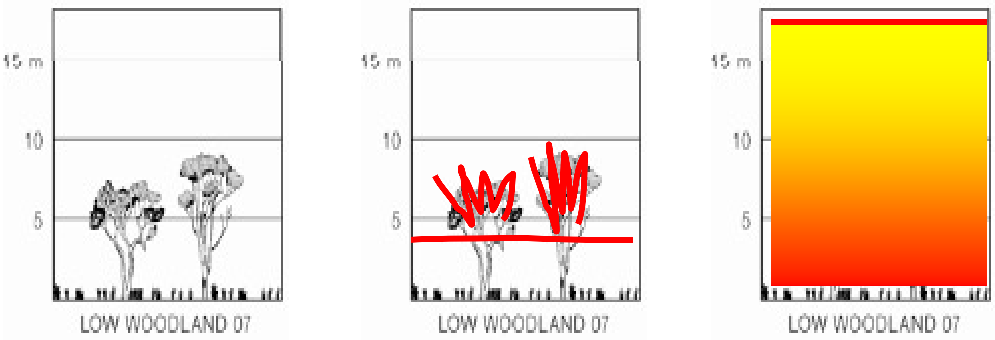
If wind in open is 45 kph, wind speed below woodland canopy is 20-25 kph.
Grass flame height = 3 - 4 m,
Red lines represent flame spikes **if upper trunks are flammable.** Flame spikes into canopy

Duration of tall flame in grass fuel bed is 10 sec.
Maximum duration of flame in canopy is 10 – 20 seconds
Duration of low smoulder flame in litter bed is a few seconds.

Equivalent height for continuous flame = 4m
Assume 100m flame width
Incident radiation at 50m distance = 1.5 kW / sq m

Woodland sub type 07

Ecological woodland structure Tallest possible flame height AS3959 flame height



If wind in open is 45 kph, wind speed below woodland canopy is 20-25 kph.
Litter bed and shrub flame height = 3 - 5 m,

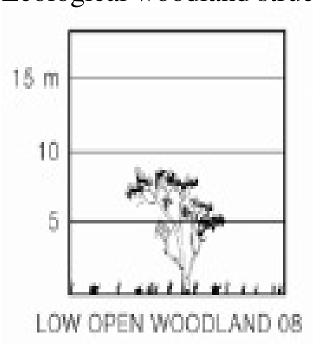
Red lines represent flame spikes **if upper trunks are flammable.** Maximum flame height above canopy is approx equal to depth of canopy foliage

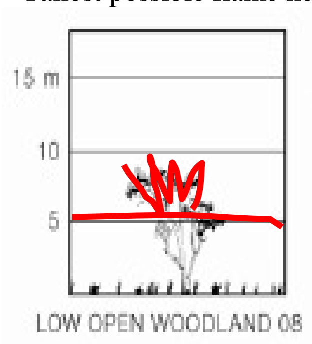
Duration of tall flame in litter / shrub bed is 20 - 30 sec.
Maximum duration of flame in canopy is 10 - 20 seconds
Duration of low smoulder flame in litter bed is a minute or two.

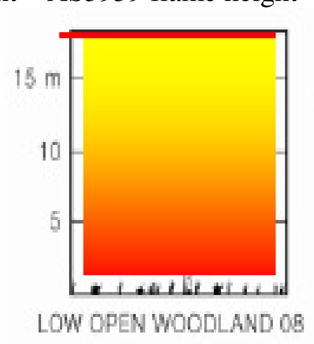
Equivalent height for continuous flame = 4m
Assume 100m flame width,
Incident radiation at 50m distance = 1.5 kW / sq m

Woodland sub type 08

Ecological woodland structure Tallest possible flame height AS3959 flame height





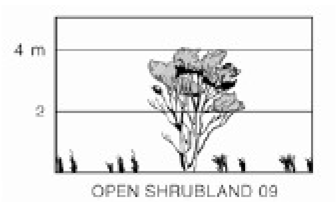


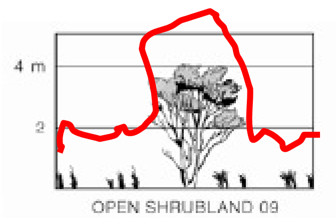
If wind in open is 45 kph, wind speed below woodland canopy is 20-25 kph.
Litter bed and shrub flame height = 3 - 5 m,
Red lines represent flame spikes if upper trunks are flammable
Duration of tall flame in litter / shrub bed is 20 - 30 sec.
Maximum duration of flame in canopy is 10 – 20 seconds
Duration of low smoulder flame in litter bed is a minute or two.

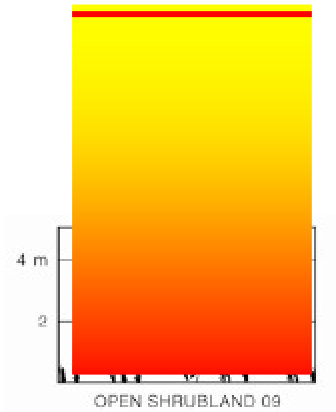
Equivalent height for continuous flame = 5m
Assume 100m flame width,
Incident radiation at 50m distance = 1.5 kW / sq m

Woodland sub type 09

Ecological woodland structure Tallest possible flame height AS3959 flame height







If wind in open is 45 kph, wind speed below woodland canopy is 20-25 kph.
Litter bed and shrub flame height = 2 - 3m

Maximum flame height above canopy is approx equal to depth of canopy foliage
Duration of tall flame in litter / shrub bed is 20 - 30 sec.
Maximum duration of flame in canopy is 10 – 20 seconds
Duration of low smoulder flame in litter bed is a minute or two.

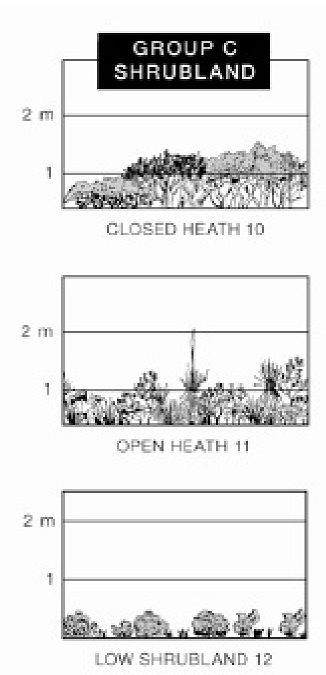
Equivalent height for continuous flame = 4m
Assume 100m flame width
Incident radiation at 50m distance = 1.5 kW / sq m

Summary
The height of the deemed wall of flame for woodland fuel type fails to match actual flame height in any of five cases. It significantly underestimates once, but all other cases, it overestimates by a factor of three. Sub Type 05 underestimates radiation load by more than half, but most woodland vegetation sub types overestimate it by 7 times.

AS3959 woodland sub type	Equivalent* flame height (m)	AS3959 flame height (m)	Actual incident radiation** kW / sq m	AS3959 incident radiation** kW / sq m
05	25	15m	24	10 kW
06	4	15m	1.5	10
07	4	15m	1.5	10
08	5	15m	1.5	10
09	4	15m	1.5	10

* Equivalent flame height is flame height for a solid wall of flame, where emissivity =approx 1
**Radiation calculations based on 100m wide flame at 50m separation distance.

SHRUB VEGETATION TYPE



AS3959 / Table 1 Flame height calculations
AS3959 equations for shrub and scrub fuels are:

Step 1 Rate of spread
R = 0.023 x wind^1.21 x veg height^0.54
AS3959 requires us to use veg height of 1.5m for scrub and authorities require us to use 45 kph wind speed
This makes R = 2.9 kph

Step 2 Adjustment for level or upslope
Rslope = R * exp (0.069 x slope)
Assume zero slope
Therefore ***Rslope = R***

Step 3 Calculate Byram fire line intensity
I = H x fuel load x Rslope / 36
AS3959 requires us to use H = 18600 and fuel load 15 t / ha,
Therefore I = 18600 x **15** x 2.9 / 36 = 22,200 kW / m

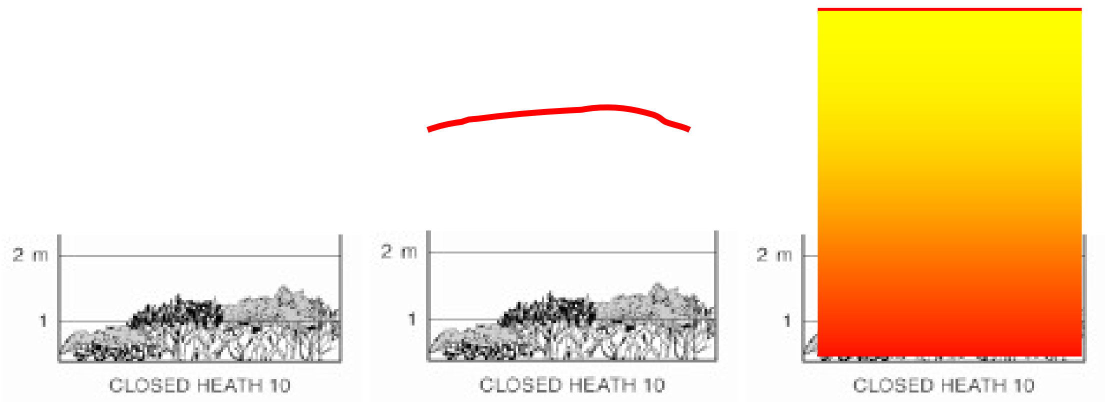
Step 4 Flame length calculation
Lf = 0.0775 x Byram intensity^0.46
Therefore, Lf = 7.7 m

AS3959 radiation calculations

Using view factor analysis, as required by AS3959, a 100m wide 8m tall wall of flame emits 100 kW / sq m from this vegetation for 2 minutes.
Incident radiation at 50m distance = 6 kW / sq m

Shrubland sub type 10

Ecological woodland structure Tallest possible flame height AS3959 flame height



If wind in open is 45 kph, wind speed at fuel bed level is 20-25 kph.
Shrub flame height = 6 m
Assume high proportion of dead fine fuel, flame height is approx 9 x shrub layer depth (O'Bryan, 2005) (0.5 m x 9 + 1.5 = 6m)

Duration of tall flame in shrub bed is 20 - 30 sec.
Duration of low smoulder flame in shrub bed is less than a minute.

Flame height - continuous flame = 6m
Assume 100m flame width,
Incident radiation at 50m distance = 5 kW / sq m

Shrubland sub type 11

Ecological woodland structure Tallest possible flame height AS3959 flame height

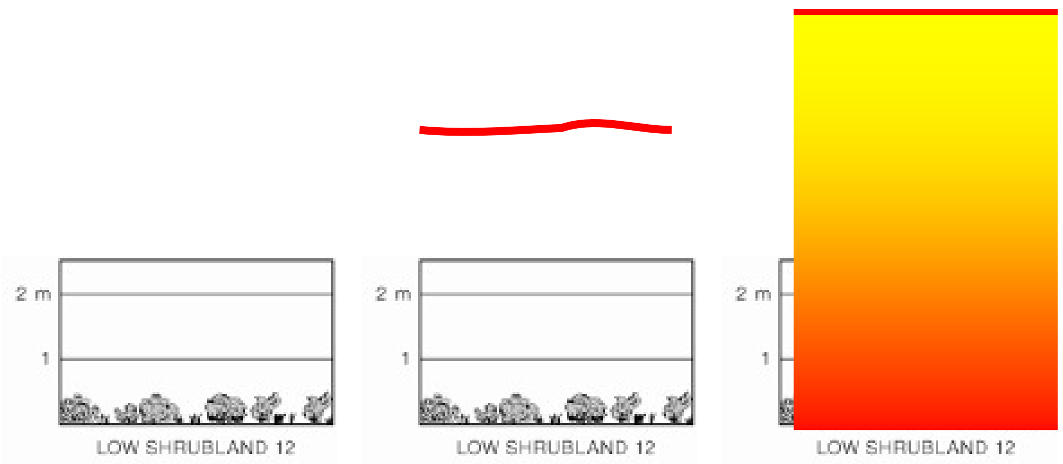
If wind in open is 45 kph, wind speed at fuel bed level is 20-25 kph.
Shrub flame height = 10 m
Assume high proportion of dead fine fuel, flame height is approx 9 x shrub layer depth (O'Bryan, 2005) (1m x 9 + 1 = 10m)

Duration of tall flame in shrub bed is 20 - 30 sec.
Duration of low smoulder flame in shrub bed is less than a minute.

Flame height - continuous flame = 10m
Assume 100m flame width
Incident radiation at 50m distance = 8 kW / sq m

Shrubland sub type 12

Ecological woodland structure Tallest possible flame height AS3959 flame height



If wind in open is 45 kph, wind speed at fuel bed level is 20-25 kph.
Shrub flame height = 5 m
Assume high proportion of dead fine fuel, flame height is approx 9 x shrub layer depth (O'Bryan, 2005) (0.5m x 9 + 0.5 = 5m)

Duration of tall flame in shrub bed is 20 - 30 sec.
Duration of low smoulder flame in shrub bed is less than a minute.

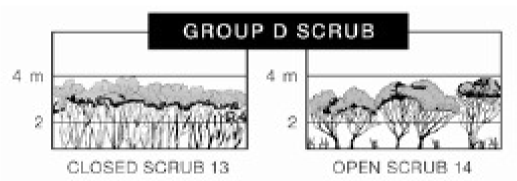
Flame height - continuous flame = 5m
Assume 100m flame width
Incident radiation at 50m distance = 4 kW / sq m

Summary
The height of the deemed wall of flame for shrubland fuel type is reasonably close to actual worst case flame height in the vegetation sub types. It slightly underestimates in one case and underestimates in the others. Similar results apply for radiation loading.

AS3959 shrub sub type	Equivalent* flame height (m)	AS3959 flame height (m)	Actual incident radiation** kW / sq m	AS3959 incident radiation** kW / sq m
10	6	8m	5	6
11	10	8m	8	6
12	5	8m	4	6

* Equivalent flame height is flame height for a solid wall of flame, where emissivity =approx 1
**Radiation calculations based on 100m wide flame at 50m separation distance.

SCRUB VEGETATION TYPE



AS3959 / Table 1 Flame height calculations
AS3959 equations for shrub and scrub fuels are:
Step 1 Rate of spread
R = 0.023 x wind^1.21 x veg height^0.54
AS3959 requires us to use veg height of 3m for scrub and authorities require us to use 45 kph wind speed
This makes R = 4.2 kph

Step 2 Adjustment for level or upslope
Rslope = R * exp (0.069 x slope)
Assume zero slope
Therefore ***Rslope = R***

Step 3 Calculate Byram fire line intensity
I = H x fuel load x Rslope / 36
AS3959 requires us to use H = 18600 and fuel load 25 t / ha,
Therefore I = 18600 x **25** x 4.2 / 36 = 53,800 kW / m

Step 4 Flame length calculation
Lf = 0.0775 x Byram intensity^0.46
Therefore, Lf = 12 m

AS3959 radiation calculations

Using view factor analysis, as required by AS3959, a 100m wide 12 m tall wall of flame emits 100 kW / sq m from this vegetation for 2 minutes.
Incident radiation at 50m distance = 9 kW / sq m

Scrub sub type 13

Ecological woodland structure Tallest possible flame height AS3959 flame height

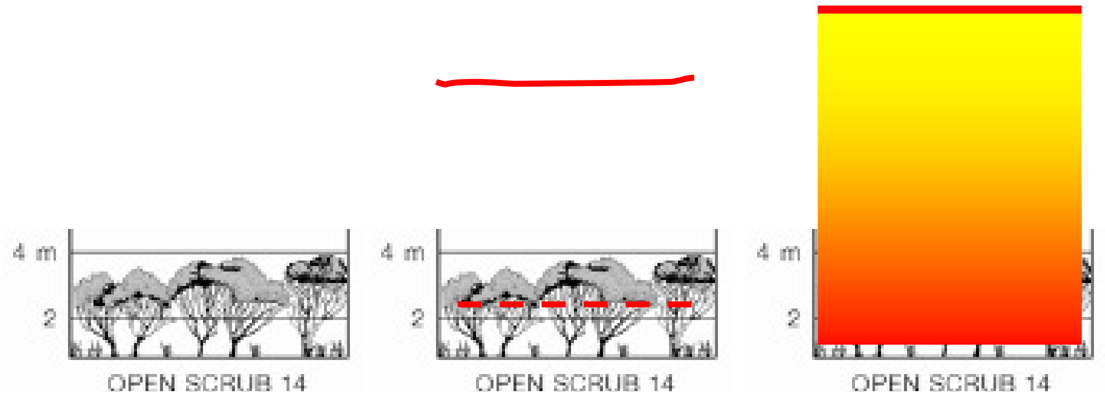
If wind in open is 45 kph, wind speed at fuel bed level is 20-25 kph.
Assume flammable trunks and adequate fuel for 3 - 4m flame height in litter bed. Flame height is approx 3 x canopy layer depth (O'Bryan, 2005) (1 m x 3 + 4 = 7 m)
Flame top height = 7 m, but equivalent flame height is 4m

Duration of tall flame in shrub bed is 20 - 30 sec.
Duration of low smoulder flame in shrub bed is less than a minute.

Equivalent height for continuous flame = 4 m
Assume 100m flame width,
Incident radiation at 50m distance = 4 kW / sq m

Scrub sub type 14

Ecological woodland structure Tallest possible flame height AS3959 flame height



If wind in open is 45 kph, wind speed at fuel bed level is 20-25 kph.
Assume flammable trunks and adequate fuel for 2-3 m flame height in litter bed. Flame height is approx 3 x canopy layer depth (O'Bryan, 2005) (2m x 3 + 4 = 10 m)
Shrub flame top height = 10 m, but equivalent flame height is 8m

Duration of tall flame in shrub bed is 20 - 30 sec.
Duration of low smoulder flame in shrub bed is less than a minute.

Equivalent height for continuous flame = 8 m
Assume 100m flame width
Incident radiation at 50m distance = 6 kW / sq m

Summary
The height of the deemed wall of flame for shrubland fuel type overestimates actual worst case flame height in both vegetation sub types by up to 3 times. Radiation loading is overestimated up to a factor of two.

AS3959 scrub sub type	Equivalent* flame height (m)	AS3959 flame height (m)	Actual incident radiation** kW / sq m	AS3959 incident radiation** kW / sq m
13	4	12m	4	9
14	8	12m	6	9

* Equivalent flame height is flame height for a solid wall of flame, where emissivity =approx 1
**Radiation calculations based on 100m wide flame at 50m separation distance.

OVERALL CONCLUSION

AS3959 deemed fuel load specifications for each of the four vegetation types – forest, woodland, shrubland and scrub - generate uniform flame heights and radiation loadings. When actual flame height and radiation loads are estimated for each of the defined vegetation sub types, the range is considerable and there is no uniformity within each of the four vegetation types. The deemed ones rarely come close to the actual flame height and radiation. They underestimate in three cases, but usually they overestimate substantially.

- The deemed forest flame height underestimates once but generally overestimates actual sub types between two to eight times. Its deemed radiation load is close once, but generally overestimates between two and 18 times.
- The deemed woodland flame height underestimates once but generally overestimates actual sub types by three times. Its deemed radiation load underestimates once by over half, but generally overestimates by 7 times.
- The deemed shrub flame height and radiation are reasonably close to actual sub types, but in one case, the deemed underestimates slightly.
- The deemed scrub flame height over estimates actual sub types by up to three times. It overestimates radiation load by up to double.

This means a safety factor is built in to the deemed fuel loadings, but it is variable and inconsistent. It is usually in the positive, but in three cases, it underestimates radiation loading. This applies to the AS3959 assumption that emissivity is 0.95. If actual emissivity is lower because of flame discontinuities, the safety factor can theoretically be doubled. The other variable required to cause damage besides radiation is flame duration. AS3959 assumes two minutes duration, whereas actual flash flame duration is typically less than 30 seconds. For the sake of argument, this theoretically quadruples the safety factor.

Thus forest vegetation types have a radiation safety factor of 16 – 144 times (2 X 2 x 4 to 18 X 2 x 4), woodland vegetation types - up to 56 times (7 X 2 X 4), shrub vegetation types - 8 times (2 X4) and scrub vegetation types - up to 16 times (2 X 2 X 4).

These safety factors assume the actual vegetation structures are at highest fuel loadings. If they have been managed to reduce or remove the understorey or the litter bed layer, the flame heights and consequent radiation loads will be negligible. In this case, the safety factor is immeasurably huge. But AS3959 does not contemplate this possibility.

The AS3959 process requires the resident to use the deemed fuel loads to calculate radiation loads from the wall of flame and BAL level compute design standards to mitigate the deemed risk. It requires the new builder to pay thousands of dollars extra for fire retardant materials. Many people will find this unreasonable and an improper use of their money.

This Appendix raises two concerns:

- The built in safety factor is not quantifiable
- The built in safety factor may be 50 to 100 times more than required.

A simple alternative can be readily applied. The actual condition of the vegetation type can be assessed and actual peak flame height and radiation load calculated. A known safety factor can then be applied, eg, radiation load can be doubled or tripled for safety.

Other relevant considerations are (1) that the AS3959 process assumes the wall of flame is the source of all risks to the new house. If this is incorrect, the expenditure by the house builder to comply is in vain. Paper 7C finds that the assumption is incorrect. (2) That the AS3959 process assumes that fortification against radiation will reduce house loss probability, implying that radiation is a major cause of house loss. If this is incorrect, the expenditure by the house builder to comply is in vain. Paper 3A finds that the assumption is incorrect.

In short, the AS3959 process requires the resident to adopt one type of risk management strategy - BAL design specifications.
It assumes the artificial fuel loads define risk level.
It assumes they quantify risk
It disallows other risk management strategies on site – fuel and flame and ember management
It disallows fuel management by owner of the vegetation with the wall of flame
It gives the impression that AS3959 alone will reduce bushfire risk, with no need for other actions
It gives the impression that design specifications of building materials and design mitigate risk of house loss.

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