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**Influence of Local Vegetation on Fire Spread Mechanisms in Surface Fires**

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**International Master of Science in Fire Safety Engineering**

# Influence of Local Vegetation on Fire Spread Mechanisms in Surface Fires

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Read and approved,



Frederik Buhk

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## Abstract

The climate change in northern Europe is not only leading to more extreme weather events but also causing long dry summers. This affects the moisture content of the ground and the vegetation. Causing an increased number of wildfires within Germany posing a risk to the environment, society, and firefighters. Surface fire spread in wildfires can be influenced by several environmental conditions and parameters. As the extensive knowledge gained for the US, Australia, Canada, and southern Europe might be not fully applicable to northern Europe a parametric study is carried out based on a field experiment in Saxony-Anhalt Germany. The present work utilizes the particle model of the wildland-urban interface part implemented in the Fire Dynamics Simulator to analyse numerically the influence of the local vegetation on the surface fire spread. Therefore, a 9 m<sup>2</sup> area of grassland is modelled and the influence of parameters such as packing ratio, moisture fraction, grass height, ambient temperature, and others are analysed. The vegetation is represented using particles. The combustion is based on a three-step pyrolysis model. The results show the importance of the energy released in ratio to the energy required for pyrolysis. This is observed in models with lower grass blades, a low packing ratio or high moisture contents as these are not leading to a sustained spread. Furthermore, vegetation-specific pyrolysis kinetic parameters are used. However, the significance of these cannot be identified for the chosen case. The chosen parameters in this work are only based on single measurements or assumptions. Therefore, future research should improve the parameters by analysing a larger number of samples. In addition, it should be investigated for other case studies whether individual pyrolysis kinetic parameters are required or if the default ones are sufficient as the deviations are neglectable compared to the uncertainty of the model.

## Abstract (German)

Der Klimawandel in Nordeuropa führt nicht nur zu mehr extremen Wetterereignissen, sondern auch zu langen trockenen Sommern. Dies wirkt sich auf den Feuchtigkeitsgehalt des Bodens und der Vegetation aus. Dadurch kommt es zu einer erhöhten Anzahl von Waldbränden in Deutschland, die eine Gefahr für die Umwelt, die Gesellschaft und die Feuerwehren darstellen. Die Ausbreitung von Flächenbränden kann durch verschiedene Umweltbedingungen und Parameter beeinflusst werden. Da die umfangreichen Kenntnisse, die für die USA, Australien, Kanada und Südeuropa gewonnen wurden, für Nordeuropa möglicherweise nicht vollständig anwendbar sind, wird eine parametrische Studie auf der Grundlage eines Feldexperiments in Sachsen-Anhalt durchgeführt. In der vorliegenden Arbeit wird das im Fire Dynamics Simulator implementierte Partikelmodell des „Wildland-Urban-Interface“ Teils verwendet, um den Einfluss der lokalen Vegetation auf die Ausbreitung des Oberflächenfeuers numerisch zu analysieren. Dazu wird eine 9 m<sup>2</sup> große Grünlandfläche modelliert und der Einfluss von Parametern wie Packungsdichte, Feuchtigkeitsanteil, Grashöhe, Umgebungstemperatur und anderen analysiert. Die Vegetation wird durch Partikel dargestellt. Die Verbrennung basiert auf einem dreistufigen Pyrolysemodell. Die Ergebnisse zeigen, wie wichtig die freigesetzte Energie im Verhältnis zu der für die Pyrolyse benötigten Energie ist, da niedrigere Grashöhe, eine niedrigere Packungsdichte oder hohe Feuchtigkeitsgehalte nicht zu einer nachhaltigen Ausbreitung führen. Außerdem werden vegetationspezifische pyrolysekinetische Parameter verwendet. Deren Einfluss ist jedoch für den betrachteten Fall nicht signifikant. Die zur Modellierung der verschiedenen Fälle gewählten Parameter beruhen lediglich auf einzelnen Messungen oder Annahmen. Daher sollten künftige Forschungsarbeiten die Parameter durch die Analyse einer größeren Anzahl von Proben verbessern. Darüber hinaus sollte für andere Fallstudien untersucht werden, ob individuelle pyrolysekinetische Parameter erforderlich sind oder ob die Standardparameter ausreichen, da die Abweichungen im Vergleich zur Unsicherheit des Modells vernachlässigbar sind.

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# 1 Introduction

The change in fire regimes driven by the recent climate change is leading to an increased number of wildfires also within northern Europe [1,2]. Thus, wildfires are posing an emerging problem for society, environment and firefighters in Germany. Due to the comparable large wildland-urban interface (WUI) and wildland-industrial interface (WII) in Germany, smaller fires can lead to events causing significant threats to the population [3]. To be prepared for these events, it is crucial to understand the mechanisms involved in wildfires as well as the influences of the local vegetation.

## 1.1 Background

Long dry summers are causing dry vegetation and wildfire-prone environments [1]. These conditions are influencing the spread mechanisms of the wildfires. To understand the wildfire behaviour in model regions in Germany experiments have been carried out. The model regions are Brandenburg and Saxony-Anhalt. The vegetation in these regions is typically pine forests with sandy ground. Based on these and the numerical simulations performed within the scope of this thesis the influence of the local vegetation on surface fire spread mechanisms is analysed.

Within this work, the term surface fire is used to describe wildland fires mainly burning the litter layer and the first two meters in height of the vegetation. The upper part of the duff layer may be included as well. However, it is difficult to define a clear border between litter and duff layer.

To analyse the influence of the local changes on the surface fire spread it is crucial to investigate the underlying fundamentals of heat transfer. Not only the convection and radiation but also the conduction within the fuel is important. Furthermore, the different stages the material goes through when it is heated are important. The duration and energy consumption of these phases are also heavily influenced by boundary conditions such as the moisture content of the fuel as well as the relative humidity of the air.

## 1.2 Objectives and Aim

The objective of this thesis is to analyse the effect of local vegetation and fuels on the flame spread in wildfire scenarios in a model region of Germany. The German model regions of the TREEADS project are Brandenburg and Saxony-Anhalt. In these regions, 48 to 73 % of the forests are pine forests with a dry ground, even in the depth. In these areas, surface fires are more common than other fires, e.g. crown fires. The duff layer is comparable thin with a thickness of approximately 30 to 50 cm. The sandy ground underneath the duff layer has very limited organic compounds and is generally considered non-combustible [4]. Due to climate change, the moisture content of the ground is decreasing even more over the years. Therefore, several numerical simulations with changed parameters are carried out to understand the localized effects on the flame spread. For validation, the simulations will be compared with experiments carried out by BAM. The results will provide a better insight into the wildfires in the model region developing knowledge and research in the field of wildfire behaviour.

The following research questions shall ensure that the set objectives are met:

1. What are the main fire spread mechanisms in the litter layer and the near-ground vegetation?
2. How are the spread mechanisms influenced by the structure of the local vegetation and dead fuels?

### 1.3 Limitations

Only the surface fuels within the first half meter as well as the litter layer are considered to be contributing significantly to the flame spread. However, it has to be noted that smouldering groundfires and smouldering fires after the flame front last for a long time and might lead to reignition [5]. Thus, the firefighters usually need to provide a fire watch to monitor the conditions. Other parts of the TREEADS project focus more on extinguishing strategies which increase the safety of the firefighters. These parts are not covered within the thesis. Furthermore, a big safety issue and fuel in the model regions are ammunition leftovers from the war. However, this topic is not covered in this work.

The focus of this study is on modelling and comparing the models with the experiment. However, all mentioned experiments were carried out by researchers at BAM. The experiments are described for a better understanding of the overall problem and the models.

For simulating the wildfire spread the particle model of FDS is utilized. FDS has several limitations which pose limitations for the overall project. Especially in the field of wildfire simulations and more particularly the pyrolysis models, the software is not yet fully developed. Regular updates of the software may change mechanisms and thus change results. However, FDS is a widely used and accepted software in the industry as well as in research and thus also used within this thesis.

Another limitation is the timeline. As there is only limited time available for the thesis there are results and findings which cannot be analysed further due to lack of time. Furthermore, the simulations have some weaknesses as the timeline is too tight to optimize the simulations further. However, these results and weaknesses may open further research within this field.

## 2 Theory

For a better understanding of wildland fire spread some basics are described briefly in the next subchapters. The general energy balance behind fire spread, as well as wildland fuel beds and the different heat transfer mechanisms in wildfires, play a crucial role in modelling the influences of different parameters on the wildland fire spread.

### 2.1 Fire Spread

The propagation of the fire in a geometric way is also called fire spread. For the fire being able to spread several conditions need to be met. First, unburned fuel needs to be available in the vicinity of the fire. However, it can be also another fuel bed which is not directly connected with the burning fuel as there are different pathways for fire spread and ignition. The ignition of the virgin fuel can be either through direct flame contact, firebrands or exposure to heat through radiation and convection [6]. For the ignition of the virgin fuel and thus the fire spread more energy needs to be produced than required for pyrolysis and ignition of the pyrolysis gases. The used pyrolysis model is described in Chapter 3.2. However, to describe the balance more in heat terms for flaming combustion the incoming heat flux from the flame  $\dot{Q}_F''$  needs to be larger than the heat losses  $\dot{Q}_L''$  to sustain spread. This is also described in Equation (1) which describes a mass loss rate  $\dot{m}''$  for steady burning conditions using the heat flux described before and the heat of gasification  $\Delta H_g$  [7,8].

$$\dot{m}'' = \frac{\dot{Q}_F'' - \dot{Q}_L''}{\Delta H_g} \quad (1)$$

### 2.2 Wildfire Fuel Bed

The different fuels present in wildfires are clustered into a fuel bed. In general, the fuel bed is divided into three different fuel layers shown in Figure 1.

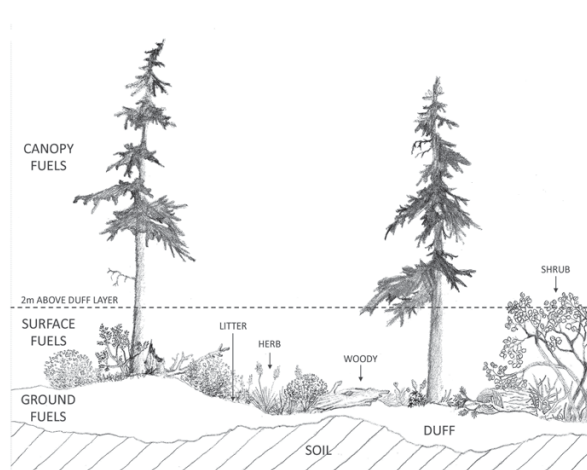


Figure 1: Wildland Fuel Bed by Keane (2015) [9]

The lowest layer are the ground fuels which are all organic matter below the ground line. All fuels above the groundline up to a height of 2 m belong to the surface fuels. Everything above a height of 2 m is classified as a canopy fuel. The layers are composed of different fuels of all different sizes from small particles up to large trees everything needs to be accounted for [9]. As nature has no clear boundaries these layers are more recommendations and in reality, layers transition smoothly without a strict boundary to the next layer. In this work, ground to



surface fuels are of interest. The upper part of the duff layer as well as the litter layer and low vegetation and dead fuels are considered. Furthermore, dead fuels are clustered quantitatively. The time it takes the fuel to reach 63.21 % of the equilibrium moisture content describes the size of the fuel. It is distinguished between 1 h, 10 h, 100 h and 1000 h fuels [9]. The shorter the time the faster the fuel adapts to its surrounding moisture conditions. Thus, a lower time describes smaller fuel particles. Most wildland fuel particles, except leaves, can be described geometrically as cylinders. Particles such as branches, pine needles and grass blades can be simplified with this geometry. Therefore, they are described by their diameter and their length. The surface-to-volume ratio of cylindrical particles is only dependent on the diameter (d) and can be calculated by Equation (2) [10].

$$\sigma = \frac{4}{d} \quad (2)$$

In the considered pine forests in the model region the fuel bed layers are distributed in the following way: The ground fuels are determined mainly by the duff layer, which has a thickness of 30 to 50 cm. On top of this layer the surface fuels are found. This layer mainly consists of grass, moss, and litter, as well as less densely distributed shrubs and smaller trees. The canopy fuel is mainly described by pine trees.

### 2.3 Wildfire Spread Mechanisms

In wildfires the three main spread mechanisms are firebrands, radiation, and convection. Firebrands lead to a significantly increased rate of spread (ROS) as they ignite new fires, known as spot fires, ahead of the spreading flame front. However, firebrands with a larger travel distance which are capable to ignite spot fires are mainly found in crown fires [11,12]. Thus, firebrands are not further analysed within this report.

Radiation plays a significant role in fires. As most of the fuel combusts in the visible and infrared spectrum heat is radiated by magnetic waves. The radiation heats up unburnt fuels and may lead to pyrolysis and ignition of the pyrolysis gases. However, the ignition based on this heat transfer mechanism is depending on the thermal thickness of the material. Several experiments have shown that only radiation is not sufficient to support groundfire spread [13,14]. In groundfires mainly thermally thin fuels are present. Such as pine needles, grass blades, shrubs with leaves and much more. Thermally thin material heats up homogeneously and there is no significant temperature gradient present. This is due to the heat lost to the surrounding ambient conditions. Most of the time the thermally thin fuels are at some point losing heat to their surrounding in the same ratio as they heat up from radiation. Thus, they keep a constant temperature. The experiments have shown that the reached temperatures of the fuel particles are not high enough for pyrolysis and thus to sustain a spread [14,15].

For a sustained spread with thermally thin fuels the main driver is found to be convection. As soon as the temperature of the surrounding air is higher than the temperature of the fuels, they heat up more. This might lead to pyrolysis. The ignition of the pyrolysis gases then causes a propagating flame front [13–15].

Next to the explained heat transfer mechanisms the concept of conduction is crucial as well. As the heat within the material is transferred by conduction. The rate of conduction is dependent on the material and the temperature gradient. Small particles such as pine needles and grass blades typically heat up homogenously. Thermally thick fuels such as branches and logs with a larger diameter have a temperature gradient over the diameter. Thus, the temperature at the boundary layer is typically higher than the temperature in the centre of the material [13].

Independent of the heat transfer mechanism, pyrolysis can be simplified in a three-step process consuming energy. Heating up the material first causes dehydration. When all the moisture content evaporated, energy is also used to degrade and vaporise solid fuel. Products of the degradation process are char and gaseous pyrolysis product. In the next step the char is using oxygen of the surrounding air to oxidize to ash and CO<sub>2</sub> [16,17]. The chemical composition of the gaseous pyrolysis products is a complex problem which highly depends on the pyrolyzed fuel as well as the boundary conditions. It is not yet fully understood how to predict the exact composition of these flammable gases [18]. Anyhow, this process can also be simplified, and the numerous outcomes are described as one product which is based on the pyrolyzed material (i.e. cellulose in case of wildfires).

## 3 Methodology

### 3.1 Fire Spread Modelling

In this work the Fire Dynamics Simulator (FDS) is used for the numerical simulations. It was developed by the National Institute of Standards and Technology (NIST) of the United States of America. It is an open-source software which is regularly updated and fully documented. FDS is a computational fluid dynamics (CFD) software solving three dimensional Navier Stokes equations for incompressible low velocity flows. FDS is widely used and accepted by the engineering and science community for simulating compartment fires. However, Wildland Urban Interface Fire Dynamics Simulator (WFDS) was developed as a tool dedicated for wildland fires, which was later implemented into FDS and is no standalone CFD-software anymore. In the following the underlying principles and models of FDS are described briefly. A full detailed description is beyond the scope of this work. Full descriptions can be found in the FDS User Guide and the Technical References [19,20].

To solve the three-dimensional Navier-Stokes equations the domain is subdivided into several smaller volumes, the cells. In these cells the basic laws of physics are applied. Thus, mass, momentum and energy are conserved. The state of each cell is calculated at each time step. To save computational time the domain can be also split up into several meshes. Each mesh would consist out of several cells of the domain. Thus, parallel computing is made possible [20]. However, in this work only one mesh will be used to avoid unwanted influences of the mesh boundaries.

In combustion processes unstable flows introduced due to high Reynolds numbers lead to turbulences. This means that whirls also called eddies are formed. The larger eddies are made of smaller eddies. This is cascading down until the smallest eddies which can be determined by the Kolmogorov-scales. To resolve these small eddies directly in CFD simulations very small cells are needed. This approach is called Direct Numerical Simulation (DNS). Due to the small cell sizes and thus small timesteps DNS is computationally comparable expensive. The computational costs are determined by computing time and needed computing power. To reduce the computational costs Large Eddy Simulation (LES) can be used. With this approach only the large eddies with the size of at least the cells are resolved. To account for the energy of the smaller eddies sub grid models are used. With the LES approach cells can be larger compared to the DNS approach [21].

FDS is capable of modelling wildland fires in three different ways. Utilizing either the level-set, boundary fuel or the particle model. While the last two are developed for a more detailed scale and can use a simplified pyrolysis model, the level-set mode is designed for larger spread simulations on a more operational scale. It considers simplified fuel models and accounts for slopes. Furthermore, vegetation maps can be imported using global information system software. The level-set methods can be used with four different modes. Main difference between the modes is the way they deal with wind. With more detailed resolved wind, the computation time increases. However, no level-set method is able to account for spot-fires. The boundary fuel model can be used to model the fuel bed as a porous medium which consists out of dry fuel, air and moisture. The model accounts for drag and convection within the layer. The third way to model wildland fires with FDS is the particle model. This method

uses Lagrangian particles to represent the fuels. Several parameters can be assigned to the particles which influence the heating as well as the combustion. For example, the particle shape can be determined to be cylindrical, spherical or cartesian [20]. One particle does not need to represent exactly one fuel particle from the real world. In this mode particles are assigned a packing ratio. This describes the bulk density of the fuels. Thus, the number of fuels within a certain volume. Therefore, the fuel load as well as the ratio between fuels and air is described. The particles are heated by radiation and convection [20].

As the present fuels can be represented well using particles, the particle model of FDS is utilized within this work. This way, the litter layer as well as the lower vegetation can be assigned different properties. Furthermore, the particles can be initialised randomly. Thus, it can be accounted to some extent for the layout in real wildland fuel beds. This would not be the case when using the boundary fuel model. In addition, a pyrolysis model can be used. This would not be the case for the level-set mode. Next to the presented facts, BAM used and intends to use the particle model for other small-scale calculations. Thus, it is useful in the sense of consistency to choose the particle model for the calculations in this work as well.

### 3.2 Pyrolysis Model

Every combustion takes place in the gaseous phase. Thus, liquid and solid fuels need to be turned into gas before they can burn. The process of vaporising liquid or solid fuel under the influence of heat is called pyrolysis. The energy provided in the form of heat is used to create pyrolysis gases. These gases are then combustible with oxygen from surrounding air as long as the concentration is in the flammable range [8]. The process of pyrolysis and the exact chemistry of pyrolysis gases are complex phenomena which highly depend on the fuel and the conditions at which it is heated. This process is hard to implement. Thus, a simplified pyrolysis model which consists out of three steps is implemented. The model consists out of a drying, pyrolysis and oxidation phase [6,16,17]. The first phase is not actually the pyrolysis as only the moisture within the fuel evaporates but no fuel itself. The second phase is then already described by thermal degradation. During the endothermic process, the dry solid fuel is turned into char, pyrolysis gases and soot. In the last step the char oxidizes and becomes ash [6,17]. It has to be noted that the process is very simplified. Those processes take place in parallel, as the fuel is not in a homogeneous state the whole time. Thus, parts are already oxidizing while other parts are still drying.

A first order Arrhenius equation is used to describe the pyrolysis reaction rate [20]:

$$k_{pyr} = m_{pyr} \cdot A \cdot e^{-\frac{E_a}{R \cdot T}} \quad (3)$$

In FDS, this pyrolysis model is widely used if one is doing CFD simulations including pyrolysis. However, the kinetic parameters of pyrolysis are important. Thus, the activation energy ( $E_a$ ) and the pre-exponential coefficient (A) need to be determined by experiments to model the pyrolysis for the respective material [20]. The parameters are needed for the second step where the pyrolysis gases are formed as a product. The chemical formula of the pyrolysis products is also depending on the fuel which is degrading. BAM carried out several small-scale experiments on the kinetics of six different wildland fuels performing a thermogravimetric analysis. The different fuels analysed are pine needles, oak leaves, maple leaves, European

beech leaves, grass blades and moss. The results obtained from these experiments will be used to set up the models described in Chapter 3.4.

### 3.3 Grid Independence Study

CFD simulations always introduce a certain level of uncertainty. A big influence on the uncertainty is the used cell size. To limit the influence of the cell size, a sensitivity study is carried out. Aim of the sensitivity study, also called grid independence study, is to find a cell size where measurements converge to the previous larger cell size. Thus, a point where a finer mesh leads to the same results is found.

Decreasing the cell size leads to a better resolution of the turbulence and thus the flows. Aim is to find a cell size where the resolution of the flows is in a good relation to the computational costs. Starting from a lower resolution it is expected to have a step wise change of parameters with a decreasing cell size.

For the grid independence study the base case developed in Chapter 3.4.2 is used. Therefore, the number of particles initialised is independent of the grid size and thus the same for all simulations. Figure 2 displays the temperature measured close to the vegetation layer for the different cell sizes.

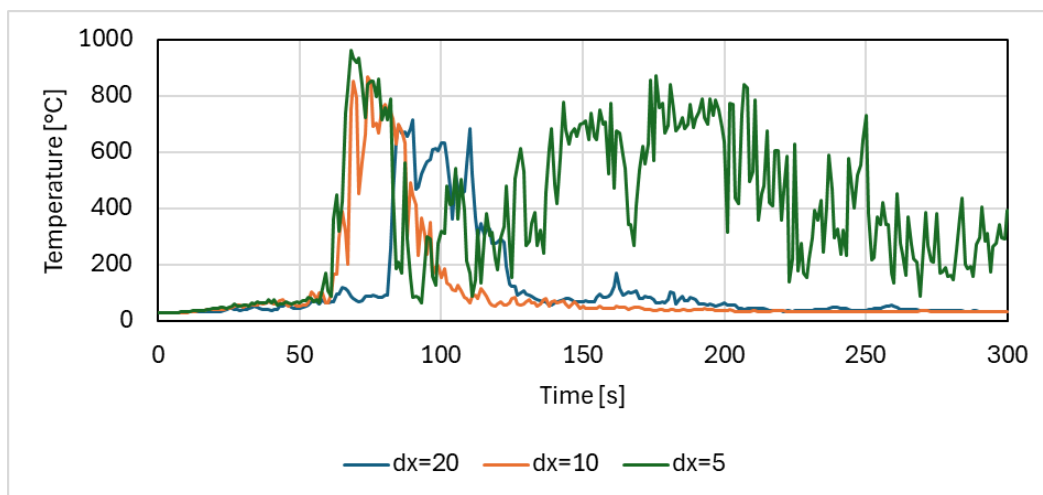


Figure 2: Numerical prediction of temperature in measurement point 5 using cell sizes of 5 cm, 10 cm and 20 cm.

The main differences observed between the different cell sizes is that there is a temperature increase again after the main flame front passed. Anyhow, this behaviour is expected as the litter layer burned in the experiment as well, and the lower resolution might not be sufficient for particles with a higher packing ratio. Simulations with a higher resolution are not carried out due to a lack of time.

Isolating the first peak temperatures in Figure 3 which describe the flame front propagating alongst the surface, the temperature seems to converge between 10 and 5 cm cell sizes. The time step when the flame front passes is similar as well as the order of magnitude of the peak temperature. Smaller differences in temperature can occur as the particles are initialised randomly within the respective volume. As the behaviour of the burning after the flame front passed is only occurring for a cell size of 5 cm, this cell size is also used within this work.

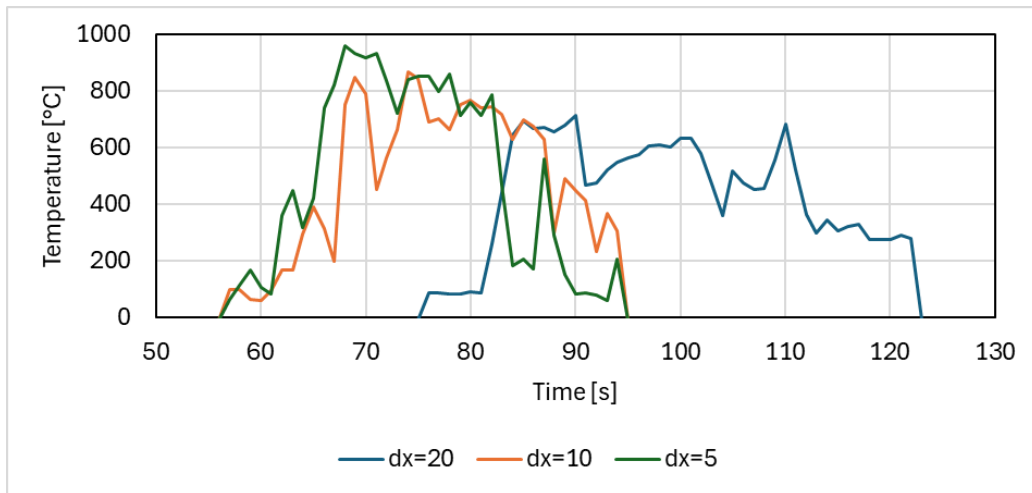


Figure 3: Numerical prediction of temperature in measurement point 5 using cell sizes of 5 cm, 10 cm and 20 cm. Isolated flame fronts.

Next to the grid independence study carried out the  $D^*$  approach can be used. This approach is used to compare the ratio between the dimensionless flame height ( $D^*$ ) and the cell size ( $\delta x$ ). The value calculated is then compared with values used for validations of FDS [19]. Based on this it can be estimated whether the resolution is rather fine or coarse. As a pyrolysis model is used the HRR is unknown at this stage. Thus, the resolution using the  $D^*$  approach is analysed in Chapter 4.8 as part of the results.

Furthermore, the sensitivity to the number of particles per cell is analysed varying the number of particles initiated within the volume. Due to time limitations this sensitivity analysis is carried out using a 10 cm cell size. The particles are always initialised randomly. In the first simulation 14400 particles are initialised for the vegetation layer and 10800 particles for the litter layer. In the second simulation five times as many particles are used. Thus, 72000 particles for the vegetation layer and 54000 particles for the litter layer. The difference in temperature observed in Figure 4 is neglectable. The deviation of the mean by 2 % might be caused by the randomized initialisation. In addition, the HRR displayed in Figure 5 shows only neglectable differences. Thus, the smaller number of particles is used as it requires less computational time.

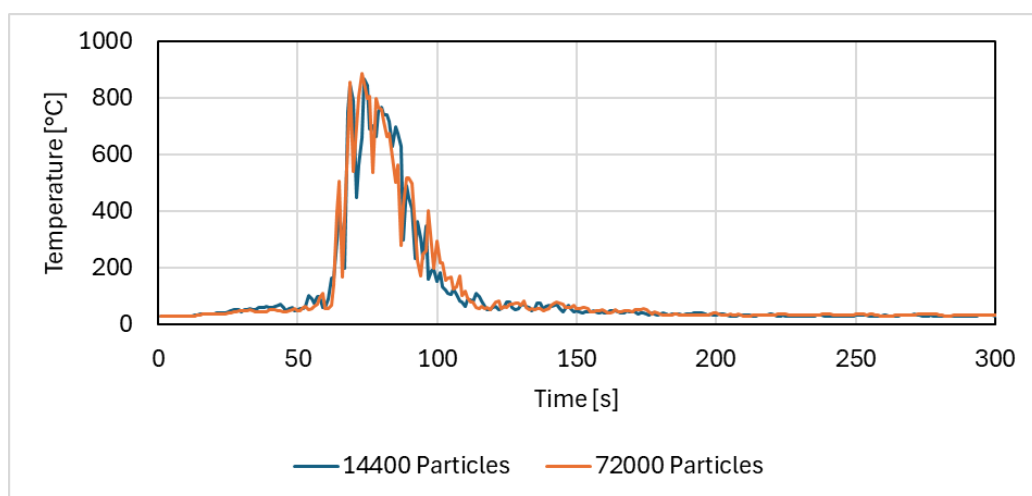


Figure 4: Numerical prediction of temperature in measurement point 5 using different numbers of particles representing the layer. Number of particles describes the number used to represent the grass blades.

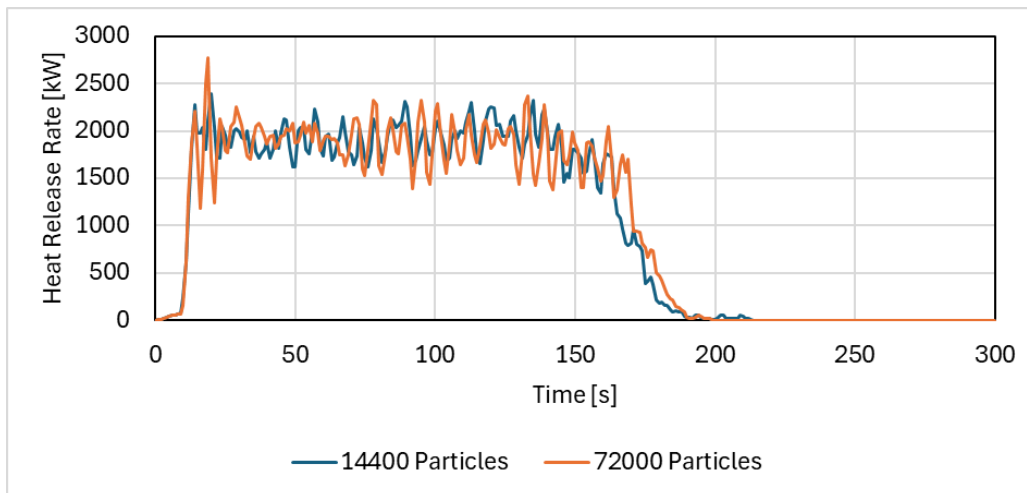


Figure 5: Numerical prediction of the Heat Release Rate using different numbers of particles representing the layer. Number of particles describes the number used to represent the grass blades.

### 3.4 Setup of the Models

To analyse the influence of the local vegetation and other local conditions on surface fire spread, several simulations were developed as a parametric study. Therefore, a base case is designed based on the field experiment carried out by BAM in September 2023 in Saxony-Anhalt which is one of the German model regions of the TREEADS project. For a better understanding of the conditions during the experiment the area and main criteria are described first. Afterwards the base case is defined. The base case is to be validated by comparing the numerical results with the experimental results.

#### 3.4.1 Description of field experiment and samples

The experiment was carried out in Saxony-Anhalt, Germany. The surface fire spread on a 400 m<sup>2</sup> area within a pine forest was analysed. During the experiments the researchers had to ignite several times at different positions and in different ways as the fire spread was not sustained. In the photos of the experiments shown in Figure 6, a square of approximately 9 m<sup>2</sup> burned and showed the best spread.



Figure 6: Field experiment carried out showing area of interest. Photos from BAM.

The ignition during the experiment was carried out using a drip-torch with a gasoline diesel mixture. As the drip-torch is not safe to use in lab experiments BAM also carried out small scale experiments using a calorimeter to standardize the used energy for ignition of different fuels applied in a line. The most stable heat release rate (HRR) was shown by burning isopropanol. Thus, it is intended to use this fuel for the ignition in further lab experiments.



The 9 m<sup>2</sup> area which showed sustained spread mainly consisted of 1 h fuels mostly being grass blades. However, as the area is located within a pine forest, there are also pine needles, moss, branches, and other fuel particles covering the ground. Furthermore, the pine trees were influencing the present grass species and other vegetation in the surface layer as well as other ground conditions.

In order to carry out lab scale experiments and develop CFD models BAM collected different samples in the vicinity to the field experiment. It is aimed for samples which represent the burned area. The collected samples are shown in Figure 7. The 9 m<sup>2</sup> area is represented best by sample 2. Thus, it is focused on the analysis of this sample. It has to be noted that the sample contains grass, moss, pine needles as well as some smaller leaves. Figure 8 shows the thickness of the litter layer described by sample 2. It has a thickness of approximately 0.15 m. The dry packing ratio of sample 2 is 36.93 kg/m<sup>3</sup>. Furthermore, the grass blades are assumed to have a length of approximately 0.2 m within the area of interest. Smaller samples consisting just of grass blades show a packing ratio of 8.6 kg/m<sup>3</sup>.



Figure 7: Samples for determining the packing ratio of the considered fuel bed. Photos from BAM.



Figure 8: Thickness of litter layer described by sample 2. Photo from BAM.

### 3.4.2 Set up of Base Model

As the fuel bed in the experiment was mainly composed of grassland, it was decided to focus on modelling the grassland fire spread utilizing the particle model, including a three-step pyrolysis with FDS. Before setting up the final models several test cases were run to understand the parameters and their influence in FDS. All the simulations were set up and performed using FDS version 6.8.0. As most validation cases for the WUI part of FDS were



carried out using the LES mode to resolve the turbulence [19] the simulation mode for all simulations described within this report is set to LES.

Smaller test cases carried out before setting up the model resulted in numerical instabilities. These were occurring at the boundaries of the mesh. To avoid these problems in the models, the mesh has a volume of 125 m<sup>3</sup> and a cubic shape. Thus, there is a buffer layer of 1 m around the area of interest. The cell size of the cubic cells is chosen to be 5 cm. The cell size is based on the grid independence study carried out in Chapter 3.3.

In general, the fuel bed is simulated in three different layers as shown in Figure 9. All layers cover the whole 9 m<sup>2</sup>. The first layer is a solid obstruction. This obstruction is assigned the material properties and the thickness used for the ground in the grassland fire validation carried out by Moinuddin et al. [22]. The aim of this obstruction is to act as a heat sink and account for heat losses to materials below the litter layer. The obstruction has a geometric thickness of 5 cm. However, for the thermal calculations a material thickness of 0.2 m is considered. Furthermore, the density of the material is 1300 kg/m<sup>3</sup>, the specific heat is chosen to be 2 kJ/kgK and the conductivity is 0.25 W/mK [22].

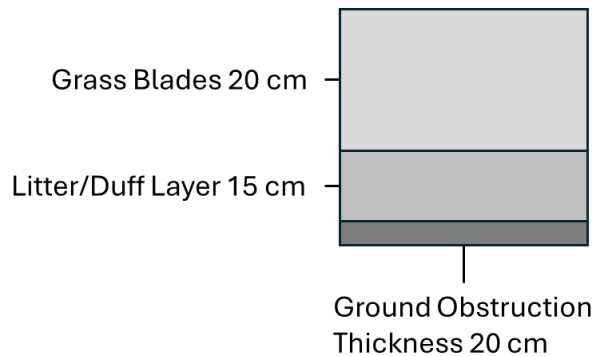


Figure 9: Different fuel layers used in FDS model.

The second layer is the litter layer, and the third layer is the vegetation. Both are modelled using Lagrangian particles. The litter layer, which also covers the upper part of the duff layer, has a thickness of 0.15 m. This is based on sample measurements carried out close to the area of the field experiment, as shown in Figure 8. It must be noted that the fuel bed in the samples consists mainly of grass and moss. Some pine needles and leaves are in it as well. However, Figure 6 shows the area of interest which is mainly covered by grass blades. Thus, the same particle parameters as for the grass blades have been chosen. The only differences between the layers are thickness, packing ratio and moisture fraction. The moisture fraction of the litter layer was measured by BAM for the samples shown in Figure 7. As sample 2 is closest to the analysed vegetation the measured moisture fraction of 35 % is assumed for the model.

The grass blades are estimated to have a length of 0.2 m and thus the layer height is chosen to be 0.2 m as well. Dry grass and other dead fuel particles present can be classified as a 1 h fuel. As the diameter is below 6 mm grass adapts relatively quickly to its surrounding moisture conditions [23]. Anyhow the used moisture content of the grass blades is based on the moisture of extinction. The concept of a moisture of extinction is a simplified way in the field of wildland fires to predict whether the fire spread will be sustained or not. It is based on the energy released in comparison to the energy needed to evaporate first the moisture and then

create pyrolysis gases. For grass the moisture of extinction is between 12 and 15 % [6]. During the experiment, partial extinction of the grass blades was identified. At some points it seems to be based on the change in grass height. At other points it might be based on the moisture content of the grass. Thus, it is assumed that the moisture content of the grass blades was close to the moisture of extinction. Therefore, a moisture fraction of 0.15 is chosen to represent the field experiment well.

Smaller tests simulations carried out in advance as well as the small sensitivity analysis in Chapter 3.3 show that the number of particles is not influencing the spread significantly. Furthermore, the grassland validation case also used one particle per cell [19,22]. Thus, the litter layer is represented by 10800 particles and the vegetation layer by 14400 particles. The numbers are equivalent to one particle per cell for cubic cells with a length of 5 cm. However, the particles are initialized randomly within the volume of each layer. This is done to try to represent reality more accurately, as the layers are less homogenous. Anyhow, it must be noted that the layers are still homogenous compared to the real world as all particles are assigned the same parameters. Since the drag of the particles is only calculated in the cell where they are initialized, it is decided to limit the particles length by the cell size (i.e. 5 cm). Thus, longer grass blades are represented by more than one particle in the model. The default drag coefficient from FDS is used [20]. The surface-to-volume ratio is chosen to be  $7500 \text{ m}^{-1}$  since this is the order of magnitude of smaller particles such as pine needles and grass blades [10].

The pyrolysis model assigned to the particles follows the simplifications described in Chapter 3.2. Therefore, the kinetic parameters determined by BAM for grass are used. The fuel which is combusted is based on cellulose and is commonly used for modelling wildfires. The chemical formula used for the fuel vapor is  $\text{C}_{2.1}\text{H}_{6.2}\text{O}_{2.2}$ . Waliszewska et al. found the heat of combustion for grassland to be  $18433 \text{ kJ/kgK}$  [24]. The used radiative fraction is used as 0.3 and the soot yield as 0.01. Those values were also used in the grassland validation [22]. The

In the simulations, the ignition is carried out using a line burner. The HRR of the burner follows the experiments by using a ramp. Therefore, the heat release rate per unit area (HRRPUA) from the experiment using isopropanol is calculated to be able to scale the HRR based on the length. Table 1 shows the used HRRPUA and the resulting HRR at the considered timesteps. Figure 10 shows the resulting HRR assigned to the line burner.

Table 1: Heat Release Rate Per Unit Area (HRRPUA) and Heat Release Rate (HRR) at considered timesteps used for line burner for ignition.

Time [s]	HRRPUA [kW/m <sup>2</sup> ]	HRR [kW]
0	0	0
3	175	26
6	366	55
9	447	67
12	554	83
15	605	91
18	559	84
21	540	81
24	485	73
27	358	54
30	298	45
33	226	34
36	122	18
39	81	12
42	72	11
45	10	1
48	7	1
51	0	0

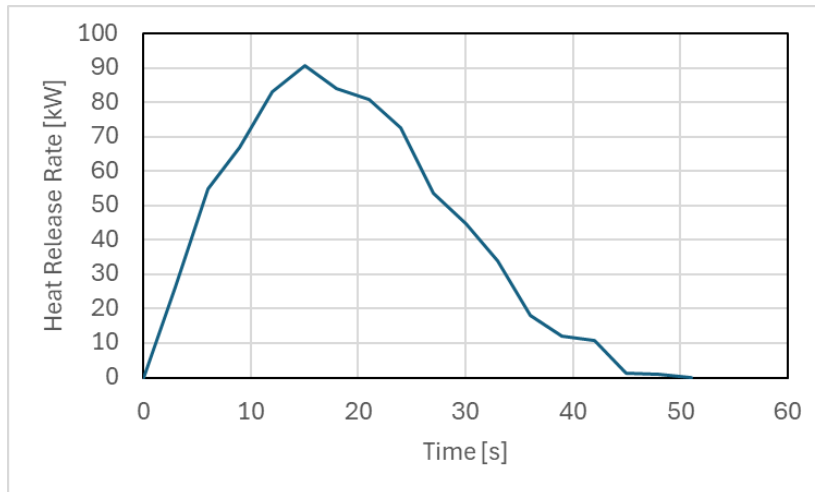


Figure 10: Scaled heat release rate from isopropanol experiments used as a line burner for ignition.

Even if the ignition parameters differ from the ones used in the field experiment, they have been chosen as they are more repeatable, and it is intended to use these in future experiments. The line burner is modelled over the full length of 3 m with a width of 5 cm at the beginning of the area as displayed in Figure 11. The surface is positioned on top of the litter layer described in the next paragraph. It is assumed that the burning liquid is igniting the grass blades but not the full litter or duff layer.

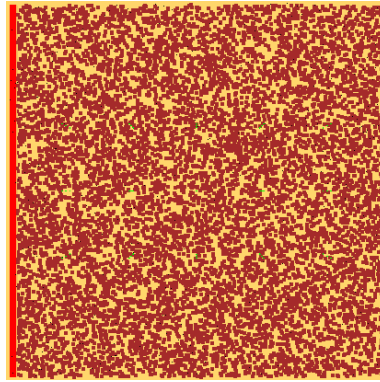


Figure 11: Layout of FDS model showing line burner for the ignition in red and particles.

As there was hardly any wind during the experiment it is decided not to introduce any wind as ambient conditions. Furthermore, this allows to eliminate one factor influencing the base case and makes it easier to apply findings to their parameters.

The ambient temperature is assumed to be 30 °C. This deviates from the 25 °C measured during the experiment. However, in the domain of wildland fires, there is a rule of thumb that states that there is a higher probability of wildfires with a sustained spread in case the ambient temperature is 30 °C or higher, the wind speeds are 30 km/h or above and the relative humidity is below 30 % [25]. Based on this rule of thumb, the ambient temperature was chosen as the experiment was not carried out in the main fire season. This makes it slightly more difficult for the validation but adds value to the understanding of the surface fire spread for operational use, since sustained wildfires are more likely to occur at high ambient temperatures.

#### 3.4.3 Set Up of Parametric Study

The local vegetation can influence the surface fire spread in several ways. Not only the species, but also the ground conditions and other parameters. For the parametric study the parameters grass height, packing ratio, moisture content, wind, pyrolysis kinetic parameters as well as the ambient temperature are chosen. The following paragraphs justify the choice and describe the parameters more in detail.

As described before a parametric study is carried out to analyse the influence of different parameters on the surface fire spread in wildfires. In total 12 different variations of the base case are identified. Where applicable one parameter is always resulting in two models. One in which the value is lowered and one in which the value is elevated. The parameters of interest are listed in Table 2 and the justifications follow in the next paragraphs.

The first parameter of interest is the height of the grass blades. The experiment wasn't showing a sustained spread. At some parts of the area, it looks like there is a change in the height of the grass blades. Thus, a hypothesis is that lower grass blades do not deliver enough energy for a sustained spread. To analyse the influence of the grass blade height, three additional simulations are carried out. One with an elevated grass blade height, one with a lowered height and one with a transition. Half of the area has the base height, and the other half is lowered to the same height used in the model with the lower grass.

Local conditions such as the nutrients within the ground, the type of ground, and other parameters are not only influencing the species of vegetation but also the vegetation density. Comparable to the grass height changing the packing ratio is leading to a change in the fuel load. Next to the fuel load, the ratio between air and fuel is also changed. For the simulations, only the packing ratio of the grass blades is changed but not the packing ratio of the litter layer. The ratio in which the packing ratio is changed was chosen arbitrarily. Thus, the lower value is  $1 \text{ kg/m}^3$ , and the higher value is reached by raising the value by the same amount it was lowered for the lower value.

As already described, the moisture fraction is highly influencing the spread as energy is needed to vaporise the water first. If less energy is released than is needed for the evaporation no sustained spread will occur. Especially in the northern European countries the moisture content is still assumed higher compared to south. However, the climate change is leading to a decreasing ground moisture and thus also less moisture content within plants and dead fuels. To analyse the influence of the moisture fraction in FDS the moisture fraction of the litter layer and the grass blades is changed with the same ratio. The ratio is again arbitrarily chosen based on a very low value for the grass blades to be 1 %. This is also leading to a rise of 15 %.

Another interesting behaviour was identified during the experiment. Higher flames as well as a better combustion was identified at places where a dead branch was lying on the ground. Thus, it was decided to carry out one simulation with branches in between the grass blades. Therefore, one branch was placed perpendicular and one parallel to the spread direction of the flame front. The length of the branches is assumed to be 1 m. Each branch is displayed by one particle per cell with a particle length of 5 cm. Thus, one branch is represented by 20 particles with an assumed diameter of 7.5 cm. Utilizing Equation (2) the surface to volume ratio of the branches is  $54 \text{ m}^{-1}$ . The moisture fraction of dead fuels is in the range of 2 to 30 % [6]. Since the branches are in contact with the ground the dead fuel is assumed to be more in the wet range of dead fuels with a moisture fraction of 25 %. Using the density of branches described by Gryk et al. [26] and the assumed geometry a packing ratio of  $500 \text{ kg/m}^3$  is calculated.

As convection is the driving heat transfer mechanism, several experiments and real wildfires show the strong influence of wind. The wind during the field experiment was comparable low and FDS is made for low flow velocities. Anyhow, the influence of the wind is of interest. Therefore, a simulation with wind is carried out. As the wind speed during the real-scale experiment was nearly unmeasurable, a wind speed of 1.5 m/s is assumed to have visible influences. Following wind speed tables, which are also used in firefighting operations, this is based on the highest speed, which can be considered as low winds or nearly no wind. The wind direction is chosen to blow perpendicular to the ignition line. This way, the flame front is only accelerated in one direction.

The default kinetics for pyrolysis modelling wildfires using FDS are used in most wildland fire simulations carried out [27–29]. However, these values are describing the pyrolysis kinetics of pine needles. Not only the type of fuel but also the local species may have a significant influence on the pyrolysis kinetics. A simulation using the default kinetic parameters is carried

out to analyse whether the determination of local pyrolysis parameters is needed or if the differences in the spread behaviour due to the changed kinetics can be neglected. As in the base case, the pyrolysis kinetic parameters are the same for all particles within the domain. Thus, only one fuel type is used.

Not only the wind but also other ambient conditions influence wildfire behaviour. For the heat loss of particles to the surrounding, the ambient temperature is a significant factor, as the driving force for temperature change is temperature difference. Furthermore, the ambient temperature in the base model is 30 °C. As this deviates from the measured temperature during the experiment, it is assessed whether a change in ambient temperature leads to significant differences in numerical simulations. Thus, the ambient temperature is varied around the base model by 10 °C.

*Table 2: Names and descriptions of all simulations for the parametric study.*

#	Name	Parameter	Value change
01	base_case	-	-
02	grass_low	Grass blade height	- 10 cm
03	grass_high	Grass blade height	+ 10 cm
04	grass_transition	Grass blade height	Partially - 10 cm
05	grass_packing_low	Packing Ratio	- 7.6 kg/m <sup>2</sup>
06	grass_packing_high	Packing Ratio	+ 7.6 kg/m <sup>2</sup>
07	moisture_content_low	Moisture Fraction	- 0.14
08	moisture_content_high	Moisture Fraction	+ 0.15
09	branch	2 branches	
10	wind	Wind Speed	1.5 m/s
11	kinetic_parameters_csiro	Default pyrolysis kinetics	
12	ambient_temperature_low	Ambient Temperature	- 10 °C (20 °C)
13	ambient_temperature_high	Ambient Temperature	+ 10 °C (40 °C)

### 3.5 Metrics and Measurements

In wildland fires some metrics are common to describe and analyse the wildland fire behaviour. Some of these metrics are used in this work to analyse the results. Therefore, the definition of these metrics is introduced within this chapter, and in addition it is described how the metrics are measured in the simulations.

One of the main measurements used to describe wildland fire spread is the rate of spread (ROS) [6,12]. The ROS describes the velocity at which the flame front is propagating in a one-dimensional way. It is widely used at the operational level to estimate at which time a wildfire will reach an important point. Such as an egress road, an important infrastructure, or even an urban interface. To analyse the wildfire behaviour of the different simulations, the ROS will be used to describe whether the fire is spreading faster or slower compared to the base model. The spread is analysed in the main spread direction towards the virgin fuel. The grid of gas phase temperature devices shown in Figure 12 is used to determine the time it

takes the flame front from one temperature measurement point to another measurement point.

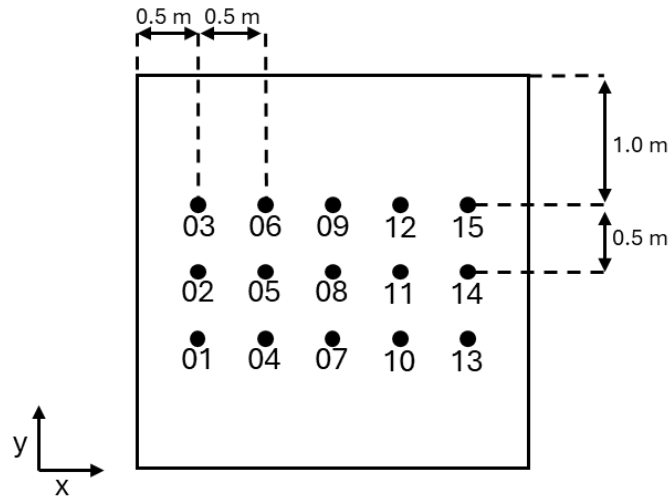


Figure 12: Gas phase temperature measurement points including numbering and distances in FDS model.

First, the timestep at which the flame front arrives at the first point is determined using a graph. Once the temperature rises significantly, it is assumed that the flame front has reached the first point. For the second point, the same methodology is used to determine the time step. Using the distance between the measurement points the ROS is calculated using Equation (4).

$$ROS = \frac{Distance}{Time} = \frac{D}{t_2 - t_1} \quad (4)$$

The residence time is used to describe the time when flaming combustion connected to the flame front is occurring. Thus, the time it takes one point from ignition to extinction or burnout. However, sometimes smaller spots are flaming or smouldering combustion takes place after the flame front has already passed. The residence time by definition considers only the time flaming combustion of the main flame front takes place [6]. In the models the residence time is determined by the temperature gas phase devices. Therefore, the timesteps at which the temperature rises significantly for the first time and then drops again significantly for the first time are determined. The difference between those timesteps for the same device is then used as the residence time as described in Equation (5).

$$t_r = t_{drop} - t_{rise} \quad (5)$$

The flame front depth is similar to the residence time. But instead of describing a time, it describes the flame front in a geometric way. The flame front depth is the distance between the first and last points under flaming combustion on one axis [6]. As the possibility of geometric measurements in Smokeview is limited, the flame front depth is calculated using the ROS and residence time as shown in Equation (6).

$$D = ROS \cdot t_r \quad (6)$$

The heat release rate (HRR) is used to describe the burning behaviour. FDS automatically generates the data for the HRR. As the same burner is included in all simulations, and the HRR of the burner is neglectable, the HRR of the burner is included in the results as well. Using the HRR, the burning behaviour of the different simulations can be compared with the focus on the energy released. Thus, conclusions might be made with regards to the energy balance.

The temperature slice files and other visual results from the simulations are displayed using Smokeview in Version 6.8.0. Smokeview is capable of displaying the Heat Release Rate Per Unit Volume (HRRPUV). This is often used to visualize the flames. In the following chapters, it is also used to describe the general flame shape. The HRRPUV displays at which point energy is released (i.e. combustion takes place). Thus, in which cells oxidation reactions are taking place. This is comparable to the definition of flames. Anyhow, the mixing reactions highly depend on the turbulence model. Furthermore, smoke can be displayed which also helps to understand the flow directions within the domain [30].



## 4 Results

The numerical results are shown and compared using different measurements as well as images from the CFD simulations. Furthermore, the resolution of all simulations is assessed using the  $D^*$  approach explained in Chapter 3.3.

For the measurements, several gas-phase temperature devices were distributed in a grid over the fuel bed. In addition to the wildfire behaviour metrics described before allows to analyse whether the litter layer is burning after the flame front caused by the grass blades passed.

In addition to the gas-phase devices, slice files are used to analyse the temperature development in a two-dimensional way. This allows to identify shapes within the flame front and analyse the flow behaviour.

### 4.1 Change in Grass Height

The influence of different grass blade lengths is first analysed by temperature measurements. As wildfires typically spread in a spherical or elliptical shape, gas-phase devices 5 and 8 are used to analyse the spread at the head of the wildfire.

Figure 13 displays the temperature over time of the base case as well as the models using shorter and longer grass blades. It can be identified that the shorter grass blades do not lead to sustained burning of the litter layer.

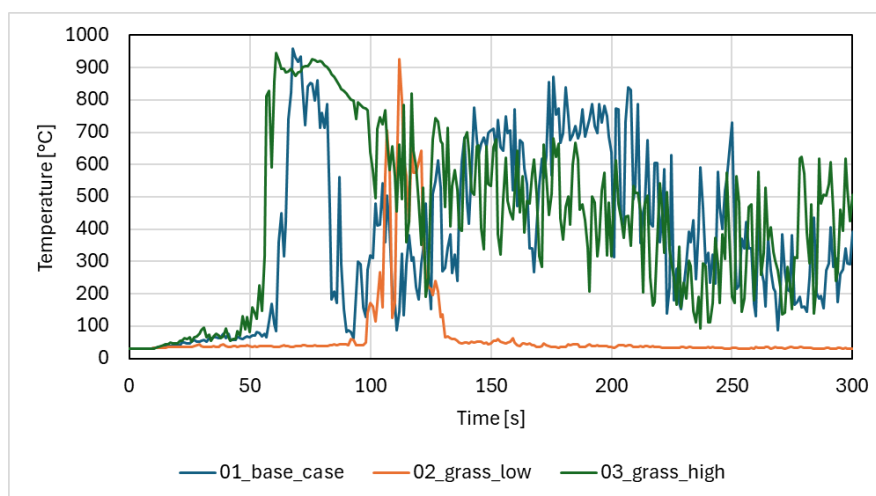


Figure 13: Numerical estimation of the influence of grass height on temperature in point 5.

As the main interest is the fire spread, the temperature development during the passage of the flame front is isolated in Figure 14. Based on graphs it can be observed that the peak temperature in all three models is in the same order of magnitude. However, the duration of peak temperatures as well as the residence time are different.

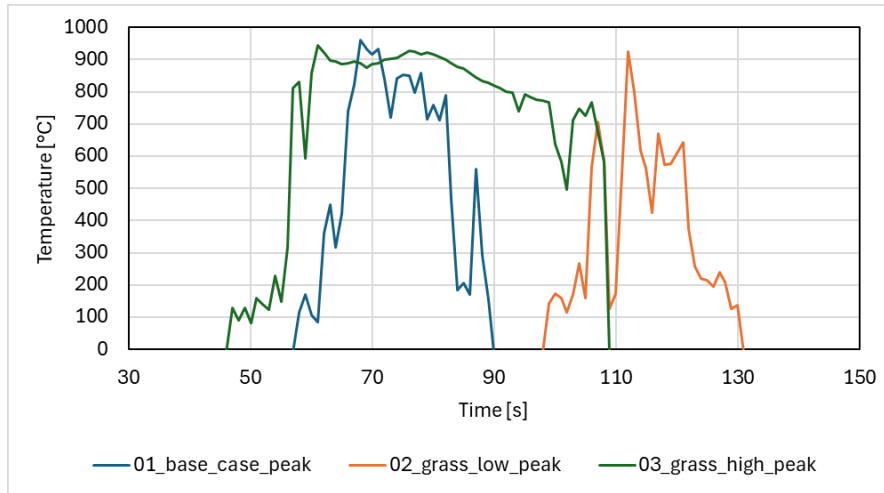


Figure 14: Numerical estimation of the influence of grass height on temperature in point 5. Isolated flame fronts.

The flame front in the base model results in a residence time of 32 s and a ROS of 0.022 m/s. Lowering the grass height results in the same residence time and a lower ROS of 0.008 m/s, which is about a third of the ROS in the base case. Increasing the grass blade length causes a residence time of 62 s and a ROS of 0.023 m/s. Thus, the residence time is nearly double the time from the base case. However, the ROS is in the same order of magnitude.

Looking at the visuals displaying the HRRPUV in FDS, which is used to analyse the flame shape, it can be identified that the flame front has a sawblade shape, which is common in wildfires [15]. The shape is shown in Figure 15. Furthermore, the burning of the litter layer after the flame front passed can be identified for the base case and the high grass layer but not for the low grass height in Figure 16. The low grass height is leading to the extinction of the flame front at later point. The flame length is increasing with an increasing vegetation height. This is based on the fuel mass available. The flame lengths vary between approximately 1 m for the low grass height, over 1.6 m for the base case, and up to 3.8 m for the long grass blades. Whether the results are reasonable or not is discussed in Chapter 5.

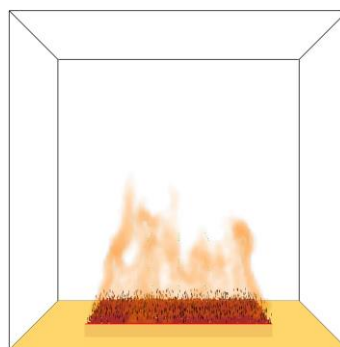


Figure 15: Sawblade shape of flame front common in wildfires. Screenshot displaying numerical heat release rate per unit volume from base case at 60 s.

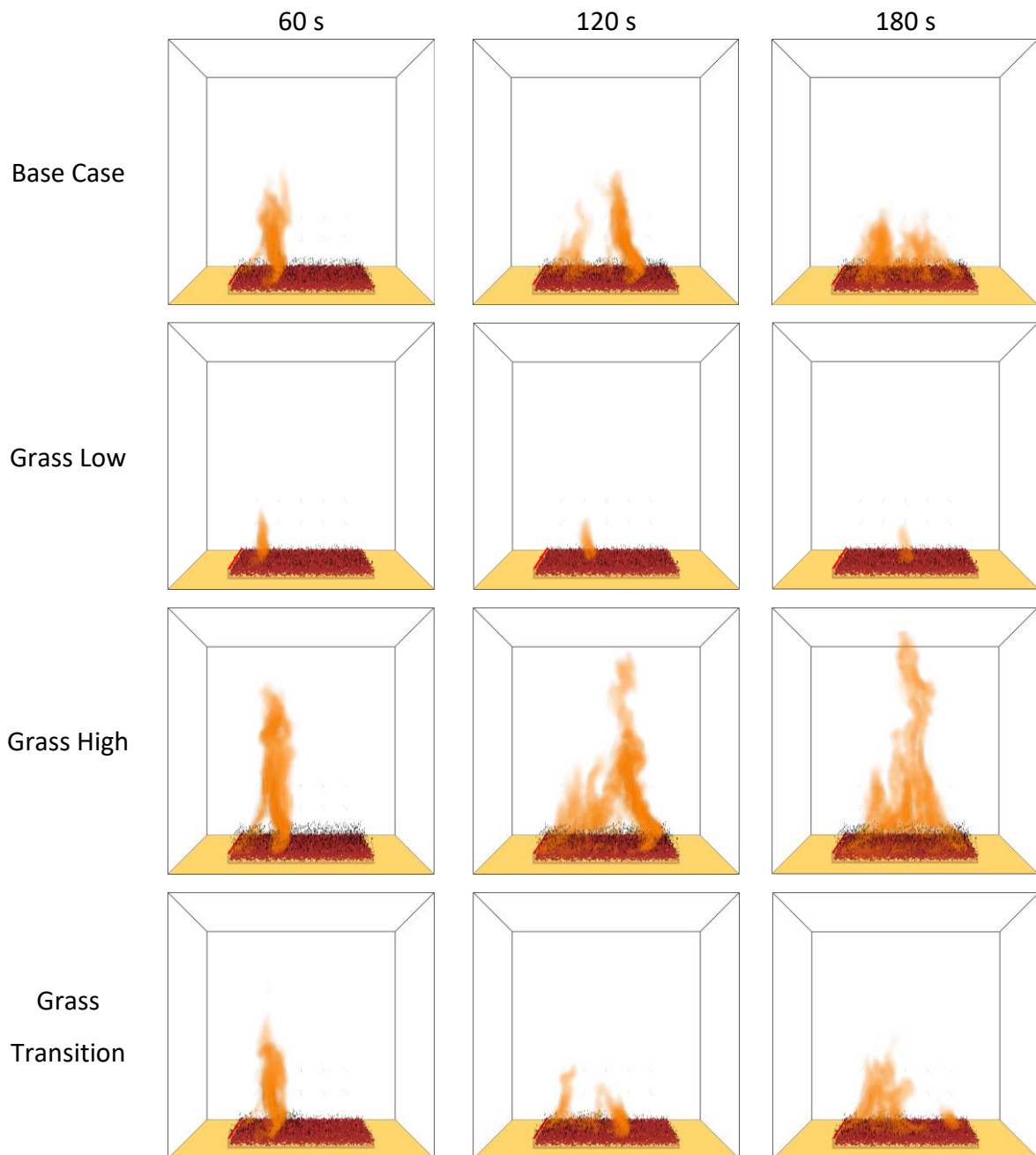


Figure 16: Development of the flame front and burning of litter layer using numerical heat release rate per unit volume for base case, grass low, grass high and grass transition simulations at 60 s, 120 s and 180 s.

Using a temperature slice file with a top view in Figure 17 allows to identify that the flame front is spreading at a uniform rate over its full width for the base model. After 180 s the complete vegetation layer has burned and only the litter layer is burning. The behaviour of the flame front is similar for the higher grass blades. Thus, the slices are not displayed. However, in case of a lower vegetation layer height, the flame front is decreasing in its length and starts to get a slightly bent shape until it extinguishes at some point as shown in Figure 18.

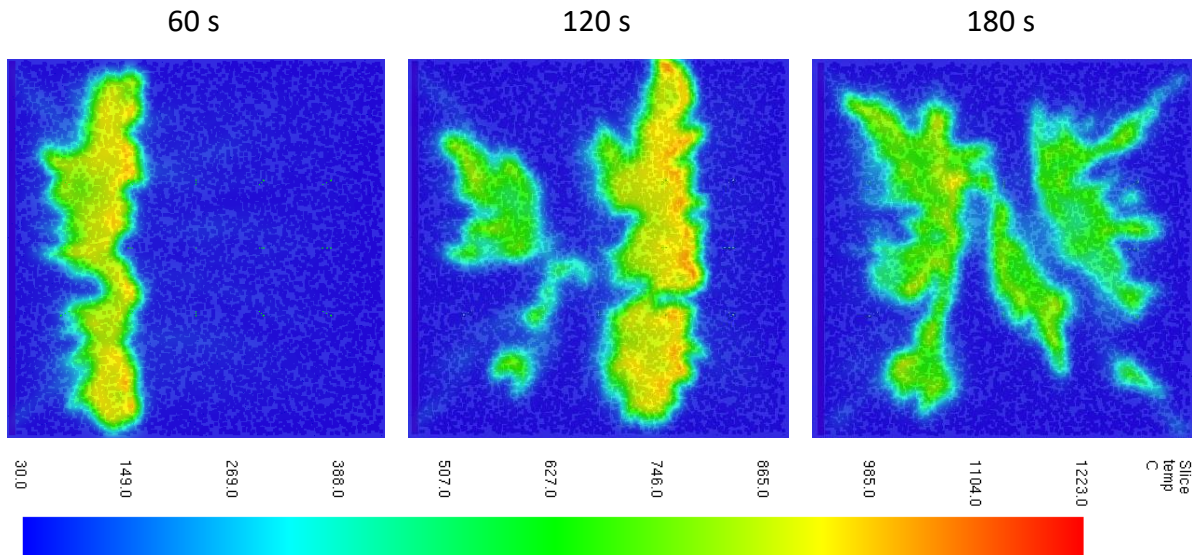


Figure 17: Development of the flame front and burning of litter layer base case simulation. Temperature slice file at  $Z=0.05$  m at 60 s, 120 s and 180 s.

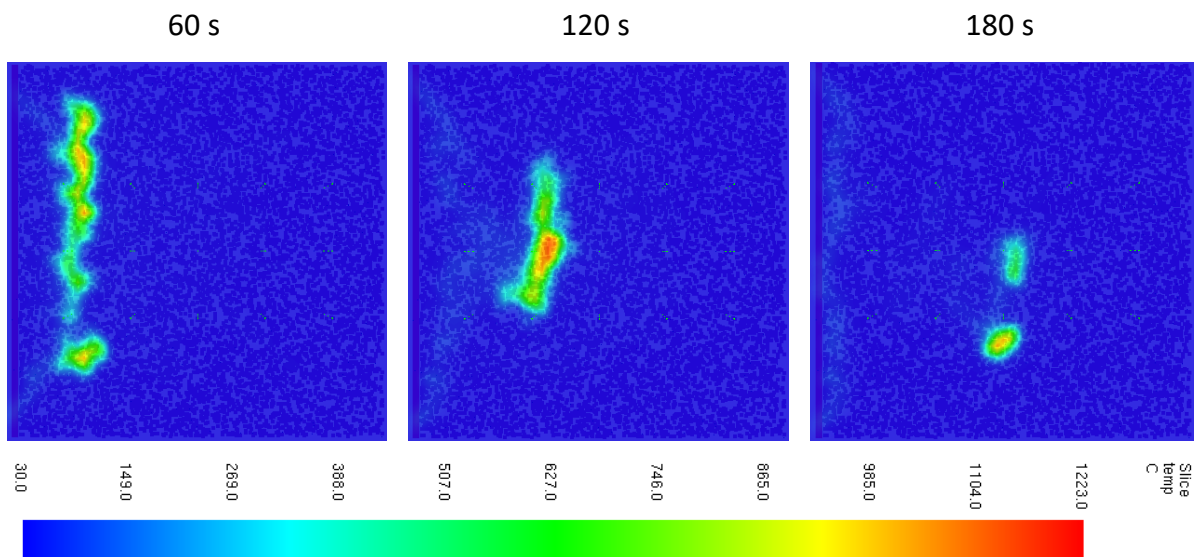


Figure 18: Development of the flame front and burning of litter layer grass low simulation. Temperature slice file at  $Z=0.05$  m at 60 s, 120 s and 180 s.

Furthermore, a simulation transitioning from the normal grass height to the low grass height is carried out. The results are only compared visually and by means of the HRR as the influence of the grass heights themselves is already analysed. First, the spread is comparable to the base case. Once the flame front reaches the shorter grass length after 1.5 m, the HRR in Figure 19 drops. In addition, Figure 20 shows that the flame front is becoming narrower over time. At approximately 250 s, the flame front extinguishes, and the second half, where the lower grass is located, shows no burning after flaming front passage, while the first one does.

Comparing the HRR of the different cases, the observed behaviour can be confirmed. In the base case, the flame front spreads over the whole surface within approximately 160 s, afterwards the HRR drops for a while and increases again due to the burning litter layer. For the low grass height, the extinction around 190 s is also visible in the plotted graph.

Furthermore, the amount of energy released is smaller than for the other simulations this is not only due to the smaller mass of grass blades but also because the litter layer is not burning. Increasing the vegetation layer height is causing a higher HRR, which also causes the litter layer to burn directly with the spreading flame front. Thus, the HRR has its maximum when the flame front reaches the end of the area.

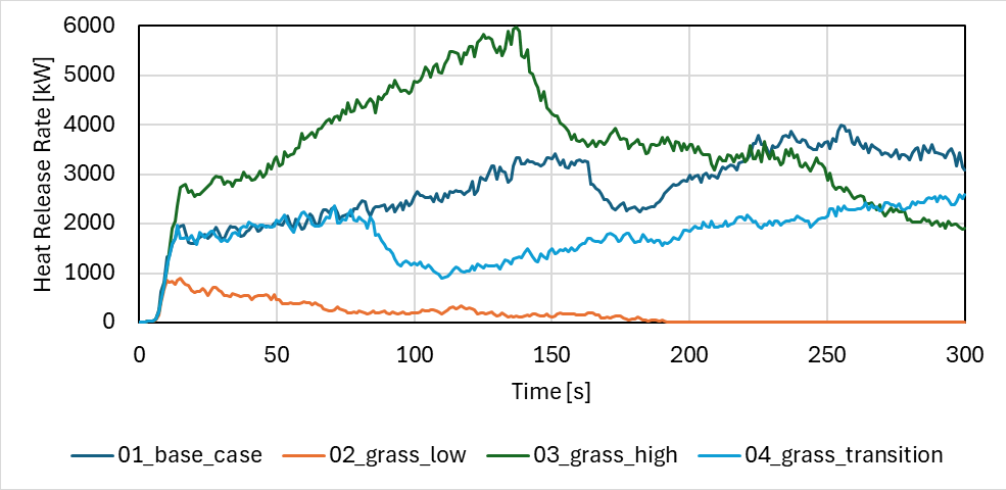


Figure 19: Influence of grass height on the numerically predicted heat release rate.

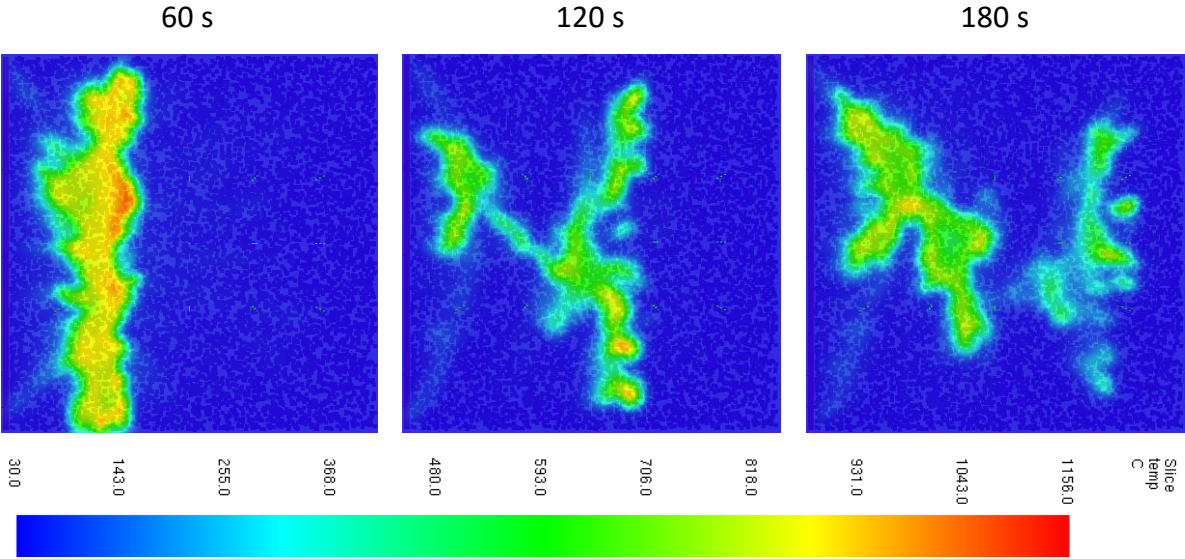


Figure 20: Development of the flame front and burning of litter layer grass transition simulation. Temperature slice file at  $Z=0.05$  m at 60 s, 120 s and 180 s.

#### 4.2 Change in Grass Packing Ratio

Changing the packing ratio of the vegetation layer to a low value leads to no sustained fire spread at all. The grass blade particles are not igniting. This can be seen in the temperature graph in Figure 21, as well as in Figure 22, displaying the flame behaviour.

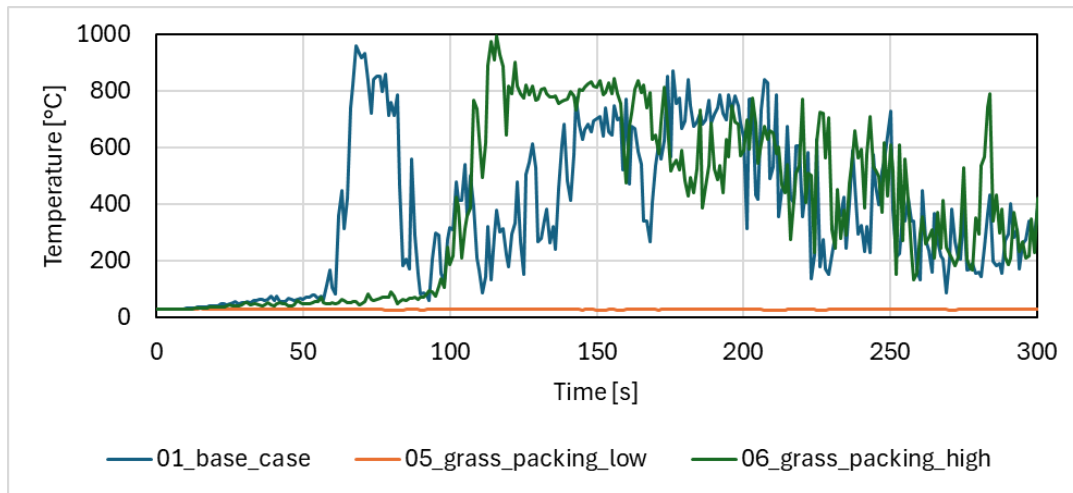


Figure 21: Influence of grass packing ratio on temperature in point 5.

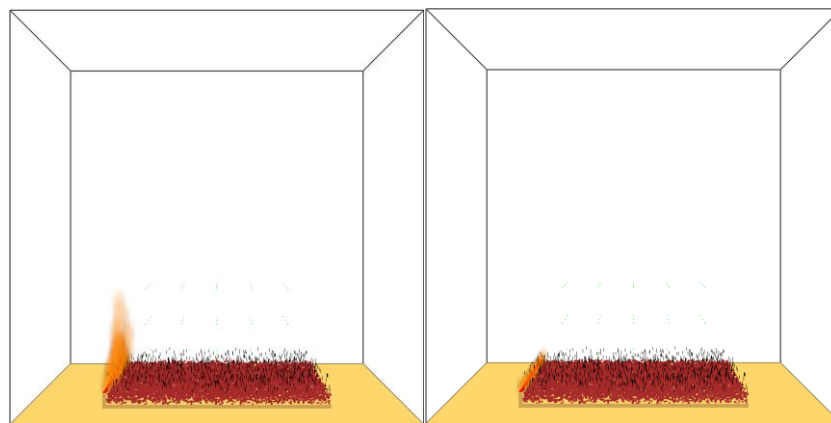


Figure 22: Burner leading to no ignition for low packing ratio of grass blade layer. Screenshots displaying heat release rate per unit volume at 7.5 s and 20.1 s.

Isolating the flame front demonstrates that a higher packing ratio is resulting in a sustained spread with a peak temperature in the same order of magnitude as the base simulation. This can be identified in Figure 23. However, the peak in temperature is reached later and the heat is sustained for a longer period. This indicates not only a smaller ROS but also a longer residence time. The rate of spread is found to be 0.02 m/s for the more densely packed model while it cannot be determined for the one with a low packing ratio. The high packing ratio also results in a residence time of 62 s.

Comparing the temperature slice files of the base case and the simulation with the large packing ratio in Figure 24 it can be identified that the flame front depth is larger in case of the higher packing ratio. This is also shown by the calculations carried out. The values for all simulations can be found in Table 4.



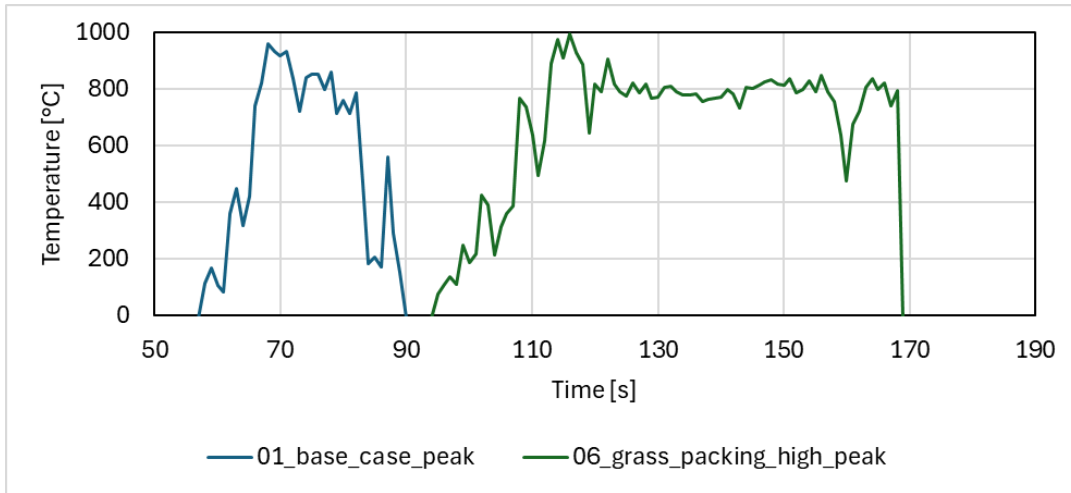


Figure 23: Numerical estimation of the influence of grass packing ratio on temperature in point 5. Isolated flame fronts.

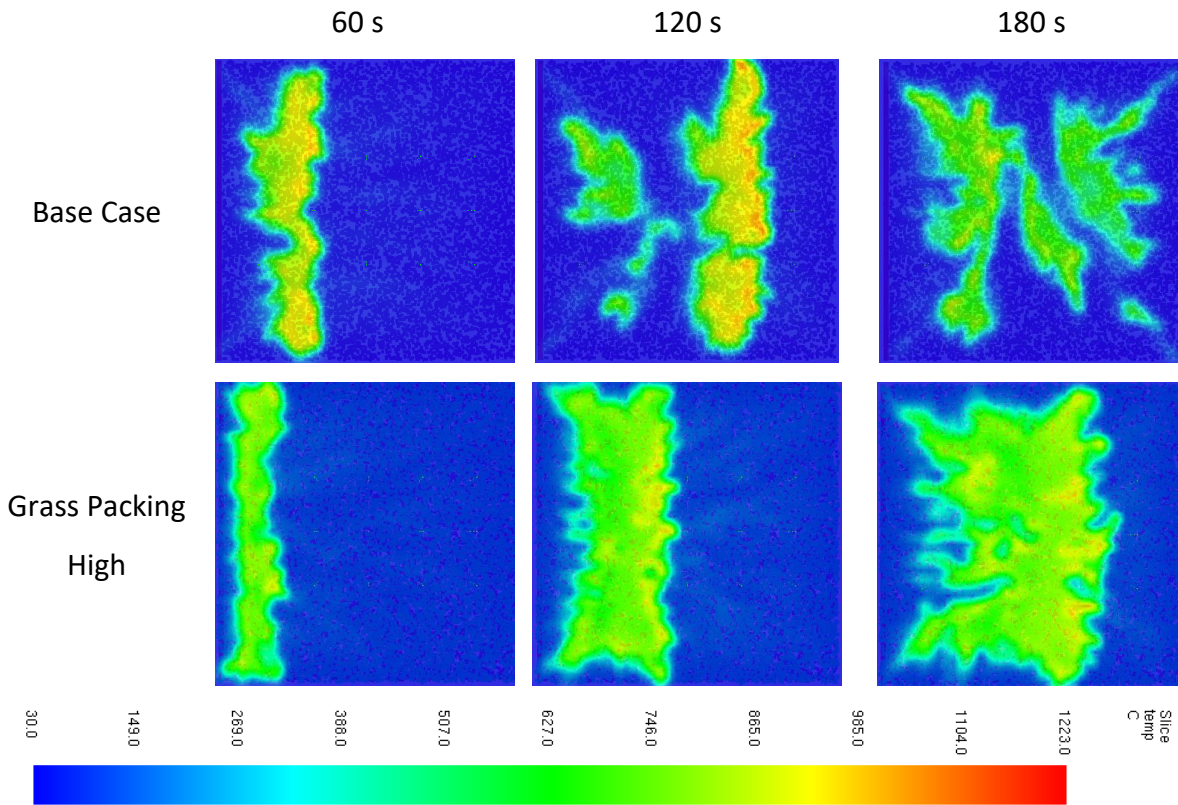


Figure 24: Development of the flame front and burning of litter layer base case and grass packing high simulation. Temperature slice file at  $Z=0.05$  m at 60 s, 120 s and 180 s.

The sawblade shape of the flame front, as shown in Figure 15 can be identified again. Furthermore, the litter layer is burning after the flame front passes in the simulation with the increased packing ratio, as shown in Figure 25. The litter layer burns in a circular shape with a flame height up to approximately 3.5 m in the centre. The litter layer is not extinguishing within the simulated time of 300 s.

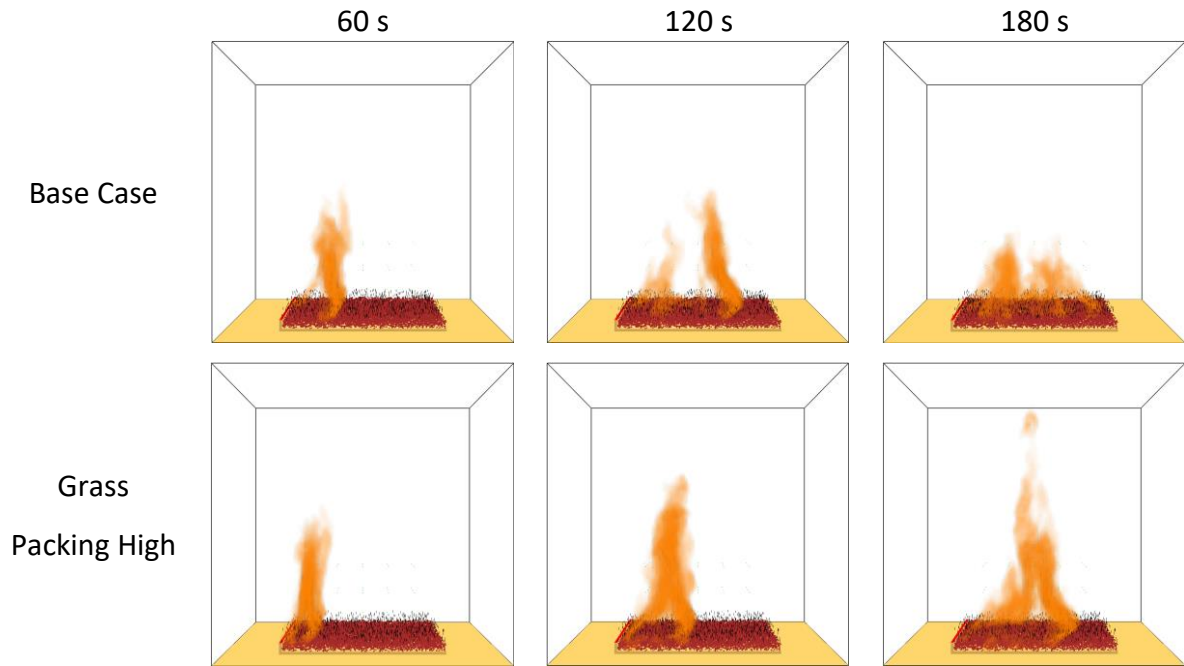


Figure 25: Development of the flame front and burning of litter layer using numerical heat release rate per unit volume for base case and grass packing high simulations at 60 s, 120 s and 180 s.

Analysing the HRRPUV for the model with the low packing ratio in combination with the HRR in Figure 26, it can be identified that the vegetation extinguishes once the burner used for ignition is turned off. Thus, the amount of pyrolysis gases generated from the amount of organic matter is insufficient to release enough heat for a sustained spread. The HRR of the high packing ratio proves that a higher packing ratio leads to a higher energy release. Furthermore, it can be identified that HRR is not growing again within the simulated time after the main flame front passed.

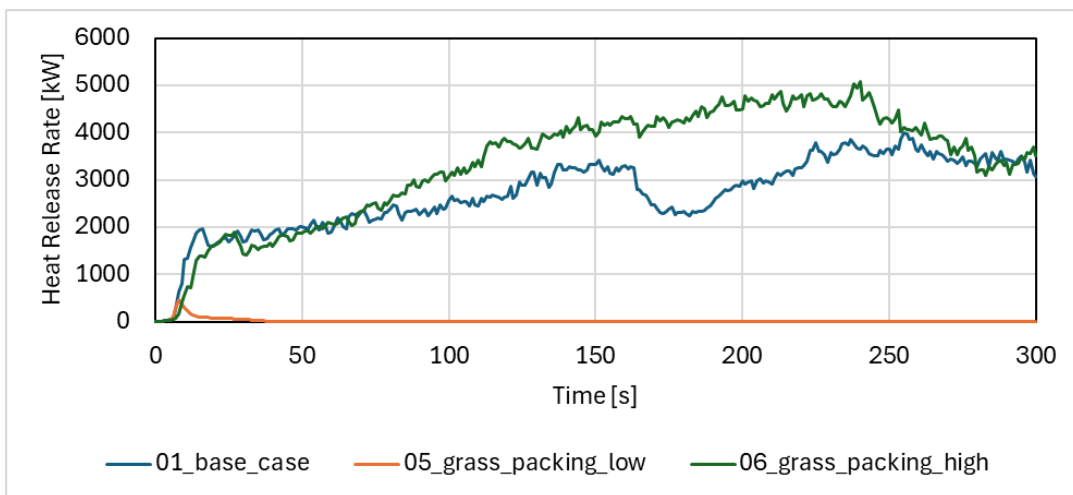


Figure 26: Influence of grass packing ratio on the numerically predicted heat release rate.

### 4.3 Change in Moisture Content

Moisture is mainly influencing the spread by the needed amount of energy to evaporate the water. Thus, it is expected that a higher moisture content causes a lower ROS. This is also seen in the conducted simulations. In addition, Figure 27 shows that a low moisture content is



resulting in a burning litter layer while the energy is not sufficient for igniting the litter layer in case of a high moisture content.

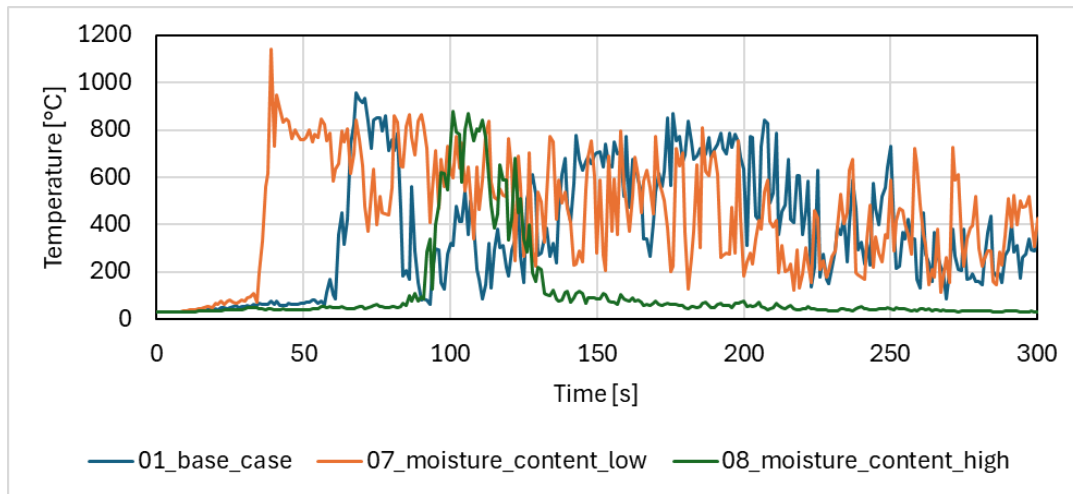


Figure 27: Numerical estimation of the influence of moisture content on temperature in point 5.

Not only the ROS is decreasing to 0.012 m/s with increasing moisture fraction, but also the residence time is increasing to 116 s. This is also displayed in Figure 28 using the isolated flame front temperature plots. Lowering the moisture fraction leads to a faster ROS of 0.036 m/s. However, the residence time of 39 s is also longer compared to the base case.

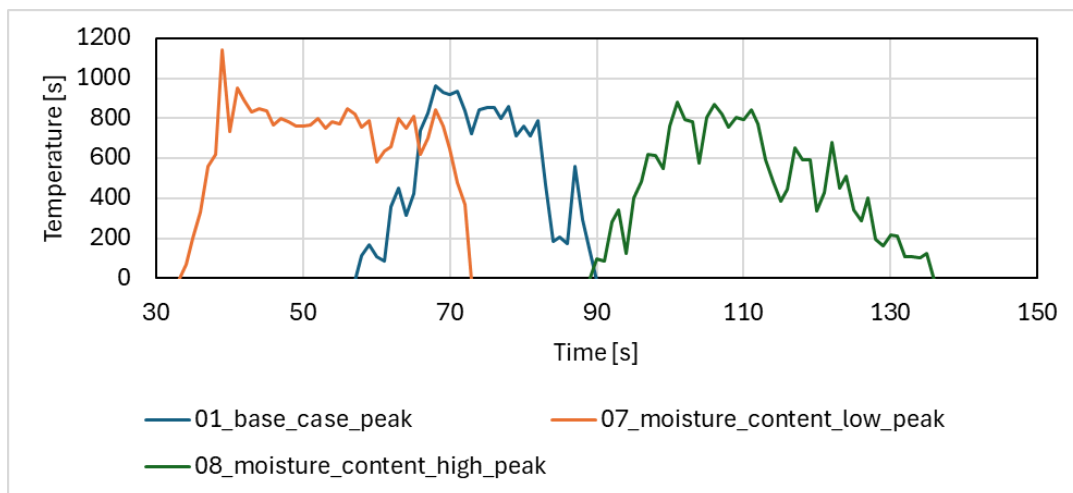


Figure 28: Numerical estimation of the influence of moisture content on temperature in point 5. Isolated flame fronts.

As in the other simulations, the flame front shows the sawblade shape. Comparable to the lowered grass height, the flame front becomes narrower and a bent shape. However, the flame front is not extinguishing within the modelled time and area. Figure 29 shows that the flame heights vary between the different simulations. While a high moisture content leads to a maximum flame height of 1.5 m, a low moisture content leads to a larger flame length of approximately 4 m. However, the flame height as well as the burning area are decreasing towards the end of the simulation. This is also displayed in Figure 30 using the temperature slice files.

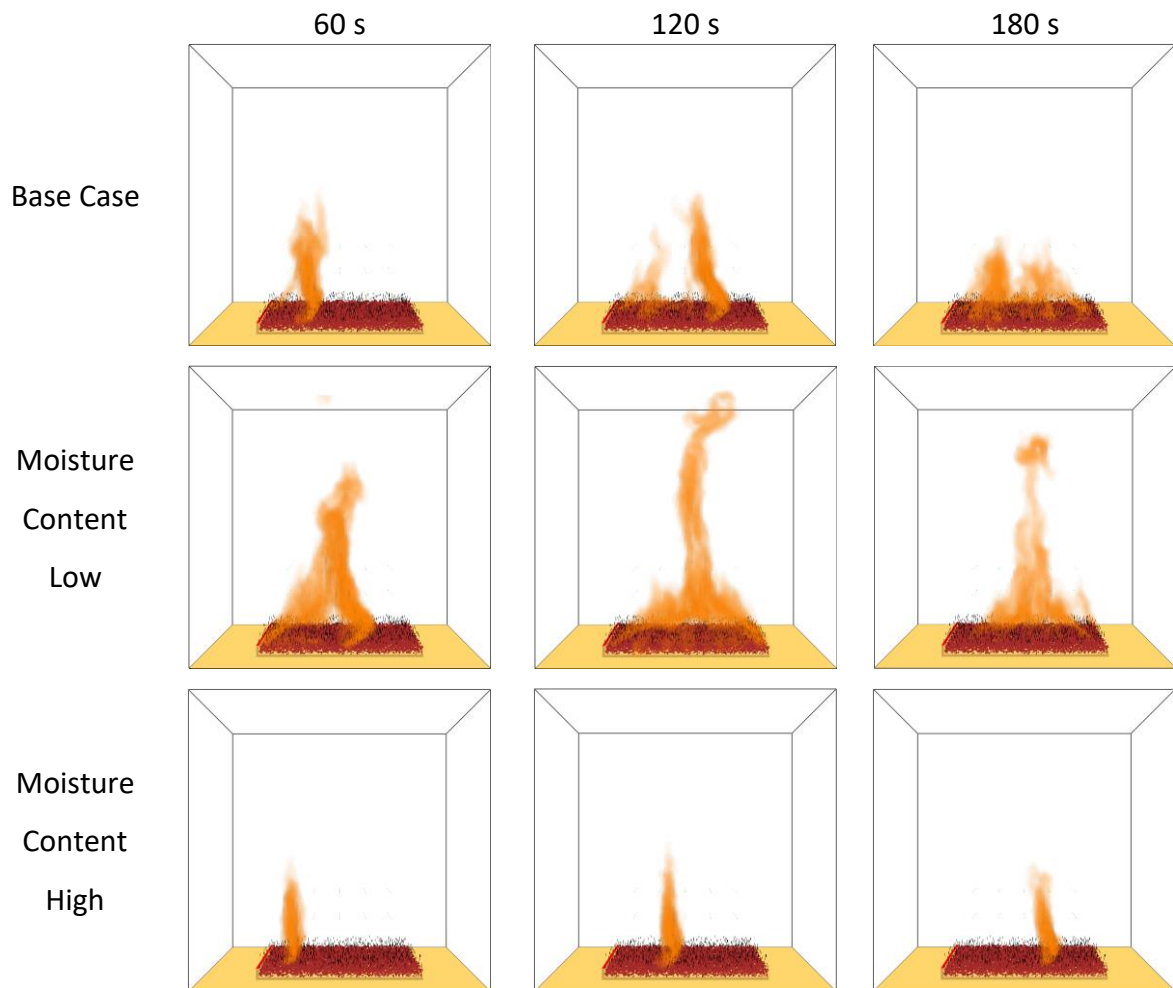


Figure 29: Development of the flame front and burning of litter layer using numerical heat release rate per unit volume for base case, moisture content low and moisture content high simulations at 60 s, 120 s and 180 s.

Analysing the HRR in Figure 31 the decrease in released energy at the end of the simulation using a lower moisture content can be identified as well. The energy release for the high moisture content shows a comparable stable HRR. This is connected to the homogeneous spread of the flame front without the litter layer burning afterwards. At the end, the released energy is decreasing. This is in line with the decreasing width of the flame front, as well as the fact that the flame front reaches the end of the modelled area.

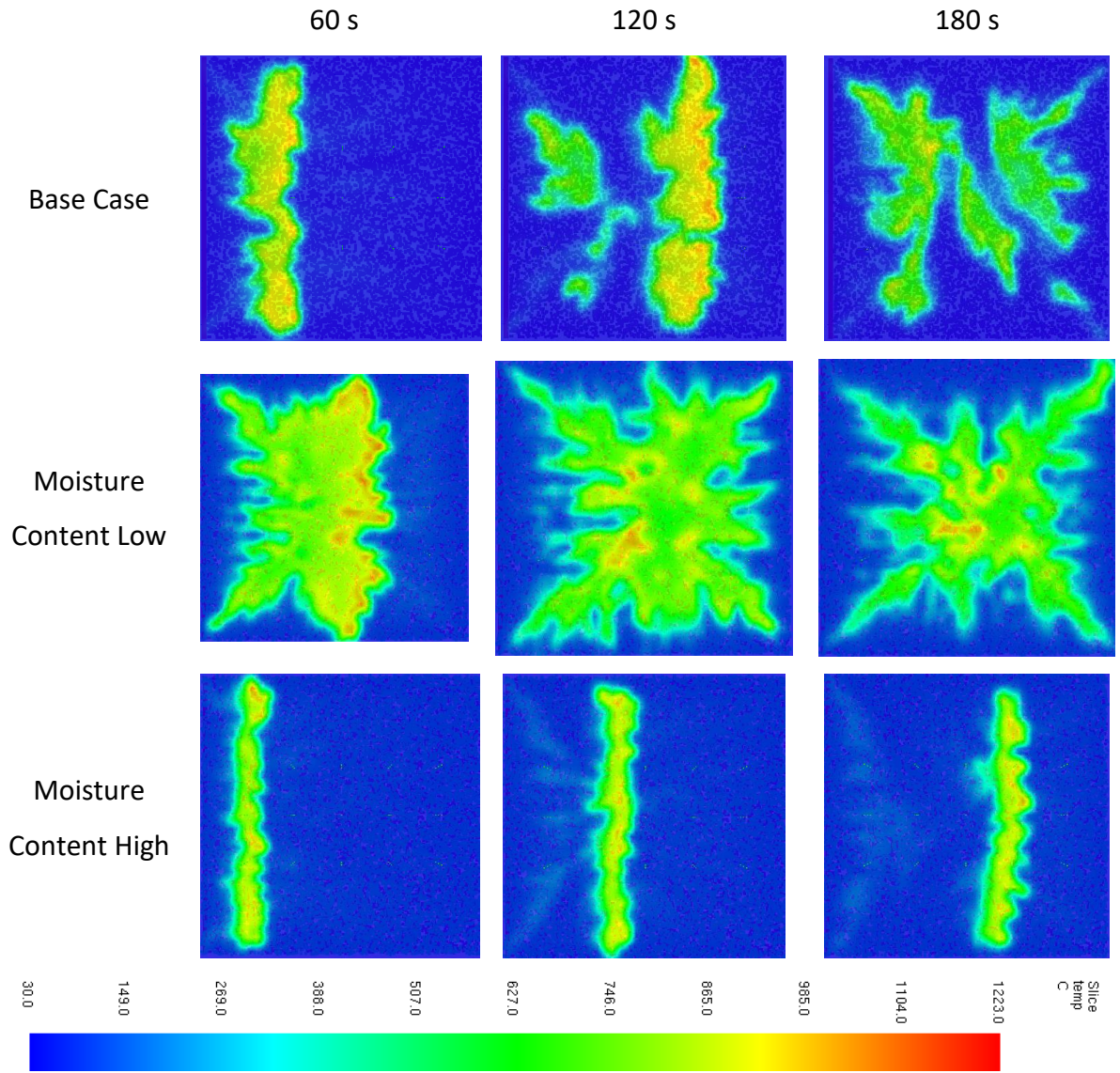


Figure 30: Development of the flame front and burning of litter layer base case, moisture content low and moisture content high simulation. Temperature slice file at Z=0.05 m at 60 s, 120 s and 180 s.

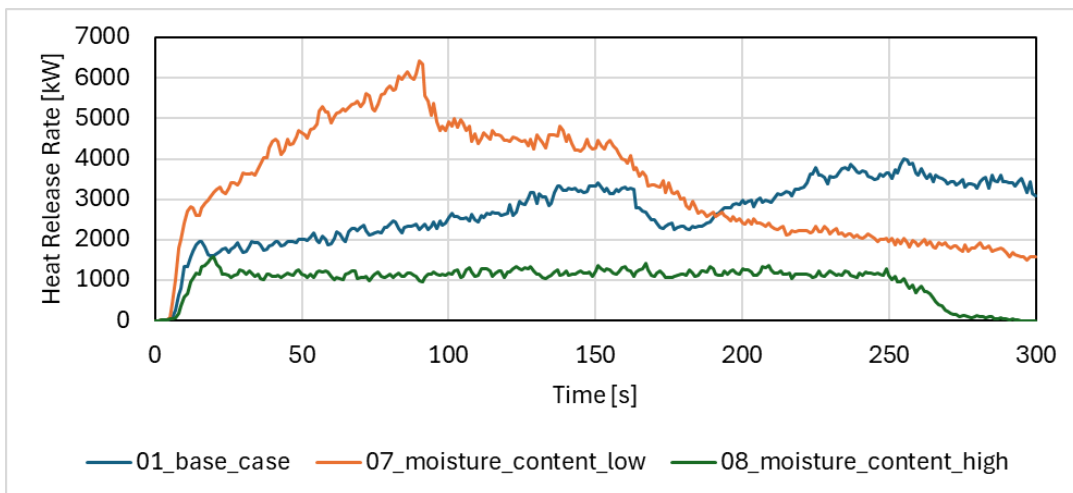


Figure 31: Influence of moisture content on the numerically predicted heat release rate.

#### 4.4 Branches Within Fuel Bed

The effects of branches introduced into the fuel bed are analysed only visually and by means of the HRR. Therefore, the HRR is shown in Figure 32 and compared with the base case. No major differences are identified.

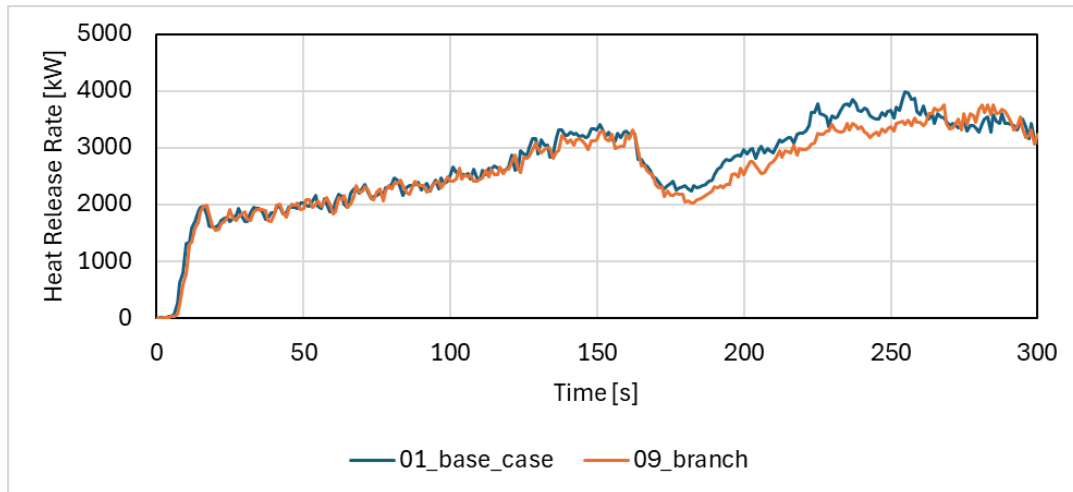


Figure 32: Influence of two branches introduced into the fuel bed on the numerically predicted heat release rate.

Visually, the flame front arrives at the perpendicular branch at timestep 54 s and at the parallel branch at timestep 80 s. The branches are not directly starting to burn. However, during the period after the flame front passed, some burning of the branches is identified in Figure 33. Analysing the temperature slice files shown in Figure 34 only minor differences are identified.

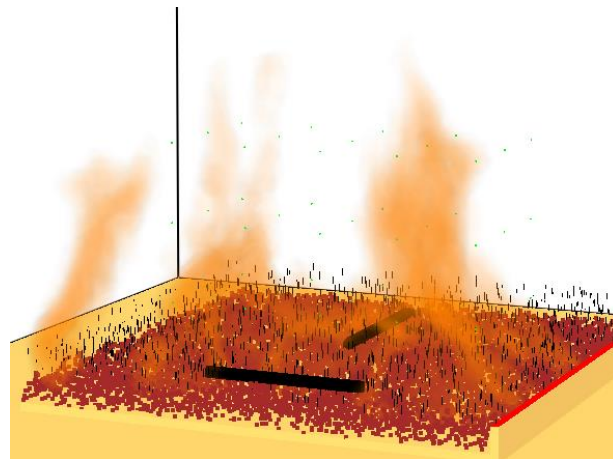


Figure 33: Partial burning of branches displayed using heat release rate per unit volume from numerical simulation at 160 s.



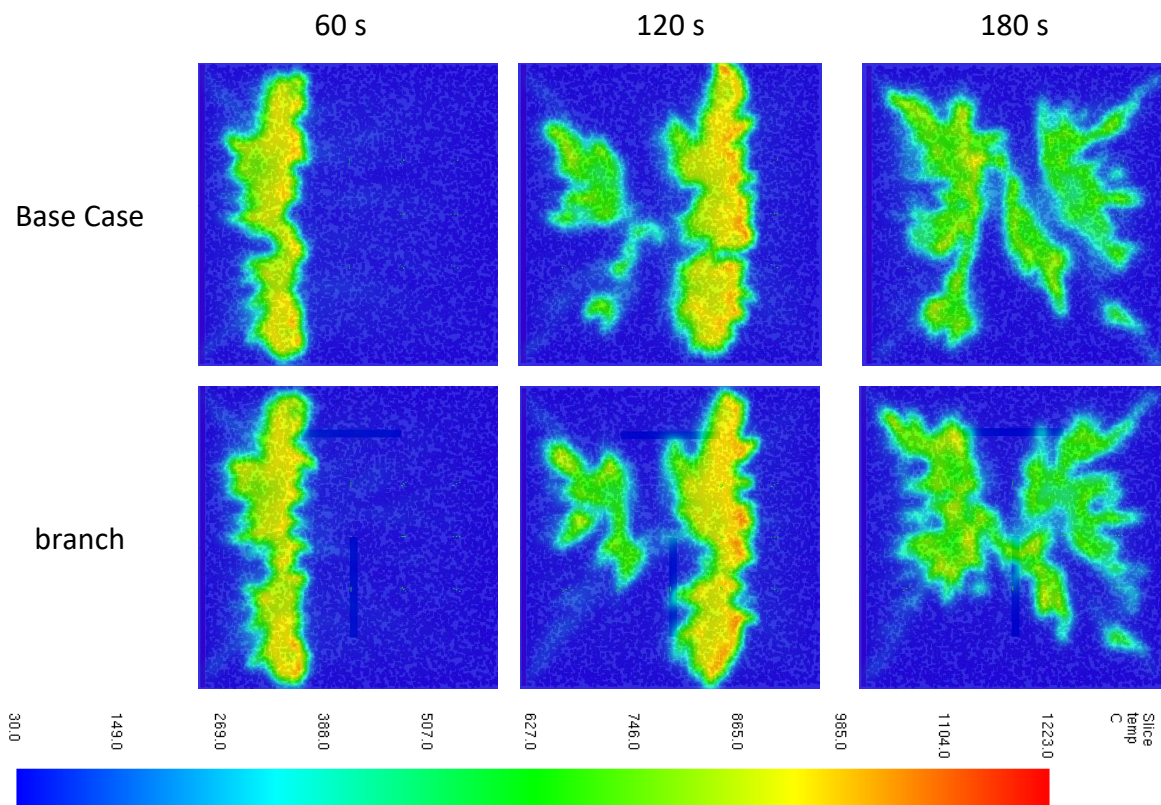


Figure 34: Comparison of the flame front and burning of litter layer between base case and model with introduced branches. Temperature slice file at  $Z=0.05$  m at 60 s, 120 s and 180 s.

#### 4.5 Wind towards Spread Direction

Introducing wind to the simulation is causing numerical instabilities in the conducted simulation. Due to the previous problems and the analysis of the cells causing errors, it is assumed that the interaction between the flames and the mesh boundary is the reason for the instabilities.

Due to this assumption, the results in the first few seconds are still analysed. As shown in Figure 35 the wind is forcing the flames to tilt and increases the ROS but decreases the residence time. Furthermore, the flame front depth is increased compared to the base simulation. This is also resulting in a larger HRR, as displayed in Figure 36.

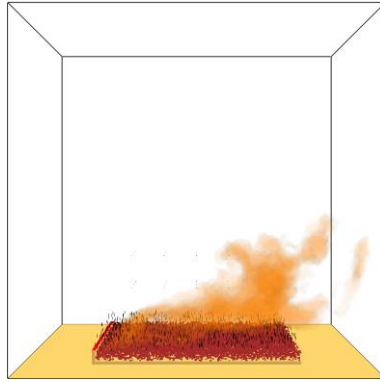


Figure 35: Tilted flame with increased flame depth due to induced wind. Screenshot displaying numerical heat release rate per unit volume at 60 s.

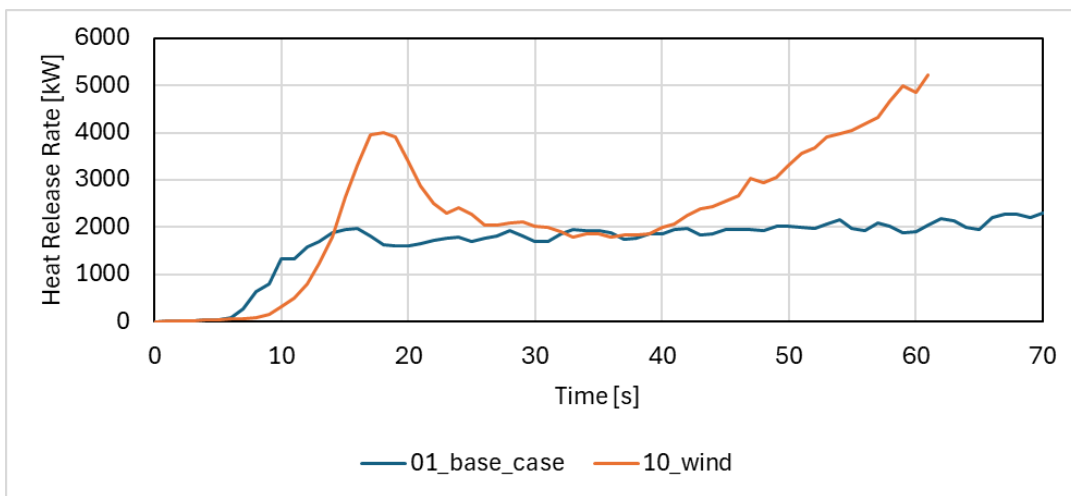


Figure 36: Influence of wind on the numerically predicted heat release rate.

#### 4.6 Change of Pyrolysis Kinetic Parameters

Comparing the results for the FDS default values describing pyrolysis kinetics for pine needles with the base case, which uses adapted pyrolysis kinetic parameters for grass blades, it can be observed that the temperature measurements are in the same order of magnitude. This is displayed in Figure 37 and Figure 38. Especially when looking at the burning after the flame front has passed. Anyhow, the peak, which indicates the flame front, is slightly delayed for the default parameters. The same behaviour can be observed in the HRR in Figure 40. Thus, it indicates that the pyrolysis in the local vegetation happens faster compared to the default parameters. The residence time of 27 s is smaller using the default parameters. The ROS of 0.02 m/s is in the same order of magnitude.

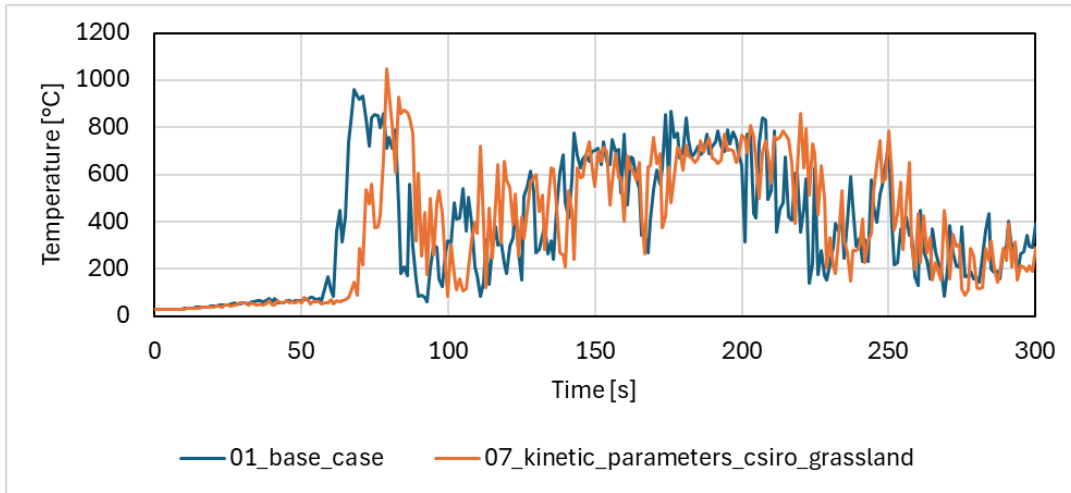


Figure 37: Numerical estimation of the influence of kinetic parameters on temperature in point 5.

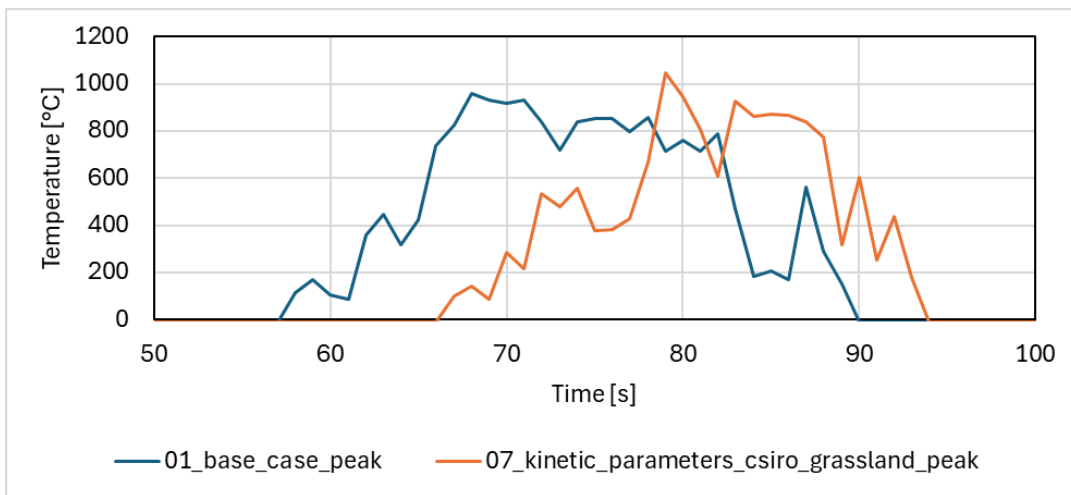


Figure 38: Numerical estimation of the influence of kinetic parameters on temperature in point 5. Isolated flame fronts.

The flame lengths for the default parameters look slightly longer, as shown in Figure 39. However, they are in the same order of magnitude. The overall burning behaviour is also comparable. Looking at the HRR, the only difference observed is a slight difference between the curves and that the HRR drops later in case of the default parameters.

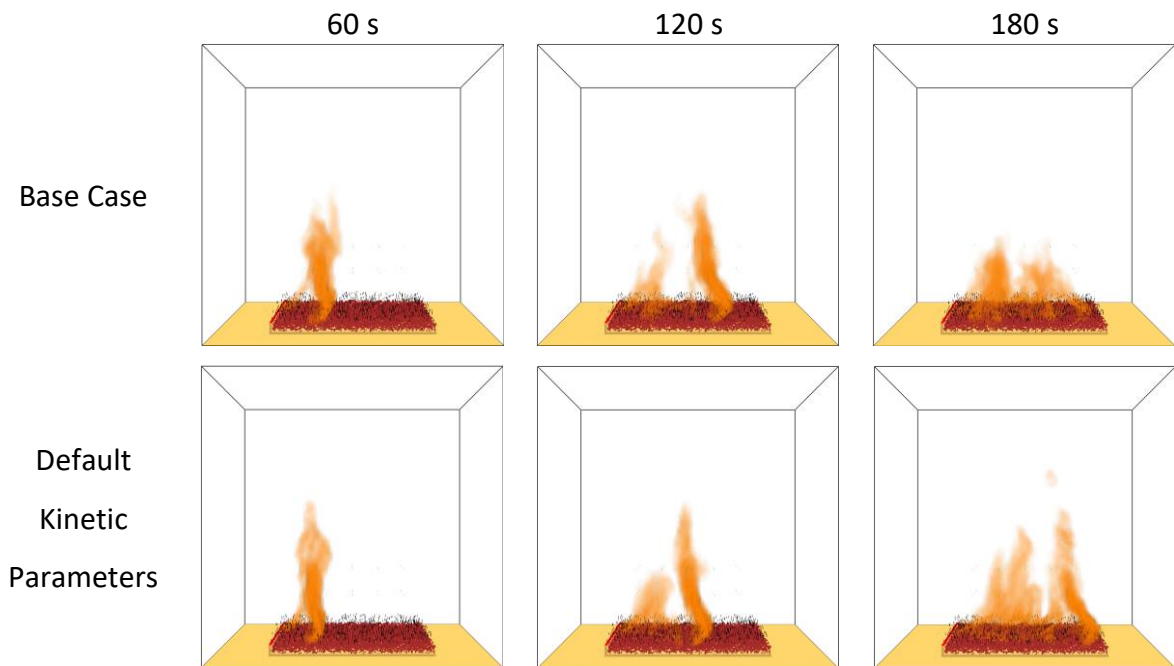


Figure 39: Development of the flame front and burning of litter layer using numerical heat release rate per unit volume for base case and default kinetic parameters at 60 s, 120 s and 180 s.

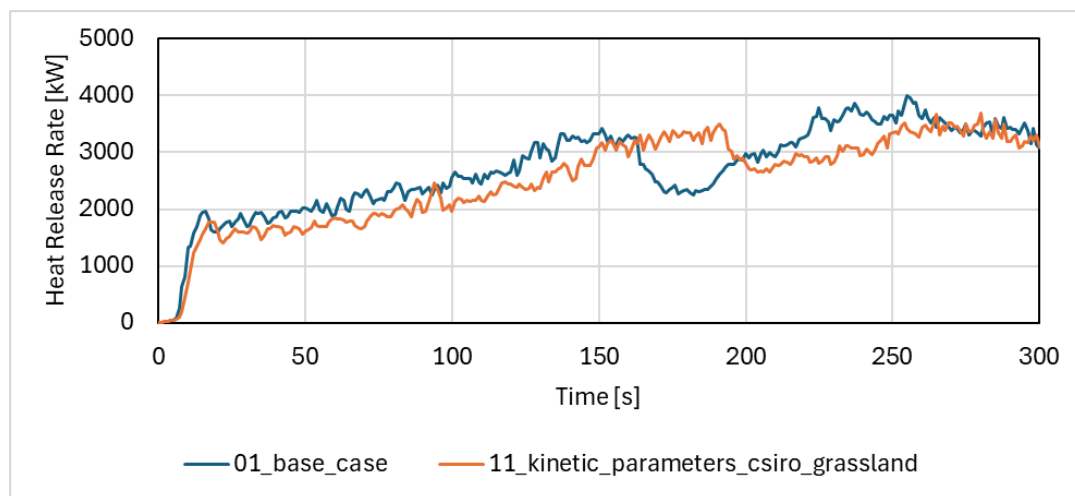


Figure 40: Influence of individual local pyrolysis kinetic parameters on the numerically predicted heat release rate.

#### 4.7 Change of Ambient Temperatures

A change in ambient temperature does not change the evolution of temperature significantly, as shown in Figure 41. The residence time and the rate of spread are in the same order of magnitude as the base case. This is shown in Figure 42 where the flame fronts from the grass blades are isolated.



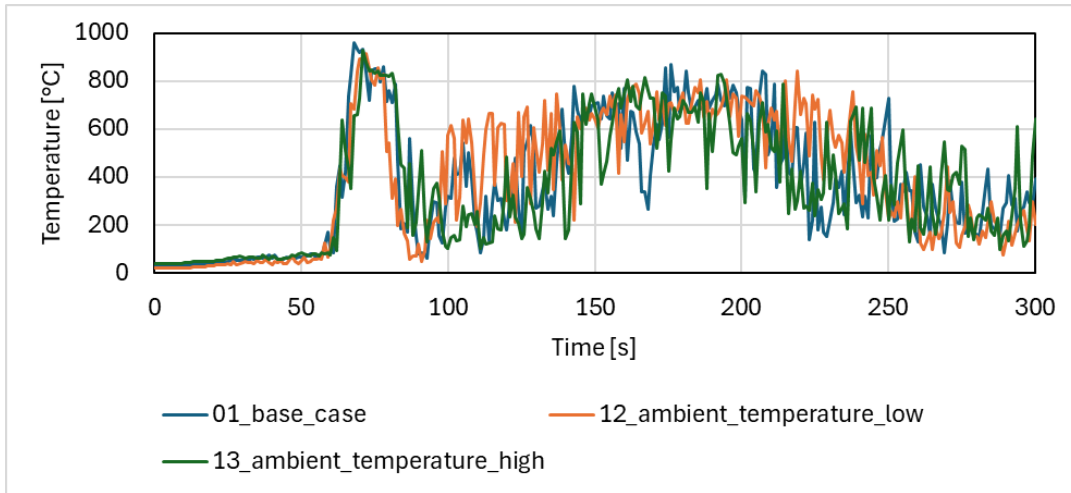


Figure 41: Numerical estimation of the influence of ambient temperature on temperature in point 5.

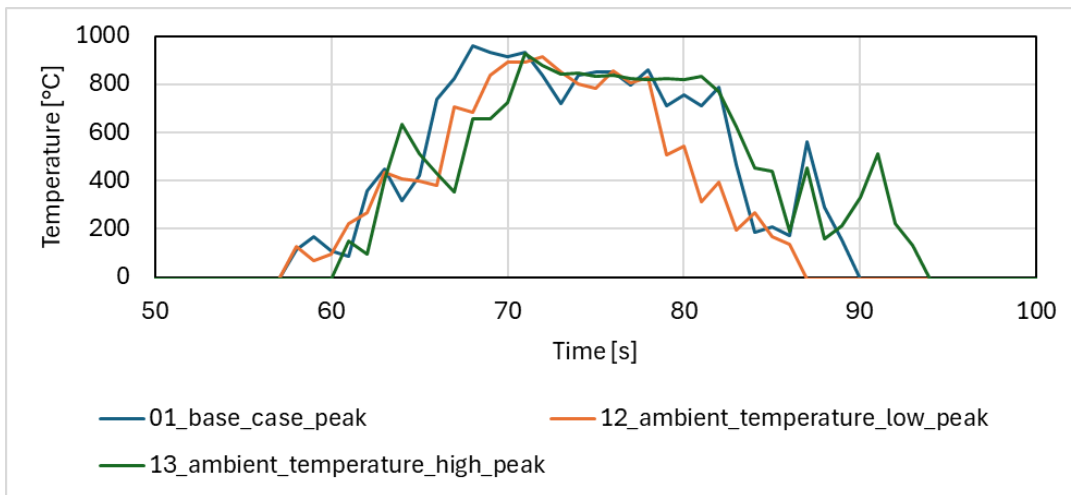


Figure 42: Numerical estimation of the influence of ambient temperature on temperature in point 5. Isolated flame fronts.

Furthermore, the HRR shown in Figure 43 is comparable to the base case. The burning behaviour analysed in Figure 44 shows no major difference in the simulations compared to the base case. Thus, no further analysis is carried out.

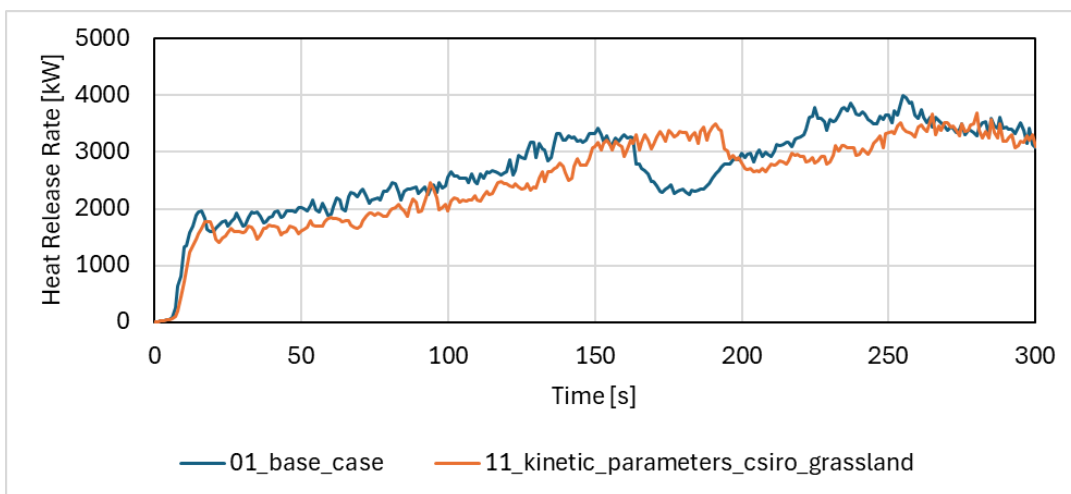


Figure 43: Influence of ambient temperature on the numerically predicted heat release rate.

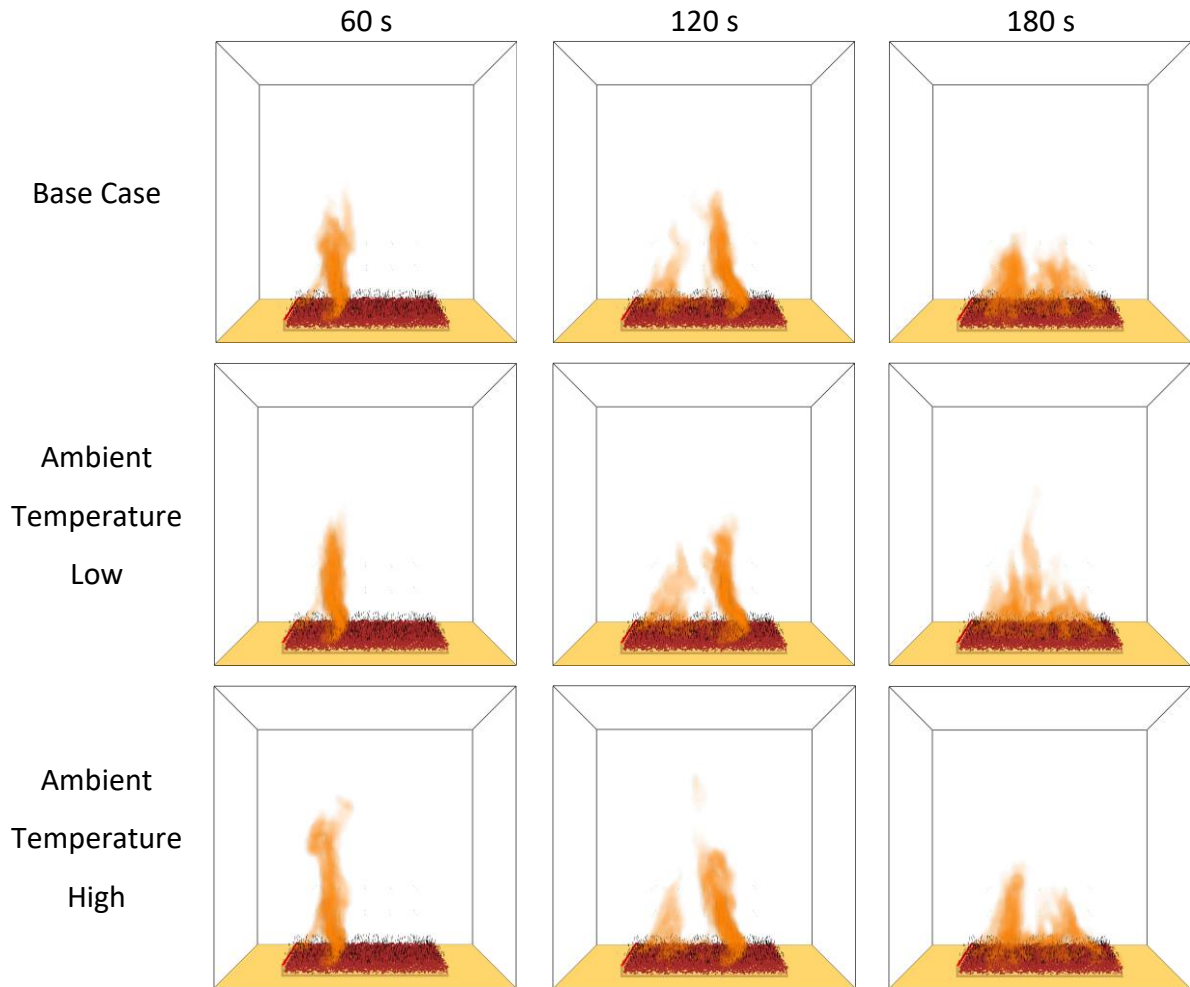


Figure 44: Development of the flame front and burning of litter layer using numerical heat release rate per unit volume for base case, ambient temperature low and ambient temperature high simulations at 60 s, 120 s and 180 s.

#### 4.8 Mesh Resolution

As described in Chapter 3.3 the mesh resolution can be analysed using the  $D^*$  approach. Therefore, the HRR is needed.

Heskestad's flame height correlation is utilized using equation (7). This describes the nondimensional flame height ( $D$ ) using the HRR as well as the ambient conditions.

$$D^* = \left( \frac{\dot{Q}}{\rho_\infty \cdot c_p \cdot T_\infty \cdot \sqrt{g}} \right)^{\frac{2}{5}} \quad (7)$$

The base case, which is developed in Chapter 3.4.2 results in a mean HRR of 2700 kW. In order to analyse the resolution of the parametric study, the lowest as well as the highest mean HRR are utilized. The lowest mean HRR is reached in the case with a lower grass layer height, with a value of 185 kW, while the highest value of 3500 kW is caused by the higher grass blades. Using these values with a cell size of 5 cm,  $D^*/\delta x$  is calculated and displayed in Table 3. Comparing the results with the values of the FDS Validation Guide, the resolution of all cases can be considered fine to very fine.

Table 3: Analysis of mesh resolution for base case and parametric study utilizing the  $D^*$  approach.

#	$\dot{Q}$ [kW]	$D^*$	$D^*/\delta x$
01	2700	1.41	28.25
02	185	0.48	9.67
03	3500	1.57	31.34

#### 4.9 Summary of Results

Summarising the results, it can be concluded that the fuel load as well as the moisture content influence the wildfire spread. This is based on the energy released compared to the energy required. Table 4 summarises the main values found for all the different simulations.

Table 4: Overview of numerical results focusing on the main flame front caused by combustion of the vegetation layer. Percentual deviation compared to the base case in brackets.

#	Simulation	Residence Time [s]	ROS [m/s]	Flame Front Depth [m]	Flame Height [m]
01	base_case	32	0.02	0.72	1.6
02	grass_low	32 (-)	0.01 (- 50 %)	0.26 (- 64 %)	1 (- 37 %)
03	grass_high	62 (+ 93 %)	0.02 (-)	1.47 (+ 104 %)	3.8 (+ 138 %)
04	grass_transition <sup>1</sup>	-	-	-	-
05	grass_packing_low <sup>2</sup>	-	-	-	-
06	grass_packing_high	62 (+ 93 %)	0.02 (-)	1.24 (+ 72 %)	3.5 (+ 119 %)
07	moisture_content_low	39 (+ 22 %)	0.04 (+ 100 %)	1.39 (+ 93 %)	4 (+ 150 %)
08	moisture_content_high	46 (+ 44 %)	0.01 (-50 %)	0.57 (- 21 %)	1.5 (- 6 %)
09	branch <sup>1</sup>	-	-	-	-
10	wind <sup>3</sup>	-	-	-	-
11	kinetic_parameters_csiro	27 (- 15 %)	0.02 (-)	0.54 (- 25 %)	1.6 (-)
12	ambient_temperature_low	29 (- 9 %)	0.02 (-)	0.69 (- 4 %)	1.6 (-)
13	ambient_temperature_high	33 (+3 %)	0.03 (+50 %)	0.83 (+ 15 %)	1.6 (-)

<sup>1</sup> No global results due to local change

<sup>2</sup> No ignition of vegetation particles

<sup>3</sup> Numerical instabilities

## 5 Discussion

Before creating the base case, a validation case was studied, and several test cases were carried out to understand the particle model of FDS. Afterwards, the base case was defined in Chapter 3.4.2. The theoretical background allowed to identify several parameters of interest which were varied for further models of a parametric study, and the results were displayed.

The following subchapters are used to compare the base case with the experiment as well as critically discuss the results. Furthermore, the findings of the parametric study are compared and judged. In addition, the problems encountered during the first test cases and their solutions are presented. Followed by a critical review of the overall used methodology and suggestions for further work within this field.

### 5.1 Test Cases

In the process of setting up and understanding the particle model, several test cases which were not presented in this work were carried out. This subchapter presents the main findings and problems faced. The aim of presenting not only the final simulations is to support future work carried out in this field. As the documentation of the wildland urban interface part is only based on one example.

First, numerical instabilities must be mentioned. Several test cases resulted in numerical instabilities and thus the simulations were terminated automatically. It seems that these problems were caused by the interaction between flames and the mesh boundaries. In the first models, a smaller distance between the mesh boundaries and the modelled vegetation was used. Several parameters were adjusted but none of them led to a stable simulation. Finally, increasing the distance between the mesh boundaries and the particles to 1 m allowed stable simulations. To avoid these numerical instabilities in the final models, it was also decided to not to use several meshes, as the flame front would need to pass through mesh boundaries while spreading.

Several other test cases resulted in no sustained spread. This is caused by the ratio between energy released and energy required. Due to the change of several parameters at once, it is difficult to identify the exact parameter causing this phenomenon. However, this behaviour is also described for some simulations of the parametric study.

In one small test case the HRRPUA of the ignition burner is displayed between the two particle layers. This behaviour was identified in a simulation with a very high particle density. Thus, the cells might have become packed too densely for the gases to rise and burn in and above the particle layer.

Overall, it can be said that the particle model is, in my opinion, not as easy to understand as the typical compartment applications of FDS. Anyhow, it helped a lot to work into the systematics of the model using a trial-and-error approach. Numerous smaller test cases were needed before defining the base case.

## 5.2 Comparing Experiment with Base Case

Comparing the observed wildfire behaviour during the experiment with the achieved numerical results, it can be said that the simulation cannot be validated using the experiment. Noting that the results are only compared visually.

The flame heights achieved using numerical methods are comparable higher. Furthermore, the burning behaviour after the flame front passes is unreasonable. In the experiment some smaller spots show flaming combustion and others show smouldering combustion. However, not the whole area is burning as identified in the numerical results.

Using the timestamps of the photos shown in Figure 45 and assuming a distance of 3 m, a ROS of 0.015 m/s can be estimated. Which is a deviation of 25 % compared to the 0.02 m/s for the base case. Anyhow, the ROS is in the same order of magnitude. The uncertainty of both results is comparably high as the ROS is assessed in both cases. For the numerical result, the peak of the temperature measurement is used to determine when the flame front reached and passed the measurement point. Using the time between two measurement points results in the ROS. In the experiment, the distance is estimated and the full ROS is calculated at once as the number of pictures is limited. Thus, the numerical results are deemed to be comparable good using the amount of data available.



Figure 45: Field experiment used for comparison. Time between photos 195 s. Photos from BAM.

The long flame lengths mentioned before might be caused by the fact that FDS is not capable of simulating smouldering combustion. Meaning there is either flaming combustion or no combustion at all. Thus, all pyrolysis gases are combusted under the presence of flames and the flame lengths are larger. Additionally, mixing and pyrolysis are complex processes. The chemical composition as well as the amount of pyrolysis gases may not represent reality. In addition, the full litter and upper duff layer are composed of flammable organic materials in the model. In forests, the upper duff layer is also including humus and other organic matter these particles are combustible as well, but they tend to be more densely packed and have a different surface to volume ratio. Thus, they are rather prone to smouldering combustion but not flaming combustion. Which causes combustion in those layers to take place in between the particles and not only at the upper surface [13,31].

Next to the already mentioned causes, it must be noted that modelling wildfires on such a small scale is quite challenging. In the simulations carried out within this work, the vegetation is modelled as a homogeneous vegetation layer. This is not representative of real wildland fuel



beds. Typically, fuel beds are formed by a variety of different fuels in various sizes. Each fuel particle reacts differently to the relative humidity of the air and the moisture fraction of the ground. Furthermore, the packing ratio of the fuel layers cannot be assumed to be homogenous, as different particles with different densities, sizes and shapes are causing different bulk densities. The influences of these local differences are getting less important, with an increasing domain size. The larger the domain, the more representative a more homogeneous and clustered fuel description is.

### 5.3 Importance of Parameters

Discussing all parameters of the parametric study one by one and putting the results into perspective, it can be said that the results are mostly as expected from the theory.

The grass height is controlling the fuel load in general. As the base case shows a sustained spread, it is expected that all the grass is burning. Anyhow, it is crucial to note that the ratio between the released energy from the combustion and the needed energy for pyrolysis plays an important role in wildfires. This can be identified especially with shorter grass blades. The energy released is not sufficient to cause a sustained spread over the whole surface. This behaviour is similar to the one observed during the experiments. Once the flame front reaches the lower grass, the flame front is not spreading further. A similar behaviour is identified in the case of the transition from normal to low grass. However, due to the litter layer burning heavily after the flame front passed, enough energy is provided for a sustained spread over the modelled area.

Changing the packing ratio changes the fuel load as well. Besides that, it also changes the ratio between fuel and air as an oxidizer. It cannot be clearly determined which of these ratios is causing the change in flame height. Anyhow, it is most probably the ratio between energy released and energy required, which is limiting the spread. Furthermore, the choice of the packing ratio is criticised as the decision was done just by taking an arbitrary low value. Anyhow a deeper literature research or more statistical analysis of the local parameters would have been beneficial.

The latter is also the case for a high moisture fraction. More energy is required to evaporate the whole water before the onset of pyrolysis. For the high moisture content, the spread is limited due to the amount of energy provided. The decision for the low moisture content is questionable as the material can already be considered too dry. Using the EMC as well as the lowest ambient relative humidity conditions should have been used to determine the lowest expected moisture content of the fuels.

The effects of the branches are not significant. Anyhow, for a less homogeneous and more precisely defined fuel bed the effects might be more significant. Especially if there are more moist fuels in the area and the dead branch acts as a way for the fire to still propagate. Furthermore, if the litter around the branch is smouldering, the woody fuel might turn into flaming combustion causing a faster spread. However, it is not yet possible to model smouldering fires using FDS. Thus, such influence needs to be analysed using other tools or preferably experiments.

As the wind causes numerical instabilities in the simulation carried out, the results are limited. Anyhow, the effect of wind on wildfires is known quite well. Usually, wind is assumed to accelerate the spread of the wildfire in the wind direction. This is based on the importance of convection as a heat transfer mechanism in wildfires. As the fuels are mainly thermally thin, hot surrounding air is needed for pyrolysis and thus fire spread. The wind forces the hot air in to one direction and it is not only rising due to buoyancy. Which is resulting in a faster ROS. Furthermore, it causes the shape of the wildfire to become rather elliptical than circular, with the larger extension in wind direction. These effects can also be seen in the simulations. Nevertheless, FDS is developed for low flow and incompressible calculations. Thus, one must be careful when introducing wind to FDS simulations.

Several research papers in the past were using the same pyrolysis kinetics for wildland fuels, no matter of the fuel itself. The simulation using different kinetic parameters than the default ones of FDS show that the difference between the default and the individual kinetic parameters are not significant. Thus, it makes sense to save costs and not quantify the own numerical parameters. However, note that this is only analysed for one application. For other fuel beds, the outcome might be different. One might think that the accuracy of individual parameters for a specific area is higher. However, increasing the accuracy of the kinetics in the three-step process could lead to the perception that the pyrolysis is considered very precise. But the three-step process is still simplified and comes with its own uncertainties. Furthermore, the kinetics used in this model are developed for grass blades, but the fuel bed is not only composed of grass blades. Due to the thermal thickness, only radiation is not sufficient to heat the fuel up to its pyrolysis temperature. Furthermore, a higher packing ratio is limiting the flows which has an impact on the convective heat transfer. Not only the flow speed over the fuel particles but also the mixing and cooling of the surrounding air are important for the fuels to heat up.

The influence of the ambient temperature in the simulations shows no significant effects. However, in real wildfires the ambient temperature is most of the time seen as an important parameter [10]. This is also connected with the relative humidity, which is not accounted for in the conducted numerical simulations. Thus, it is assumed that the particles have a steady moisture content and are only dried by the fire. Thus, the influence of the ambient temperature is rather related to the expected moisture content in the ground as well as in dead- and life-fuels.

Based on the observed behaviour, it can be said that the simulations can be tuned to field experiments and real wildfires using the parameters. Especially the fuel load represented in the packing ratio as well as in the vegetation height and the moisture content of the vegetation are influencing the spread significantly. Thus, it might be useful to collect more data with the focus on these parameters in the considered region. This would allow to define the parameters for numerical solutions in a more statistical way. This proposal is elaborated further in the next paragraphs.

#### 5.4 Improvements and Suggestions for Further Work

Reviewing the methodology, the particle model is, in my opinion, the right choice for modelling wildfires on this scale. Furthermore, the choice of representing the fuel bed in layers of particles to create an idealised fuel bed works well. Anyhow, it would be beneficial to collect more samples from similar vegetation. The packing ratio as well as the moisture content of the near ground vegetation should be analysed together with its height. Furthermore, the packing ratio and moisture content of the litter layer in the same place should be analysed separately. By doing this at several different sample points the parameters could be determined statistically, and one could define a fuel model which is representative of a certain region and vegetation. Comparable to the fuel model developed by Anderson [32]. The moisture content could be varied using the concept of EMC and the relative humidity of the air.

Especially, the results of the burning behaviour of the litter layer are not comparable to the experiment. Further work should focus on the burning behaviour of litter layers and whether it is feasible to model this behaviour using FDS. It is unclear whether the burning behaviour after the flame front is an artifact of the resolution or if the parameters need to be adjusted. Therefore, one should start improving the sensitivity study by using a finer grid. Anyhow, it must be mentioned that the faster spread is caused by the vegetation. Thus, depending on the use of the simulations, it might not be needed to analyse the burning behaviour of the litter layer more in depth.

Next to the outcomes and measurements the computational time and use of such simulations need to be critically discussed. Using the particle model for operational purposes seems impractical. It takes about four to seven days to complete the simulations in the resolution they are carried out. Thus, it takes even more time for larger areas, which are more of an interest to operational users. This leads to the conclusion that the particle model is more suitable for research applications.



## 6 Conclusions

The local vegetation and its parameters play a crucial role in surface fire spread. Especially the moisture fraction, packing ratio and vegetation height are of interest. A change in these parameters is mainly leading to a change in the ratio between the energy released by combustion and the energy required for pyrolysis. This is causing a change in the ROS, which is one main parameter used to describe wildfires. It is for example used to calculate the time when a wildfire will reach a vulnerable infrastructure.

Following the work carried out in this thesis the research questions can be answered as follows:

1. What are the main fire spread mechanisms in the litter layer and the near ground vegetation?

The main fire spread mechanisms in the litter layer and near ground vegetation is direct flame contact and heat exposure by radiation and convection. The dominant heat transfer mechanism in case of wildfires is convection. Wildland fuel beds mainly consist of thin particles which cannot be ignited only by radiation. As the fuel particles are experiencing cooling in parallel. Thus, they don't reach their pyrolysis temperature only through radiation. Convection causes the surrounding air to heat up more as well. Due to the shallower temperature gradient, cooling is slower, and the particles degrade and produce pyrolysis gases.

2. How are the spread mechanisms influenced by the structure of the local vegetation and dead fuels?

The structure of the local vegetation and dead fuels mainly influences the spread by changing the energy balance. The fuel load changes the mass available for combustion and thus the amount of energy released. The moisture content on the other hand leads to a higher energy consumption until the fuel undergoes combustion as the moisture needs to be evaporated before the onset of thermal degradation. Thus, a lower moisture content is causing a faster spread.

Overall, the parametric study conducted using numerical simulations demonstrates the importance of the moisture fraction as well as the vegetation height and the packing ratio. The aforementioned parameters can be used to tune the model to the identified behaviour in field experiments or wildfires. Anyhow, the values then might not match the measurements exactly as several parameters can be used to tune the model. Thus, simulations of the expected local behaviour as a precautionary measure need to be critically reviewed.

## 7 Future Research

Throughout the discussion several suggestions for future research are made. This chapter aims to list all the suggestions for an overview of relevant topics for future research. However, since the wildfire research is such a new topic especially in northern Europe, the listed suggestions are only a small part of topics for future research.

1. Collect more samples in similar vegetation to analyse the moisture content, vegetation height, and packing ratio in a more statistical way.
2. Carry out further sensitivity study with a finer grid resolution.
3. Analyse a different type of vegetation (e.g. in a deciduous forest).
4. Investigate further on the need of local pyrolysis kinetic parameters.

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## Appendix A: FDS Input Files

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&TIME T_END=300.0 /
&MISC SIMULATION_MODE='LES', TMPA=30.0 /
&DUMP PLOT3D_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV'/

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP_FRONT=1000., RAMP_Q='ignitor' /
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&RAMP ID='ignitor', T= 3 , F= 0.289363955 /
&RAMP ID='ignitor', T= 6 , F= 0.606194983 /
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&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

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&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF_ID='GROUND' /
&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF_ID='GROUND' /

&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /

&MATL ID='DIRT'
  CONDUCTIVITY = 0.25
  SPECIFIC_HEAT = 2.
  DENSITY = 1300. /

&SURF ID='GROUND'
  DEFAULT=T
  MATL_ID='DIRT'
  THICKNESS=0.2 /

&SURF ID          = 'grass surface'
  MATL_ID(1,1:1)  = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.15
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SURFACE\_VOLUME\_RATIO = 7500.  
LENGTH = 0.05  
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EMISSIONSIVITY = 0.9 /

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SURFACE\_VOLUME\_RATIO = 7500.  
LENGTH = 0.05  
GEOMETRY = 'CYLINDRICAL'  
EMISSIONSIVITY = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE\_FRACTION=0.3, SOOT\_YIELD=0.01,  
HEAT\_OF\_COMBUSTION=18433 /

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&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

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E = 209820  
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NU\_MATL = 0.25  
MATL\_ID = 'CHAR'  
HEAT\_OF\_REACTION = 418. /

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```

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MASS_PER_VOLUME=8.6, DRY=T / ***Grass Layer***
```

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&PROP ID='branch image', SMOKEVIEW_ID='TUBE', SMOKEVIEW_PARAMETERS='L=0.05','D=0.075','DIRY=1' /
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```
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```

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&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## O2\_grass\_low

```
&HEAD CHID='02_grass_low' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /
&TIME T_END=300.0 /
&MISC SIMULATION_MODE='LES', TMPA=30.0 /
&DUMP PLOT3D_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP_FRONT=1000., RAMP_Q='ignitor' /
&RAMP ID='ignitor', T= 0 , F= 0.000000000 /
&RAMP ID='ignitor', T= 3 , F= 0.289363955 /
&RAMP ID='ignitor', T= 6 , F= 0.606194983 /
&RAMP ID='ignitor', T= 9 , F= 0.739029717 /
&RAMP ID='ignitor', T= 12 , F= 0.915547025 /
&RAMP ID='ignitor', T= 15 , F= 1.000000000 /
&RAMP ID='ignitor', T= 18 , F= 0.924482097 /
&RAMP ID='ignitor', T= 21 , F= 0.891918724 /
&RAMP ID='ignitor', T= 24 , F= 0.801707592 /
&RAMP ID='ignitor', T= 27 , F= 0.591965054 /
&RAMP ID='ignitor', T= 30 , F= 0.492156993 /
&RAMP ID='ignitor', T= 33 , F= 0.373486002 /
&RAMP ID='ignitor', T= 36 , F= 0.201072209 /
&RAMP ID='ignitor', T= 39 , F= 0.134423191 /
&RAMP ID='ignitor', T= 42 , F= 0.118604805 /
&RAMP ID='ignitor', T= 45 , F= 0.015818386 /
&RAMP ID='ignitor', T= 48 , F= 0.010854458 /
&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF_ID='IGNITION' /
&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF_ID='GROUND' /
&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF_ID='GROUND' /

&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /

&MATL ID='DIRT'
  CONDUCTIVITY = 0.25
  SPECIFIC_HEAT = 2.
  DENSITY = 1300. /

&SURF ID='GROUND'
  DEFAULT=T
  MATL_ID='DIRT'
  THICKNESS=0.2 /

&SURF ID = 'grass surface'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.15
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
```

```

EMISSIONITY = 0.9 /

&SURF ID = 'litter and duff'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.42
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
  EMISSIONITY = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'
  DENSITY = 500.
  CONDUCTIVITY = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A = 2.38E+15
  E = 209820
  NU_SPEC = 0.75
  SPEC_ID = 'FUEL VAPOR'
  NU_MATL = 0.25
  MATL_ID = 'CHAR'
  HEAT_OF_REACTION = 418. /

&MATL ID='MOISTURE',
  SPECIFIC_HEAT=4.19,
  CONDUCTIVITY=0.6,
  DENSITY=1000.0,
  HEAT_OF_REACTION=2259.0,
  SPEC_ID(1,1)='WATER VAPOR',
  NU_SPEC(1,1)=1.0,
  A=6.0E+5,
  E=4.82E+4,
  N_T=-0.5/

&MATL ID = 'CHAR'
  DENSITY = 300.
  CONDUCTIVITY = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A = 430.
  E = 74800.
  MATL_ID = 'ASH'
  NU_MATL = 0.10
  SPEC_ID = 'PRODUCTS','AIR'
  NU_SPEC = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

&MATL ID = 'ASH'
  DENSITY = 67.0
  CONDUCTIVITY = 0.1

```

SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
SAMPLING\_FACTOR=1  
SURF\_ID='grass surface'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='GREEN' /

&PART ID='litter'  
SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*  
&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.3, N\_PARTICLES=7200, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /  
&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.4, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

&DEVC ID='Temp01', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,0.5/  
&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/  
&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/  
&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/  
&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/  
&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/  
&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/  
&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/  
&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/  
&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/  
&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/  
&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/  
&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/  
&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/  
&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/  
&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/  
&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/  
&DEVC ID='Temp21', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.0/  
&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/  
&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/

&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/  
&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/  
&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/  
&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/  
&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

'03\_grass\_high'

&HEAD CHID='03\_grass\_high' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=30.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

&VENT MB='XMIN', SURF\_ID='OPEN' /

&VENT MB='XMAX', SURF\_ID='OPEN' /

&VENT MB='YMIN', SURF\_ID='OPEN' /

&VENT MB='YMAX', SURF\_ID='OPEN' /

&VENT MB='ZMAX', SURF\_ID='OPEN' /

&MATL ID='DIRT'

CONDUCTIVITY = 0.25

SPECIFIC\_HEAT = 2.

DENSITY = 1300. /

&SURF ID='GROUND'

DEFAULT=T

MATL\_ID='DIRT'

THICKNESS=0.2 /

&SURF ID = 'grass surface'

MATL\_ID(1,1:1) = 'GENERIC VEGETATION'

MOISTURE\_FRACTION = 0.15

SURFACE\_VOLUME\_RATIO = 7500.

LENGTH = 0.05

GEOMETRY = 'CYLINDRICAL'

```

EMISSIONITY = 0.9 /

&SURF ID = 'litter and duff'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.42
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
  EMISSIONITY = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'
  DENSITY = 500.
  CONDUCTIVITY = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A = 2.38E+15
  E = 209820
  NU_SPEC = 0.75
  SPEC_ID = 'FUEL VAPOR'
  NU_MATL = 0.25
  MATL_ID = 'CHAR'
  HEAT_OF_REACTION = 418. /

&MATL ID='MOISTURE',
  SPECIFIC_HEAT=4.19,
  CONDUCTIVITY=0.6,
  DENSITY=1000.0,
  HEAT_OF_REACTION=2259.0,
  SPEC_ID(1,1)='WATER VAPOR',
  NU_SPEC(1,1)=1.0,
  A=6.0E+5,
  E=4.82E+4,
  N_T=-0.5/

&MATL ID = 'CHAR'
  DENSITY = 300.
  CONDUCTIVITY = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A = 430.
  E = 74800.
  MATL_ID = 'ASH'
  NU_MATL = 0.10
  SPEC_ID = 'PRODUCTS','AIR'
  NU_SPEC = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

&MATL ID = 'ASH'
  DENSITY = 67.0
  CONDUCTIVITY = 0.1

```



SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
SAMPLING\_FACTOR=1  
SURF\_ID='grass surface'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='GREEN' /

&PART ID='litter'  
SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*  
&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.5, N\_PARTICLES=21600, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /  
&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

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&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

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&TAIL /

## 04\_grass\_transition

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&MISC SIMULATION_MODE='LES', TMPA=30.0 /
&DUMP PLOT3D_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

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&RAMP ID='ignitor', T= 3 , F= 0.289363955 /
&RAMP ID='ignitor', T= 6 , F= 0.606194983 /
&RAMP ID='ignitor', T= 9 , F= 0.739029717 /
&RAMP ID='ignitor', T= 12 , F= 0.915547025 /
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&RAMP ID='ignitor', T= 18 , F= 0.924482097 /
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&RAMP ID='ignitor', T= 48 , F= 0.010854458 /
&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

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&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF_ID='GROUND' /

&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /

&MATL ID='DIRT'
  CONDUCTIVITY = 0.25
  SPECIFIC_HEAT = 2.
  DENSITY = 1300. /

&SURF ID='GROUND'
  DEFAULT=T
  MATL_ID='DIRT'
  THICKNESS=0.2 /

&SURF ID = 'grass surface'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.15
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
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```

EMISSIONITY = 0.9 /

&SURF ID = 'litter and duff'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.42
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
  EMISSIONITY = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'
  DENSITY = 500.
  CONDUCTIVITY = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A = 2.38E+15
  E = 209820
  NU_SPEC = 0.75
  SPEC_ID = 'FUEL VAPOR'
  NU_MATL = 0.25
  MATL_ID = 'CHAR'
  HEAT_OF_REACTION = 418. /

&MATL ID='MOISTURE',
  SPECIFIC_HEAT=4.19,
  CONDUCTIVITY=0.6,
  DENSITY=1000.0,
  HEAT_OF_REACTION=2259.0,
  SPEC_ID(1,1)='WATER VAPOR',
  NU_SPEC(1,1)=1.0,
  A=6.0E+5,
  E=4.82E+4,
  N_T=-0.5/

&MATL ID = 'CHAR'
  DENSITY = 300.
  CONDUCTIVITY = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A = 430.
  E = 74800.
  MATL_ID = 'ASH'
  NU_MATL = 0.10
  SPEC_ID = 'PRODUCTS','AIR'
  NU_SPEC = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

&MATL ID = 'ASH'
  DENSITY = 67.0
  CONDUCTIVITY = 0.1

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SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
SAMPLING\_FACTOR=1  
SURF\_ID='grass surface'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='GREEN' /

&PART ID='litter'  
SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.0,0.0,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*  
&INIT PART\_ID='blade of grass', XB=0.0,1.5,0.0,3.0,0.2,0.4, N\_PARTICLES=7200, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer base\*\*\*  
&INIT PART\_ID='blade of grass', XB=1.5,3.0,0.0,3.0,0.2,0.3, N\_PARTICLES=3600, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer low\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /  
&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
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&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
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&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
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&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

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&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/  
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&TAIL /



## 05\_grass\_packing\_low

```
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&DUMP PLOT3D_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP_FRONT=1000., RAMP_Q='ignitor' /
&RAMP ID='ignitor', T= 0 , F= 0.000000000 /
&RAMP ID='ignitor', T= 3 , F= 0.289363955 /
&RAMP ID='ignitor', T= 6 , F= 0.606194983 /
&RAMP ID='ignitor', T= 9 , F= 0.739029717 /
&RAMP ID='ignitor', T= 12 , F= 0.915547025 /
&RAMP ID='ignitor', T= 15 , F= 1.000000000 /
&RAMP ID='ignitor', T= 18 , F= 0.924482097 /
&RAMP ID='ignitor', T= 21 , F= 0.891918724 /
&RAMP ID='ignitor', T= 24 , F= 0.801707592 /
&RAMP ID='ignitor', T= 27 , F= 0.591965054 /
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&RAMP ID='ignitor', T= 33 , F= 0.373486002 /
&RAMP ID='ignitor', T= 36 , F= 0.201072209 /
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&RAMP ID='ignitor', T= 42 , F= 0.118604805 /
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&RAMP ID='ignitor', T= 48 , F= 0.010854458 /
&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF_ID='IGNITION' /
&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF_ID='GROUND' /
&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF_ID='GROUND' /

&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /

&MATL ID='DIRT'
  CONDUCTIVITY = 0.25
  SPECIFIC_HEAT = 2.
  DENSITY = 1300. /

&SURF ID='GROUND'
  DEFAULT=T
  MATL_ID='DIRT'
  THICKNESS=0.2 /

&SURF ID = 'grass surface'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.15
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
```

```

EMISSIONITY = 0.9 /

&SURF ID = 'litter and duff'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.42
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
  EMISSIONITY = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'
  DENSITY = 500.
  CONDUCTIVITY = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A = 2.38E+15
  E = 209820
  NU_SPEC = 0.75
  SPEC_ID = 'FUEL VAPOR'
  NU_MATL = 0.25
  MATL_ID = 'CHAR'
  HEAT_OF_REACTION = 418. /

&MATL ID='MOISTURE',
  SPECIFIC_HEAT=4.19,
  CONDUCTIVITY=0.6,
  DENSITY=1000.0,
  HEAT_OF_REACTION=2259.0,
  SPEC_ID(1,1)='WATER VAPOR',
  NU_SPEC(1,1)=1.0,
  A=6.0E+5,
  E=4.82E+4,
  N_T=-0.5/

&MATL ID = 'CHAR'
  DENSITY = 300.
  CONDUCTIVITY = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A = 430.
  E = 74800.
  MATL_ID = 'ASH'
  NU_MATL = 0.10
  SPEC_ID = 'PRODUCTS','AIR'
  NU_SPEC = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

&MATL ID = 'ASH'
  DENSITY = 67.0
  CONDUCTIVITY = 0.1

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SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
SAMPLING\_FACTOR=1  
SURF\_ID='grass surface'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='GREEN' /

&PART ID='litter'  
SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*  
&INIT PART\_ID='blade of grass', XB=0.0,3.,0.3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=1.0, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /  
&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.4, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

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&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/  
&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/  
&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/  
&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/  
&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/  
&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/  
&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/  
&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/  
&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/  
&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/  
&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/  
&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/  
&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/  
&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/  
&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/  
&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/  
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&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/  
&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/

&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/  
&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/  
&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/  
&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/  
&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## 06\_grass\_packing\_high

```
&HEAD CHID='06_grass_packing_high' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /
&TIME T_END=300.0 /
&MISC SIMULATION_MODE='LES', TMPA=30.0 /
&DUMP PLOT3D_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP_FRONT=1000., RAMP_Q='ignitor' /
&RAMP ID='ignitor', T= 0 , F= 0.000000000 /
&RAMP ID='ignitor', T= 3 , F= 0.289363955 /
&RAMP ID='ignitor', T= 6 , F= 0.606194983 /
&RAMP ID='ignitor', T= 9 , F= 0.739029717 /
&RAMP ID='ignitor', T= 12 , F= 0.915547025 /
&RAMP ID='ignitor', T= 15 , F= 1.000000000 /
&RAMP ID='ignitor', T= 18 , F= 0.924482097 /
&RAMP ID='ignitor', T= 21 , F= 0.891918724 /
&RAMP ID='ignitor', T= 24 , F= 0.801707592 /
&RAMP ID='ignitor', T= 27 , F= 0.591965054 /
&RAMP ID='ignitor', T= 30 , F= 0.492156993 /
&RAMP ID='ignitor', T= 33 , F= 0.373486002 /
&RAMP ID='ignitor', T= 36 , F= 0.201072209 /
&RAMP ID='ignitor', T= 39 , F= 0.134423191 /
&RAMP ID='ignitor', T= 42 , F= 0.118604805 /
&RAMP ID='ignitor', T= 45 , F= 0.015818386 /
&RAMP ID='ignitor', T= 48 , F= 0.010854458 /
&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF_ID='IGNITION' /
&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF_ID='GROUND' /
&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF_ID='GROUND' /

&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /

&MATL ID='DIRT'
  CONDUCTIVITY = 0.25
  SPECIFIC_HEAT = 2.
  DENSITY = 1300. /

&SURF ID='GROUND'
  DEFAULT=T
  MATL_ID='DIRT'
  THICKNESS=0.2 /

&SURF ID = 'grass surface'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.15
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
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```

EMISSIONITY = 0.9 /

&SURF ID = 'litter and duff'
  MATL_ID(1,1:1) = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.42
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH = 0.05
  GEOMETRY = 'CYLINDRICAL'
  EMISSIONITY = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'
  DENSITY = 500.
  CONDUCTIVITY = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A = 2.38E+15
  E = 209820
  NU_SPEC = 0.75
  SPEC_ID = 'FUEL VAPOR'
  NU_MATL = 0.25
  MATL_ID = 'CHAR'
  HEAT_OF_REACTION = 418. /

&MATL ID='MOISTURE',
  SPECIFIC_HEAT=4.19,
  CONDUCTIVITY=0.6,
  DENSITY=1000.0,
  HEAT_OF_REACTION=2259.0,
  SPEC_ID(1,1)='WATER VAPOR',
  NU_SPEC(1,1)=1.0,
  A=6.0E+5,
  E=4.82E+4,
  N_T=-0.5/

&MATL ID = 'CHAR'
  DENSITY = 300.
  CONDUCTIVITY = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A = 430.
  E = 74800.
  MATL_ID = 'ASH'
  NU_MATL = 0.10
  SPEC_ID = 'PRODUCTS','AIR'
  NU_SPEC = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

&MATL ID = 'ASH'
  DENSITY = 67.0
  CONDUCTIVITY = 0.1

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SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
SAMPLING\_FACTOR=1  
SURF\_ID='grass surface'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='GREEN' /

&PART ID='litter'  
SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*  
&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=16.2, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /  
&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

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&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /



&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.4, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

&DEVC ID='Temp01', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,0.5/  
&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/  
&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/  
&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/  
&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/  
&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/  
&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/  
&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/  
&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/  
&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/  
&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/  
&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/  
&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/  
&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/  
&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/  
&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/  
&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/  
&DEVC ID='Temp21', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.0/  
&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/  
&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/

&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/  
&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/  
&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/  
&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/  
&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## 07\_moisture\_content\_low

&HEAD CHID='07\_moisture\_content\_low' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=30.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

&VENT MB='XMIN', SURF\_ID='OPEN' /

&VENT MB='XMAX', SURF\_ID='OPEN' /

&VENT MB='YMIN', SURF\_ID='OPEN' /

&VENT MB='YMAX', SURF\_ID='OPEN' /

&VENT MB='ZMAX', SURF\_ID='OPEN' /

&MATL ID='DIRT'

CONDUCTIVITY = 0.25

SPECIFIC\_HEAT = 2.

DENSITY = 1300. /

&SURF ID='GROUND'

DEFAULT=T

MATL\_ID='DIRT'

THICKNESS=0.2 /

&SURF ID = 'grass surface'

MATL\_ID(1,1:1) = 'GENERIC VEGETATION'

MOISTURE\_FRACTION = 0.01

SURFACE\_VOLUME\_RATIO = 7500.

LENGTH = 0.05

GEOMETRY = 'CYLINDRICAL'

EMISSION = 0.9 /

```

&SURF ID          = 'litter and duff'
  MATL_ID(1,1:1)  = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.28
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH          = 0.05
  GEOMETRY        = 'CYLINDRICAL'
  EMISSIVITY      = 0.9 /

```

```

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

```

```

&SPEC ID='WATER VAPOR' /

```

```

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

```

```

&MATL ID          = 'GENERIC VEGETATION'
  DENSITY         = 500.
  CONDUCTIVITY    = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A               = 2.38E+15
  E               = 209820
  NU_SPEC         = 0.75
  SPEC_ID         = 'FUEL VAPOR'
  NU_MATL         = 0.25
  MATL_ID         = 'CHAR'
  HEAT_OF_REACTION = 418. /

```

```

&MATL ID='MOISTURE',
SPECIFIC_HEAT=4.19,
CONDUCTIVITY=0.6,
DENSITY=1000.0,
HEAT_OF_REACTION=2259.0,
SPEC_ID(1,1)='WATER VAPOR',
NU_SPEC(1,1)=1.0,
A=6.0E+5,
E=4.82E+4,
N_T=-0.5/

```

```

&MATL ID          = 'CHAR'
  DENSITY         = 300.
  CONDUCTIVITY    = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A               = 430.
  E               = 74800.
  MATL_ID         = 'ASH'
  NU_MATL         = 0.10
  SPEC_ID         = 'PRODUCTS','AIR'
  NU_SPEC         = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

```

```

&MATL ID          = 'ASH'
  DENSITY         = 67.0
  CONDUCTIVITY    = 0.1
  SPECIFIC_HEAT_RAMP = 'c_v' /

```

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
SAMPLING\_FACTOR=1  
SURF\_ID='grass surface'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='GREEN' /

&PART ID='litter'  
SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /

&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.4, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

&DEVC ID='Temp01', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,0.5/  
&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/  
&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/  
&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/  
&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/  
&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/  
&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/  
&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/  
&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/  
&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/  
&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/  
&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/  
&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/  
&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/  
&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/  
&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/  
&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/  
&DEVC ID='Temp21', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.0/  
&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/  
&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/  
&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/

&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/  
&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/  
&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/  
&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## 08\_moisture\_content\_high

&HEAD CHID='08\_moisture\_content\_high' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=30.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

&VENT MB='XMIN', SURF\_ID='OPEN' /

&VENT MB='XMAX', SURF\_ID='OPEN' /

&VENT MB='YMIN', SURF\_ID='OPEN' /

&VENT MB='YMAX', SURF\_ID='OPEN' /

&VENT MB='ZMAX', SURF\_ID='OPEN' /

&MATL ID='DIRT'

CONDUCTIVITY = 0.25

SPECIFIC\_HEAT = 2.

DENSITY = 1300. /

&SURF ID='GROUND'

DEFAULT=T

MATL\_ID='DIRT'

THICKNESS=0.2 /

&SURF ID = 'grass surface'

MATL\_ID(1,1:1) = 'GENERIC VEGETATION'

MOISTURE\_FRACTION = 0.30

SURFACE\_VOLUME\_RATIO = 7500.

LENGTH = 0.05

GEOMETRY = 'CYLINDRICAL'

EMISSION = 0.9 /



```

&SURF ID           = 'litter and duff'
  MATL_ID(1,1:1)   = 'GENERIC VEGETATION'
  MOISTURE_FRACTION = 0.56
  SURFACE_VOLUME_RATIO = 7500.
  LENGTH           = 0.05
  GEOMETRY         = 'CYLINDRICAL'
  EMISSIVITY              = 0.9 /

```

```

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE_FRACTION=0.3, SOOT_YIELD=0.01,
HEAT_OF_COMBUSTION=18433 /

```

```

&SPEC ID='WATER VAPOR' /

```

```

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

```

```

&MATL ID           = 'GENERIC VEGETATION'
  DENSITY          = 500.
  CONDUCTIVITY     = 0.2
  SPECIFIC_HEAT_RAMP = 'c_v'
  A                = 2.38E+15
  E                = 209820
  NU_SPEC          = 0.75
  SPEC_ID          = 'FUEL VAPOR'
  NU_MATL          = 0.25
  MATL_ID          = 'CHAR'
  HEAT_OF_REACTION = 418. /

```

```

&MATL ID='MOISTURE',
SPECIFIC_HEAT=4.19,
CONDUCTIVITY=0.6,
DENSITY=1000.0,
HEAT_OF_REACTION=2259.0,
SPEC_ID(1,1)='WATER VAPOR',
NU_SPEC(1,1)=1.0,
A=6.0E+5,
E=4.82E+4,
N_T=-0.5/

```

```

&MATL ID           = 'CHAR'
  DENSITY          = 300.
  CONDUCTIVITY     = 0.05
  SPECIFIC_HEAT_RAMP = 'c_v'
  SURFACE_OXIDATION_MODEL= T
  A                = 430.
  E                = 74800.
  MATL_ID          = 'ASH'
  NU_MATL          = 0.10
  SPEC_ID          = 'PRODUCTS','AIR'
  NU_SPEC          = 8.07,-7.17
  HEAT_OF_REACTION = -25000. /

```

```

&MATL ID           = 'ASH'
  DENSITY          = 67.0
  CONDUCTIVITY     = 0.1
  SPECIFIC_HEAT_RAMP = 'c_v' /

```

&RAMP ID='c\_v', T= 0., F=1.1 /  
&RAMP ID='c\_v', T=200., F=2.0 /  
&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'  
  SAMPLING\_FACTOR=1  
  SURF\_ID='grass surface'  
  PROP\_ID='grass image'  
  DRAG\_COEFFICIENT=2.8  
  QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
  STATIC=T  
  COLOR='GREEN' /

&PART ID='litter'  
  SAMPLING\_FACTOR=1  
  SURF\_ID='litter and duff'  
  PROP\_ID='grass image'  
  DRAG\_COEFFICIENT=2.8  
  QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
  STATIC=T  
  COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /  
&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

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&SLCF PBZ=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
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&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

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&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

&DEVC ID='Temp01', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,0.5/  
&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/  
&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/  
&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/  
&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/  
&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/  
&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/  
&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/  
&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/  
&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/  
&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/  
&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/  
&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/  
&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/  
&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/  
&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/  
&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/  
&DEVC ID='Temp21', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.0/  
&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/  
&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/  
&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/

&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
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&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/  
&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/  
&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## 09\_branch

&HEAD CHID='09\_branch' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=30.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

```
&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /
```

```
&MATL ID='DIRT'
```

```
CONDUCTIVITY = 0.25
```

```
SPECIFIC_HEAT = 2.
```

```
DENSITY = 1300. /
```

```
&SURF ID='GROUND'
```

```
DEFAULT=T
```

```
MATL_ID='DIRT'
```

```
THICKNESS=0.2 /
```

```
&SURF ID = 'grass surface'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.15
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

```
&SURF ID = 'litter and duff'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.42
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

&SURF ID = 'branch'  
MATL\_ID(1,1:1) = 'GENERIC VEGETATION'  
MOISTURE\_FRACTION = 0.25  
SURFACE\_VOLUME\_RATIO = 54.  
LENGTH = 0.05  
GEOMETRY = 'CYLINDRICAL'  
EMISSION = 0.9 /

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE\_FRACTION=0.3, SOOT\_YIELD=0.01,  
HEAT\_OF\_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'  
DENSITY = 500.  
CONDUCTIVITY = 0.2  
SPECIFIC\_HEAT\_RAMP = 'c\_v'  
A = 2.38E+15  
E = 209820  
NU\_SPEC = 0.75  
SPEC\_ID = 'FUEL VAPOR'  
NU\_MATL = 0.25  
MATL\_ID = 'CHAR'  
HEAT\_OF\_REACTION = 418. /

&MATL ID='MOISTURE',  
SPECIFIC\_HEAT=4.19,  
CONDUCTIVITY=0.6,  
DENSITY=1000.0,  
HEAT\_OF\_REACTION=2259.0,  
SPEC\_ID(1,1)='WATER VAPOR',

NU\_SPEC(1,1)=1.0,  
A=6.0E+5,  
E=4.82E+4,  
N\_T=-0.5/

&MATL ID = 'CHAR'  
DENSITY = 300.  
CONDUCTIVITY = 0.05  
SPECIFIC\_HEAT\_RAMP = 'c\_v'  
SURFACE\_OXIDATION\_MODEL= T  
A = 430.  
E = 74800.  
MATL\_ID = 'ASH'  
NU\_MATL = 0.10  
SPEC\_ID = 'PRODUCTS','AIR'  
NU\_SPEC = 8.07,-7.17  
HEAT\_OF\_REACTION = -25000. /

&MATL ID = 'ASH'  
DENSITY = 67.0  
CONDUCTIVITY = 0.1  
SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /

&RAMP ID='c\_v', T=200., F=2.0 /

&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'

SAMPLING\_FACTOR=1

SURF\_ID='grass surface'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'



STATIC=T  
COLOR='GREEN' /

&PART ID='litter'

SAMPLING\_FACTOR=1  
SURF\_ID='litter and duff'  
PROP\_ID='grass image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&PART ID='branch'

SAMPLING\_FACTOR=1  
SURF\_ID='branch'  
PROP\_ID='branch image'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&PART ID='branch perp'

SAMPLING\_FACTOR=1  
SURF\_ID='branch'  
PROP\_ID='branch image perp'  
DRAG\_COEFFICIENT=2.8  
QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'  
STATIC=T  
COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

```

&INIT PART_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N_PARTICLES=14400, CELL_CENTERED=T,
MASS_PER_VOLUME=8.6, DRY=T / ***Grass Layer***

&INIT PART_ID='branch', XB=1.5,1.55,0.5,1.5,0.2,0.25, N_PARTICLES_PER_CELL=1, CELL_CENTERED=T,
MASS_PER_VOLUME=500., DRY=T /

&INIT PART_ID='branch perp', XB=1.0,2.0,2.5,2.55,0.2,0.25, N_PARTICLES_PER_CELL=1, CELL_CENTERED=T,
MASS_PER_VOLUME=500., DRY=T /

&PROP ID='grass image', SMOKEVIEW_ID='TUBE', SMOKEVIEW_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /
&PROP ID='branch image', SMOKEVIEW_ID='TUBE', SMOKEVIEW_PARAMETERS='L=0.05','D=0.075','DIRY=1' /
&PROP ID='branch image perp', SMOKEVIEW_ID='TUBE',
SMOKEVIEW_PARAMETERS='L=0.05','D=0.075','DIRX=1' /

&DUMP DT_HRR=1., DT_DEVC=1., SIG_FIGS=4, SIG_FIGS_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /
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&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /
&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /
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&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /
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&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

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&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

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&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /

&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

&DEVC ID='Temp01', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,0.5/

&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/

&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/

&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/

&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/

&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/

&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/

&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/

&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/

&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/

&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/

&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/

&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/

&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/

&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/

&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/

&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/

&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/

&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/

&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/

&DEVC ID='Temp21', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.0/

&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/

&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/

&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/

&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/

&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/

&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/

&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/

&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/

&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/

&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/

&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## 10\_wind

&HEAD CHID='10\_wind' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=30.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&WIND SPEED=1.5, DIRECTION=270.0 /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

```
&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /
```

```
&MATL ID='DIRT'
```

```
CONDUCTIVITY = 0.25
```

```
SPECIFIC_HEAT = 2.
```

```
DENSITY = 1300. /
```

```
&SURF ID='GROUND'
```

```
DEFAULT=T
```

```
MATL_ID='DIRT'
```

```
THICKNESS=0.2 /
```

```
&SURF ID = 'grass surface'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.15
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

```
&SURF ID = 'litter and duff'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.42
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE\_FRACTION=0.3, SOOT\_YIELD=0.01,  
HEAT\_OF\_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'

DENSITY = 500.

CONDUCTIVITY = 0.2

SPECIFIC\_HEAT\_RAMP = 'c\_v'

A = 2.38E+15

E = 209820

NU\_SPEC = 0.75

SPEC\_ID = 'FUEL VAPOR'

NU\_MATL = 0.25

MATL\_ID = 'CHAR'

HEAT\_OF\_REACTION = 418. /

&MATL ID='MOISTURE',

SPECIFIC\_HEAT=4.19,

CONDUCTIVITY=0.6,

DENSITY=1000.0,

HEAT\_OF\_REACTION=2259.0,

SPEC\_ID(1,1)='WATER VAPOR',

NU\_SPEC(1,1)=1.0,

A=6.0E+5,

E=4.82E+4,

N\_T=-0.5/

&MATL ID = 'CHAR'

DENSITY = 300.

CONDUCTIVITY = 0.05



SPECIFIC\_HEAT\_RAMP = 'c\_v'  
SURFACE\_OXIDATION\_MODEL= T  
A = 430.  
E = 74800.  
MATL\_ID = 'ASH'  
NU\_MATL = 0.10  
SPEC\_ID = 'PRODUCTS','AIR'  
NU\_SPEC = 8.07,-7.17  
HEAT\_OF\_REACTION = -25000. /

&MATL ID = 'ASH'  
DENSITY = 67.0  
CONDUCTIVITY = 0.1  
SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /

&RAMP ID='c\_v', T=200., F=2.0 /

&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'

SAMPLING\_FACTOR=1

SURF\_ID='grass surface'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='GREEN' /

&PART ID='litter'

SAMPLING\_FACTOR=1

SURF\_ID='litter and duff'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /

&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=1.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.4, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=3.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=1.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.0, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /

&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

&DEVC ID='Temp01', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,0.5/  
&DEVC ID='Temp02', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,0.5/  
&DEVC ID='Temp03', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,0.5/  
&DEVC ID='Temp04', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,0.5/  
&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
&DEVC ID='Temp06', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,0.5/  
&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
&DEVC ID='Temp09', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,0.5/  
&DEVC ID='Temp10', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,0.5/  
&DEVC ID='Temp11', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,0.5/  
&DEVC ID='Temp12', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,0.5/  
&DEVC ID='Temp13', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,0.5/  
&DEVC ID='Temp14', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,0.5/  
&DEVC ID='Temp15', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,0.5/  
&DEVC ID='Temp16', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.0/  
&DEVC ID='Temp17', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.0/  
&DEVC ID='Temp18', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.0/  
&DEVC ID='Temp19', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.0/  
&DEVC ID='Temp20', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.0/  
&DEVC ID='Temp21', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.0/  
&DEVC ID='Temp22', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.0/  
&DEVC ID='Temp23', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.0/  
&DEVC ID='Temp24', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.0/  
&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
&DEVC ID='Temp28', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.0/  
&DEVC ID='Temp29', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.0/

&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
&DEVC ID='Temp31', QUANTITY='TEMPERATURE', XYZ=0.5,1.0,1.5/  
&DEVC ID='Temp32', QUANTITY='TEMPERATURE', XYZ=0.5,1.5,1.5/  
&DEVC ID='Temp33', QUANTITY='TEMPERATURE', XYZ=0.5,2.0,1.5/  
&DEVC ID='Temp34', QUANTITY='TEMPERATURE', XYZ=1.0,1.0,1.5/  
&DEVC ID='Temp35', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,1.5/  
&DEVC ID='Temp36', QUANTITY='TEMPERATURE', XYZ=1.0,2.0,1.5/  
&DEVC ID='Temp37', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,1.5/  
&DEVC ID='Temp38', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,1.5/  
&DEVC ID='Temp39', QUANTITY='TEMPERATURE', XYZ=1.5,2.0,1.5/  
&DEVC ID='Temp40', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.5/  
&DEVC ID='Temp41', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.5/  
&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
&DEVC ID='Temp43', QUANTITY='TEMPERATURE', XYZ=2.5,1.0,1.5/  
&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

## 11\_kinetic\_parameters\_csiro\_grassland

&HEAD CHID='11\_kinetic\_parameters\_csiro\_grassland' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=30.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

```
&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /
```

```
&MATL ID='DIRT'
```

```
CONDUCTIVITY = 0.25
```

```
SPECIFIC_HEAT = 2.
```

```
DENSITY = 1300. /
```

```
&SURF ID='GROUND'
```

```
DEFAULT=T
```

```
MATL_ID='DIRT'
```

```
THICKNESS=0.2 /
```

```
&SURF ID = 'grass surface'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.15
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

```
&SURF ID = 'litter and duff'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.42
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE\_FRACTION=0.3, SOOT\_YIELD=0.01,  
HEAT\_OF\_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'

DENSITY = 500.

CONDUCTIVITY = 0.2

SPECIFIC\_HEAT\_RAMP = 'c\_v'

A = 1040.

E = 61041.

NU\_SPEC = 0.75

SPEC\_ID = 'FUEL VAPOR'

NU\_MATL = 0.25

MATL\_ID = 'CHAR'

HEAT\_OF\_REACTION = 418. /

&MATL ID='MOISTURE',

SPECIFIC\_HEAT=4.19,

CONDUCTIVITY=0.6,

DENSITY=1000.0,

HEAT\_OF\_REACTION=2259.0,

SPEC\_ID(1,1)='WATER VAPOR',

NU\_SPEC(1,1)=1.0,

A=6.0E+5,

E=4.82E+4,

N\_T=-0.5/

&MATL ID = 'CHAR'

DENSITY = 300.

CONDUCTIVITY = 0.05



SPECIFIC\_HEAT\_RAMP = 'c\_v'  
SURFACE\_OXIDATION\_MODEL= T  
A = 430.  
E = 74800.  
MATL\_ID = 'ASH'  
NU\_MATL = 0.10  
SPEC\_ID = 'PRODUCTS','AIR'  
NU\_SPEC = 8.07,-7.17  
HEAT\_OF\_REACTION = -25000. /

&MATL ID = 'ASH'  
DENSITY = 67.0  
CONDUCTIVITY = 0.1  
SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /

&RAMP ID='c\_v', T=200., F=2.0 /

&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'

SAMPLING\_FACTOR=1

SURF\_ID='grass surface'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='GREEN' /

&PART ID='litter'

SAMPLING\_FACTOR=1

SURF\_ID='litter and duff'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /

&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

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&TAIL /

## 12\_ambient\_temperature\_low

&HEAD CHID='12\_ambient\_temperature\_low' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=20.0 /

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&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

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&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

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&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

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&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

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&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /
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```
&MATL ID='DIRT'
```

```
CONDUCTIVITY = 0.25
```

```
SPECIFIC_HEAT = 2.
```

```
DENSITY = 1300. /
```

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&SURF ID='GROUND'
```

```
DEFAULT=T
```

```
MATL_ID='DIRT'
```

```
THICKNESS=0.2 /
```

```
&SURF ID = 'grass surface'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.15
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSIVITY = 0.9 /
```

```
&SURF ID = 'litter and duff'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.42
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SURFACE_VOLUME_RATIO = 7500.
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LENGTH = 0.05
```

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GEOMETRY = 'CYLINDRICAL'
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EMISSIVITY = 0.9 /
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&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE\_FRACTION=0.3, SOOT\_YIELD=0.01,  
HEAT\_OF\_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'

DENSITY = 500.

CONDUCTIVITY = 0.2

SPECIFIC\_HEAT\_RAMP = 'c\_v'

A = 2.38E+15

E = 209820

NU\_SPEC = 0.75

SPEC\_ID = 'FUEL VAPOR'

NU\_MATL = 0.25

MATL\_ID = 'CHAR'

HEAT\_OF\_REACTION = 418. /

&MATL ID='MOISTURE',

SPECIFIC\_HEAT=4.19,

CONDUCTIVITY=0.6,

DENSITY=1000.0,

HEAT\_OF\_REACTION=2259.0,

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NU\_SPEC(1,1)=1.0,

A=6.0E+5,

E=4.82E+4,

N\_T=-0.5/

&MATL ID = 'CHAR'

DENSITY = 300.

CONDUCTIVITY = 0.05



SPECIFIC\_HEAT\_RAMP = 'c\_v'  
SURFACE\_OXIDATION\_MODEL= T  
A = 430.  
E = 74800.  
MATL\_ID = 'ASH'  
NU\_MATL = 0.10  
SPEC\_ID = 'PRODUCTS','AIR'  
NU\_SPEC = 8.07,-7.17  
HEAT\_OF\_REACTION = -25000. /

&MATL ID = 'ASH'  
DENSITY = 67.0  
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SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /

&RAMP ID='c\_v', T=200., F=2.0 /

&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'

SAMPLING\_FACTOR=1

SURF\_ID='grass surface'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='GREEN' /

&PART ID='litter'

SAMPLING\_FACTOR=1

SURF\_ID='litter and duff'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /

&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

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&DEVC ID='Temp44', QUANTITY='TEMPERATURE', XYZ=2.5,1.5,1.5/  
&DEVC ID='Temp45', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.5/

&TAIL /

### 13\_ambient\_temperature\_high

&HEAD CHID='13\_ambient\_temperature\_high' /

&MESH IJK=100,100,100, XB=-1.0,4.0,-1.0,4.0,0.0,5.0 /

&TIME T\_END=300.0 /

&MISC SIMULATION\_MODE='LES', TMPA=40.0 /

&DUMP PLOT3D\_QUANTITY(1:5)='TEMPERATURE','U-VELOCITY','V-VELOCITY','W-VELOCITY','HRRPUV' /

&SURF ID='IGNITION', HRRPUA=605., COLOR='RED', TMP\_FRONT=1000., RAMP\_Q='ignitor' /

&RAMP ID='ignitor', T= 0 , F= 0.000000000 /

&RAMP ID='ignitor', T= 3 , F= 0.289363955 /

&RAMP ID='ignitor', T= 6 , F= 0.606194983 /

&RAMP ID='ignitor', T= 9 , F= 0.739029717 /

&RAMP ID='ignitor', T= 12 , F= 0.915547025 /

&RAMP ID='ignitor', T= 15 , F= 1.000000000 /

&RAMP ID='ignitor', T= 18 , F= 0.924482097 /

&RAMP ID='ignitor', T= 21 , F= 0.891918724 /

&RAMP ID='ignitor', T= 24 , F= 0.801707592 /

&RAMP ID='ignitor', T= 27 , F= 0.591965054 /

&RAMP ID='ignitor', T= 30 , F= 0.492156993 /

&RAMP ID='ignitor', T= 33 , F= 0.373486002 /

&RAMP ID='ignitor', T= 36 , F= 0.201072209 /

&RAMP ID='ignitor', T= 39 , F= 0.134423191 /

&RAMP ID='ignitor', T= 42 , F= 0.118604805 /

&RAMP ID='ignitor', T= 45 , F= 0.015818386 /

&RAMP ID='ignitor', T= 48 , F= 0.010854458 /

&RAMP ID='ignitor', T= 51 , F= 0.000000000 /

&VENT XB=0.00,0.05,0.0,3.0,0.20,0.20, SURF\_ID='IGNITION' /

&OBST XB=0.00,0.05,0.0,3.0,0.05,0.20, SURF\_ID='GROUND' /

&OBST XB=0.0,3.0,0.0,3.0,0.000,0.05, SURF\_ID='GROUND' /

```
&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMAX', SURF_ID='OPEN' /
```

```
&MATL ID='DIRT'
```

```
CONDUCTIVITY = 0.25
```

```
SPECIFIC_HEAT = 2.
```

```
DENSITY = 1300. /
```

```
&SURF ID='GROUND'
```

```
DEFAULT=T
```

```
MATL_ID='DIRT'
```

```
THICKNESS=0.2 /
```

```
&SURF ID = 'grass surface'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.15
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSION = 0.9 /
```

```
&SURF ID = 'litter and duff'
```

```
MATL_ID(1,1:1) = 'GENERIC VEGETATION'
```

```
MOISTURE_FRACTION = 0.42
```

```
SURFACE_VOLUME_RATIO = 7500.
```

```
LENGTH = 0.05
```

```
GEOMETRY = 'CYLINDRICAL'
```

```
EMISSION = 0.9 /
```

&REAC FUEL='FUEL VAPOR', C=2.10, H=6.2, O=2.16, RADIATIVE\_FRACTION=0.3, SOOT\_YIELD=0.01,  
HEAT\_OF\_COMBUSTION=18433 /

&SPEC ID='WATER VAPOR' /

&SPEC ID='FUEL VAPOR', FORMULA='C2.1H6.2O2.16' /

&MATL ID = 'GENERIC VEGETATION'

DENSITY = 500.

CONDUCTIVITY = 0.2

SPECIFIC\_HEAT\_RAMP = 'c\_v'

A = 2.38E+15

E = 209820

NU\_SPEC = 0.75

SPEC\_ID = 'FUEL VAPOR'

NU\_MATL = 0.25

MATL\_ID = 'CHAR'

HEAT\_OF\_REACTION = 418. /

&MATL ID='MOISTURE',

SPECIFIC\_HEAT=4.19,

CONDUCTIVITY=0.6,

DENSITY=1000.0,

HEAT\_OF\_REACTION=2259.0,

SPEC\_ID(1,1)='WATER VAPOR',

NU\_SPEC(1,1)=1.0,

A=6.0E+5,

E=4.82E+4,

N\_T=-0.5/

&MATL ID = 'CHAR'

DENSITY = 300.

CONDUCTIVITY = 0.05



SPECIFIC\_HEAT\_RAMP = 'c\_v'  
SURFACE\_OXIDATION\_MODEL= T  
A = 430.  
E = 74800.  
MATL\_ID = 'ASH'  
NU\_MATL = 0.10  
SPEC\_ID = 'PRODUCTS','AIR'  
NU\_SPEC = 8.07,-7.17  
HEAT\_OF\_REACTION = -25000. /

&MATL ID = 'ASH'  
DENSITY = 67.0  
CONDUCTIVITY = 0.1  
SPECIFIC\_HEAT\_RAMP = 'c\_v' /

&RAMP ID='c\_v', T= 0., F=1.1 /

&RAMP ID='c\_v', T=200., F=2.0 /

&RAMP ID='c\_v', T=800., F=2.0 /

&PART ID='blade of grass'

SAMPLING\_FACTOR=1

SURF\_ID='grass surface'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='GREEN' /

&PART ID='litter'

SAMPLING\_FACTOR=1

SURF\_ID='litter and duff'

PROP\_ID='grass image'

DRAG\_COEFFICIENT=2.8

QUANTITIES='PARTICLE TEMPERATURE','PARTICLE MASS'

STATIC=T

COLOR='BROWN' /

&INIT PART\_ID='litter', XB=0.0,3.,0.,3.,0.05,0.2, N\_PARTICLES=10800, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=35.00, DRY=T / \*\*\*Lower layer\*\*\*

&INIT PART\_ID='blade of grass', XB=0.0,3.,0.,3.,0.2,0.4, N\_PARTICLES=14400, CELL\_CENTERED=T,  
MASS\_PER\_VOLUME=8.6, DRY=T / \*\*\*Grass Layer\*\*\*

&PROP ID='grass image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.0004','DIRZ=1' /

&PROP ID='branch image', SMOKEVIEW\_ID='TUBE', SMOKEVIEW\_PARAMETERS='L=0.05','D=0.075','DIRY=1' /

&DUMP DT\_HRR=1., DT\_DEVC=1., SIG\_FIGS=4, SIG\_FIGS\_EXP=2 /

&SLCF PBZ=0.4, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=1.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=1.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=2.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=3.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=4.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=4.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=1.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=2.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=2.5, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBY=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBX=0.5, QUANTITY='TEMPERATURE', VECTOR=T /

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&SLCF PBX=2.5, QUANTITY='TEMPERATURE', VECTOR=T /  
&SLCF PBX=3.0, QUANTITY='TEMPERATURE', VECTOR=T /

&SLCF PBZ=0.4, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBZ=0.5, QUANTITY='VELOCITY', VECTOR=T /  
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&SLCF PBZ=4.5, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=0.5, QUANTITY='VELOCITY', VECTOR=T /  
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&SLCF PBY=1.5, QUANTITY='VELOCITY', VECTOR=T /  
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&SLCF PBY=2.5, QUANTITY='VELOCITY', VECTOR=T /  
&SLCF PBY=3.0, QUANTITY='VELOCITY', VECTOR=T /

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&SLCF PBX=3.0, QUANTITY='VELOCITY', VECTOR=T /

&SLCF PBY=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /

&SLCF PBX=1.5, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='INTEGRATED INTENSITY', CELL\_CENTERED=T /  
&SLCF PBZ=0.4, QUANTITY='HRRPUV', CELL\_CENTERED=T /

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&DEVC ID='Temp05', QUANTITY='TEMPERATURE', XYZ=1.0,1.5,0.5/  
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&DEVC ID='Temp07', QUANTITY='TEMPERATURE', XYZ=1.5,1.0,0.5/  
&DEVC ID='Temp08', QUANTITY='TEMPERATURE', XYZ=1.5,1.5,0.5/  
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&DEVC ID='Temp25', QUANTITY='TEMPERATURE', XYZ=2.0,1.0,1.0/  
&DEVC ID='Temp26', QUANTITY='TEMPERATURE', XYZ=2.0,1.5,1.0/  
&DEVC ID='Temp27', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.0/  
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&DEVC ID='Temp30', QUANTITY='TEMPERATURE', XYZ=2.5,2.0,1.0/  
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&DEVC ID='Temp42', QUANTITY='TEMPERATURE', XYZ=2.0,2.0,1.5/  
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&TAIL /