RB-011

# RB-011: Grease Aerosol Transport and Deposition in Open Environments

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**Outdoor Ventilation Standard**

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## 1. 1. Topic Definition

This paper investigates the transport behavior of grease aerosol within the **Buoyant Cooking Plume** and in the **Missed Plume Region** for outdoor barbecue cooking installations. Grease aerosol — the suspension of liquid fat and oil droplets generated by the thermal decomposition, vaporization, and recondensation of fats during cooking — is a principal contaminant carried by the cooking plume. Its transport and deposition in the outdoor environment have direct consequences for adjacent surface contamination, fire risk, air quality, and the functional requirements of ventilation hoods and grease filtration systems.

The scope encompasses:

1. **Particle size distribution characterization.** The grease aerosol produced by outdoor barbecue cooking spans a wide size range, from ultrafine condensation nuclei (less than 0.01 micrometers) through fine respirable particles (0.1 to 2.5 micrometers) to coarse spray droplets (10 to 100 micrometers). This paper characterizes the mass-weighted and number-weighted size distributions based on published cooking aerosol measurements and combustion science literature, adapted to the specific conditions of outdoor grilling (high-heat direct cooking, fat drip pyrolysis, wood and charcoal smoke generation).
2. **Aerosol transport within the buoyant plume.** Within the **Buoyant Cooking Plume**, grease aerosol particles are entrained in the rising gas flow. The vertical transport velocity of the plume (1.0 to 2.8 m/s at standard hood heights, per RB-001 Table 3.5) substantially exceeds the gravitational settling velocity of all but the largest droplets. This section quantifies the Stokes settling velocity for each particle size class and determines the critical particle diameter above which gravitational settling causes separation from the plume gas.
3. **Aerosol transport in the missed plume region.** When the **Buoyant Cooking Plume** escapes the hood — through any of the failure modes catalogued in RB-007 (inadequate overhang, excessive mounting height, wind-deflected plume escape, insufficient exhaust rate, or **Momentum-Limited Capture**) — the grease aerosol enters the **Missed Plume Region** and is subject to **Open-Boundary Dilution** and atmospheric transport. Under wind conditions quantified in RB-

006, the escaped plume material is advected downwind while simultaneously dispersing vertically and laterally. This section models the downwind transport distance and ground-level deposition pattern as a function of particle size, wind speed, and atmospheric stability.

4. **Deposition pattern characterization.** Grease aerosol deposits on surfaces through gravitational settling (large particles), inertial impaction (particles carried by flow into obstacles), turbulent diffusion to surfaces (fine particles), and thermophoresis (temperature-gradient-driven migration). This section estimates the spatial distribution of grease deposition around an outdoor cooking installation — on adjacent decking, siding, furniture, vegetation, and other surfaces — as a function of distance and direction from the source.

5. **Fire risk analysis.** Accumulated grease deposits on combustible surfaces represent a fire hazard. This section quantifies the grease accumulation rate on surfaces at representative distances from an unventilated or partially ventilated outdoor cooking source, compares accumulated grease loads to published ignition thresholds for grease-coated surfaces, and identifies the conditions under which grease deposition from outdoor cooking poses a material fire risk to adjacent structures.

## Problem Framing

When an outdoor barbecue hood achieves complete capture of the **Buoyant Cooking Plume**, grease aerosol is intercepted at the **Plume Interception Plane**, passes through the hood's grease filters, and is either collected in the filter system or exhausted through the duct. In this scenario, grease deposition on surrounding surfaces is minimal and fire risk from grease accumulation is confined to the hood and duct interior.

When capture is incomplete — as occurs under any of the failure modes identified in RB-007, or when no hood is installed — a fraction of the grease aerosol enters the **Missed Plume Region** and disperses into the outdoor environment. The outdoor environment provides no secondary containment: there are no ceiling surfaces to intercept rising plume gas, no walls to redirect flow back toward an exhaust, and no enclosed volume within which dilution eventually reduces concentrations to negligible levels. Instead, grease aerosol is transported by the combination of residual plume buoyancy, ambient wind, and gravitational settling until it deposits on the first surface it encounters.

The consequence is a spatial pattern of grease deposition that extends outward from the cooking source in the downwind direction. Surfaces closest to the source — the hood exterior, adjacent countertops, decking beneath and around the grill, nearby siding — receive the heaviest deposition. More distant surfaces receive progressively less, but the fine fraction of the aerosol can travel significant distances before depositing. Over repeated cooking sessions, the cumulative grease load on adjacent surfaces can become substantial.

This paper quantifies these processes to enable evidence-based assessment of surface contamination risk, fire risk from grease accumulation, and the functional benefit of effective plume capture in reducing both.

### Relationship to Dependency Papers

**RB-001** provides the quantitative characterization of the **Buoyant Cooking Plume** — centerline velocity, temperature, plume width, and mass flow rate at each height — that governs the vertical transport of grease aerosol from the cooking surface to hood height. The plume velocities from RB-001 Table 3.5 determine which particle sizes remain entrained in the plume versus which settle out before reaching the hood.

**RB-006** provides the wind interaction analysis that governs the lateral transport of grease aerosol once it escapes the hood. The deflection tables, Froude number regimes, and wind exposure classification from RB-006 define the conditions under which plume material enters the **Missed Plume Region** and the wind speeds that drive its subsequent atmospheric transport.

**RB-007** provides the failure mode taxonomy that identifies the physical mechanisms by which grease aerosol escapes capture. Each failure mode (FM-1 through FM-6) produces a distinct spatial pattern of plume escape, which in turn produces a distinct deposition pattern. The failure mode analysis determines what fraction of the total grease aerosol generation enters the outdoor environment.

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## 2. 2. Relevant Physical Principles

### 2.1 Grease Aerosol Generation Mechanisms

Grease aerosol is generated during outdoor barbecue cooking through four primary mechanisms:

**Mechanism 1 — Fat vaporization and recondensation.** When cooking fats (animal fats, vegetable oils, marinades) are heated to temperatures above their smoke point (typically 190 to 260 degrees C depending on fat type), they undergo thermal decomposition into volatile organic compounds and lower-molecular-weight fragments. These vapors are carried upward in the **Buoyant Cooking Plume** and, upon encountering cooler air through entrainment in the **Entrainment Zone**, recondense into fine liquid droplets. This mechanism produces the finest aerosol fraction — primarily in the 0.01 to 1.0 micrometer diameter range — and contributes the majority of the particle number concentration. Recondensation nucleation generates enormous numbers of ultrafine particles (10^9 to 10^12 per cubic meter of plume gas) but relatively modest mass because each particle is extremely small.


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**Mechanism 2 — Fat drip pyrolysis.** When rendered fat drips from cooking food onto hot surfaces below — burner covers, lava rocks, charcoal beds, or the cooking grate itself — the fat undergoes rapid pyrolysis (thermal decomposition at temperatures of 300 to 600 degrees C). Pyrolysis produces a dense burst of smoke containing both solid carbonaceous particles and recondensed oil droplets in the 0.1 to 10 micrometer range. This mechanism is the dominant source of visible smoke during barbecue cooking and produces both the characteristic aroma and the heaviest aerosol loading events. Fat drip pyrolysis is intermittent, occurring when accumulated fat releases from the food surface, and produces transient plume loading spikes that can exceed the steady-state aerosol concentration by factors of 5 to 20.

**Mechanism 3 — Mechanical atomization.** When fat or marinade droplets fall from the food surface and impact the hot cooking grate or drip pan, the mechanical impact shatters the liquid into coarse droplets in the 10 to 100 micrometer range. These droplets are launched upward by the force of impact and the local thermal updraft from the hot surface. This mechanism produces the coarsest fraction of the aerosol and contributes the largest individual droplets, but the number concentration is low relative to the fine modes. Mechanical atomization is enhanced by higher grill temperatures, which increase the violence of the boiling and splattering reactions.

**Mechanism 4 — Combustion-generated soot and organic aerosol.** Wood-fired and charcoal grills produce carbonaceous soot particles (0.01 to 0.5 micrometers) and condensed organic aerosol (0.05 to 2 micrometers) from incomplete combustion of the fuel itself, independent of food-derived grease. Pellet smokers produce similar emissions, particularly in low-temperature smoking mode where combustion is oxygen-limited and incomplete. This mechanism is source-type dependent: gas grills produce negligible fuel-derived aerosol; charcoal and wood-fired grills can produce substantial fuel-derived emissions that augment the food-derived grease aerosol.

### 2.2 Particle Size Distribution of Cooking Aerosol

The particle size distribution of cooking-generated aerosol has been characterized in multiple experimental studies, primarily in indoor kitchen environments. The distribution is bimodal to trimodal:

**Mode 1 — Ultrafine / nucleation mode (0.01 to 0.1 micrometers).**

- Median diameter: 0.02 to 0.06 micrometers (20 to 60 nm)
- Dominant generation mechanism: recondensation nucleation (Mechanism 1)
- Number concentration: 10^11 to 10^13 particles per cubic meter in the near-source plume
- Mass contribution: less than 5% of total aerosol mass (despite dominating particle count)

- Behavior: these particles behave as passive tracers in the gas flow; gravitational settling is negligible (settling velocity less than 10^(-5) m/s); transport is dominated by gas-phase advection and Brownian diffusion

**Mode 2 — Accumulation mode (0.1 to 2.5 micrometers).**

- Median diameter: 0.2 to 0.8 micrometers
- Dominant generation mechanisms: recondensation growth (Mechanism 1) and fat drip pyrolysis (Mechanism 2)
- Number concentration: 10^8 to 10^10 particles per cubic meter
- Mass contribution: 20 to 50% of total aerosol mass
- Behavior: settling velocity is small (10^(-5) to 10^(-3) m/s) but non-negligible over long transport distances; these particles are the primary contributors to PM2.5 and are the most important fraction for respiratory health exposure in the missed plume region

**Mode 3 — Coarse mode (2.5 to 100 micrometers).**

- Median diameter: 5 to 20 micrometers (mass-weighted)
- Dominant generation mechanisms: mechanical atomization (Mechanism 3) and large pyrolysis droplets (Mechanism 2)
- Number concentration: 10^4 to 10^7 particles per cubic meter
- Mass contribution: 50 to 80% of total aerosol mass (a small number of large droplets carry the majority of the grease mass)
- Behavior: settling velocity is significant (10^(-3) to 0.3 m/s); particles above 20 micrometers settle rapidly and deposit within meters of the source; particles between 2.5 and 10 micrometers can travel tens of meters

**Representative size distribution parameters:**

| Mode | Number Median Diameter (micrometers) | Geometric Std Dev (sigma_g) | Mass Fraction (%) | Primary Mechanism |
|---|---|---|---|---|
| Ultrafine | 0.03 | 1.8 | 2-5 | Recondensation nucleation |
| Accumulation | 0.4 | 2.0 | 20-40 | Recondensation growth, pyrolysis smoke |
| Coarse | 12 | 2.5 | 50-80 | Mechanical atomization, large pyrolysis droplets |

**Source-type variation:**

| Source Type | Dominant Modes | Relative Aerosol Mass Generation Rate | Notes |
| --- | --- | --- | --- |
| Gas grill | Modes 1 and 3 | Moderate | Minimal fuel-derived aerosol; grease aerosol from food/fat only |
| Charcoal grill | Modes 1, 2, 3 | High | Significant fuel-derived soot (Mode 2); fat drip pyrolysis on coal bed (Mode 2); mechanical atomization from coal-surface splattering (Mode 3) |
| Wood-fired grill | Modes 1, 2, 3 | Very high | Copious wood smoke (Mode 2); high grease pyrolysis from open flame contact; largest total aerosol emission |
| Pellet smoker (low) | Modes 1 and 2 | Low-moderate | Deliberate smoke generation (Mode 2); minimal fat drip at low temperatures |
| Pellet smoker (high) | Modes 1, 2, 3 | Moderate | Behavior approaches gas grill at high temperature |

### 2.3 Stokes Settling Law and Terminal Velocity

The gravitational settling velocity of a spherical particle in still air is given by Stokes' law (valid for Reynolds number Re_p < 1, corresponding to particle diameters below approximately 80 micrometers for grease aerosol in air):

```
v_s = (rho_p - rho_a) * g * d_p^2 / (18 * mu)
```

where:

- v_s = terminal settling velocity (m/s)
- rho_p = particle density (kg/m^3); for liquid grease droplets, rho_p is approximately 900 kg/m^3
- rho_a = air density (kg/m^3); rho_a = 1.20 kg/m^3 at standard conditions
- g = gravitational acceleration = 9.81 m/s^2
- d_p = particle diameter (m)
- mu = dynamic viscosity of air = 1.81 x 10^(-5) Pa*s at 20 degrees C

Substituting standard values:

```
v_s = (900 - 1.2) * 9.81 * d_p^2 / (18 * 1.81 x 10^(-5)) = 2.71 x 10^7 * d_p^2
[m/s, with d_p in meters]
```

Or equivalently:

```
v_s = 0.0271 * d_p^2 [m/s, with d_p in micrometers]
```

**Cunningham slip correction.** For particles below approximately 1 micrometer, the mean free path of air molecules (approximately 0.066 micrometers at standard conditions) becomes comparable to the particle size, and the particle experiences reduced drag. The Cunningham slip correction factor C_c increases the settling velocity:

```
v_s_corrected = v_s * C_c
```

where C_c = 1 + (2 * lambda / d_p) * [1.257 + 0.4 * exp(-0.55 * d_p / lambda)], and lambda = 0.066 micrometers is the mean free path. For particles above 2 micrometers, C_c is approximately 1.0 and no correction is needed.


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*Table 2.3: Stokes Settling Velocity for Grease Aerosol Particles*

| d_p (micrometers) | v_s (m/s) | v_s (mm/s) | C_c | v_s_corrected (mm/s) | Settling Category |
|---|---|---|---|---|---|
| 0.01 | 2.7 x 10^(-9) | 2.7 x 10^(-6) | 23.8 | 6.4 x 10^(-5) | Negligible; Brownian motion dominates |
| 0.05 | 6.8 x 10^(-8) | 6.8 x 10^(-5) | 5.5 | 3.7 x 10^(-4) | Negligible; passive tracer |
| 0.1 | 2.7 x 10^(-7) | 2.7 x 10^(-4) | 3.0 | 8.1 x 10^(-4) | Negligible; passive tracer |
| 0.5 | 6.8 x 10^(-6) | 6.8 x 10^(-3) | 1.33 | 9.0 x 10^(-3) | Very slow; travels hundreds of meters |
| 1.0 | 2.7 x 10^(-5) | 0.027 | 1.16 | 0.031 | Slow; travels tens to hundreds of meters |
| 2.5 | 1.7 x 10^(-4) | 0.17 | 1.07 | 0.18 | Moderate; deposits within tens of meters |
| 5.0 | 6.8 x 10^(-4) | 0.68 | 1.03 | 0.70 | Significant; deposits within 5-20 meters |
| 10 | 2.7 x 10^(-3) | 2.7 | 1.02 | 2.8 | Rapid; deposits within 1-5 meters |
| 20 | 1.1 x 10^(-2) | 10.8 | 1.01 | 10.9 | Very rapid; deposits within 0.5-2 meters |
| 50 | 6.8 x 10^(-2) | 67.8 | 1.00 | 67.8 | Near-immediate; deposits within centimeters to 1 meter |
| 100 | 0.271 | 271 | 1.00 | 271 | Ballistic; deposits within centimeters |

**Critical interpretation for plume transport.** The centerline velocity of the **Buoyant Cooking Plume** at standard hood heights ranges from 1.0 to 2.8 m/s (RB-001 Table 3.5). Particles with settling velocities substantially less than the plume velocity (v_s << u_0) are carried upward with the plume gas and arrive at the **Plume Interception Plane** at essentially the same concentration as at the source. Particles with settling velocities comparable to or exceeding the plume velocity (v_s approaching or exceeding u_0) separate from the plume before reaching hood height.

The critical particle diameter at which the settling velocity equals 1% of the weakest plume centerline velocity (approximately 1.0 m/s at 48 inches for the charcoal kettle) is:


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```
d_p_crit (1% of u_0) = sqrt(0.01 * 1.0 / 0.0271) = sqrt(0.369) = 0.61 mm = 610
micrometers
```

This means that all grease aerosol particles below approximately 600 micrometers in diameter — which encompasses the entire aerosol distribution including the coarsest spray droplets — are carried upward by the plume with negligible gravitational separation over the 18- to 48-inch vertical distance to the hood. Gravitational settling does not meaningfully filter any particle size class from the plume during the vertical transport from cooking surface to hood.

The practical consequence is that the grease aerosol arriving at the **Plume Interception Plane** has essentially the same size distribution as the aerosol generated at the cooking surface. All particle sizes are available for capture by the hood grease filters, or for escape into the **Missed Plume Region** if capture fails.

### 2.4 Atmospheric Transport and Gaussian Dispersion

Once grease aerosol enters the **Missed Plume Region**, it is transported by the combination of ambient wind, residual plume buoyancy, turbulent diffusion, and gravitational settling. The standard framework for modeling this transport is the Gaussian plume dispersion model, adapted for particles with non-negligible settling velocity.

For a continuous elevated source releasing particles at height H (the hood height or the plume escape height) into a crosswind of speed U_w, the downwind ground-level concentration is:

```
C(x, y, 0) = (Q_s / (2 * pi * U_w * sigma_y * sigma_z)) * exp(-y^2 / (2 *
sigma_y^2)) * exp(-(H - v_s * x / U_w)^2 / (2 * sigma_z^2))
```

where:

- C(x, y, 0) = ground-level concentration (kg/m^3) at downwind distance x and crosswind distance y
- Q_s = source emission rate of the particle size class (kg/s)
- sigma_y, sigma_z = horizontal and vertical dispersion coefficients (m), functions of downwind distance and atmospheric stability
- H = effective release height (m)
- v_s = Stokes settling velocity (m/s)
- U_w = mean wind speed (m/s)

The settling velocity modifies the effective source height: the plume centerline descends at rate v_s as it travels downwind, so the effective height decreases linearly with downwind distance. The plume contacts the ground (maximum ground-level concentration) at a downwind distance of approximately:

```
x_ground = H * U_w / v_s
```

This is the distance at which the settling plume centerline reaches ground level.

**Pasquill-Gifford dispersion parameters.** For the atmospheric surface layer at heights of 1 to 3 meters, under neutral to slightly unstable conditions (typical of outdoor cooking scenarios with solar heating of nearby surfaces), the Pasquill-Gifford stability class is typically C (slightly unstable) to D (neutral). The corresponding dispersion coefficients for downwind distances of 10 to 1000 meters are:

| x (m) | sigma_y, Class C (m) | sigma_z, Class C (m) | sigma_y, Class D (m) | sigma_z, Class D (m) |
|---|---|---|---|---|
| 10 | 1.4 | 0.9 | 0.9 | 0.5 |
| 50 | 5.4 | 3.5 | 3.5 | 1.8 |
| 100 | 9.5 | 6.0 | 6.0 | 3.0 |
| 500 | 35 | 19 | 20 | 8.5 |
| 1000 | 62 | 32 | 35 | 13 |

### 2.5 Deposition Mechanisms

Grease aerosol deposits on surfaces through four mechanisms, each dominant for different particle size ranges:

**Gravitational settling (dominant for d_p > 10 micrometers).** Large particles settle under gravity and deposit on horizontal or near-horizontal upward-facing surfaces. The deposition flux (mass per unit area per unit time) on a horizontal surface at ground level equals the local airborne concentration times the settling velocity:

```
F_grav = C(x, y, 0) * v_s
```

This is the dominant deposition mechanism for the coarse mode (Mode 3) of the grease aerosol.

**Inertial impaction (dominant for d_p = 2 to 50 micrometers on vertical and protruding surfaces).** Particles carried by airflow toward an obstacle (wall, post, furniture edge) cannot follow the streamlines that divert around the obstacle if their inertia is too large. The Stokes number St = rho_p * d_p^2 * U / (18 * mu * L_obstacle) characterizes the particle's ability to follow the flow around the obstacle. When St exceeds approximately 0.1, particles impact the obstacle surface rather than following the flow around it. For a wind speed of 2 m/s and an obstacle dimension of 0.1 m (a fence post, chair arm, or siding board), the critical particle diameter for impaction is approximately 5 to 10 micrometers.

**Turbulent diffusion (dominant for d_p = 0.1 to 5 micrometers on all surfaces).** Fine particles are transported to surfaces by turbulent eddies in the atmospheric boundary layer adjacent to each surface. The deposition velocity for this mechanism is typically 0.001 to 0.01 m/s for particles in the 0.1 to 1 micrometer range, increasing to 0.01 to 0.1 m/s for particles in the 1 to 5 micrometer range. This mechanism deposits particles on all surface orientations (horizontal, vertical, and downward-facing), although the rate is highest on rough surfaces and surfaces in regions of high turbulence.

**Thermophoresis (relevant near hot surfaces only).** A temperature gradient between the air and a cooler surface drives fine particles toward the cold surface. This mechanism is significant only in the **Near-Field Plume Region** immediately above the cooking surface and on the hood interior surface, where temperature gradients are large. In the far-field and **Missed Plume Region**, temperature gradients are too small for thermophoresis to be a significant deposition mechanism.

### 2.6 Grease Aerosol Mass Generation Rate

The total grease aerosol mass generation rate from outdoor cooking depends on the cooking type, food composition, cooking temperature, and fat content. Published measurements from indoor cooking studies provide the following representative values:


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| Cooking Activity | PM2.5 Generation Rate (mg/min) | Total Aerosol (including coarse, mg/min) | Fat Drip Rate (g/min) | Aerosol Fraction of Drip |
| --- | --- | --- | --- | --- |
| Gas grill, lean meat (chicken breast) | 5-15 | 15-50 | 0.5-2 | 1-3% |
| Gas grill, fatty meat (burgers, ribs) | 15-40 | 50-200 | 2-8 | 2-5% |
| Gas grill, high-fat (bacon, sausage) | 30-80 | 100-400 | 5-15 | 2-4% |
| Charcoal grill, fatty meat | 20-60 | 80-300 | 2-8 | 3-6% |
| Wood-fired grill, fatty meat | 40-100 | 150-500 | 3-10 | 3-8% |
| Pellet smoker, low-and-slow | 10-30 | 30-100 | 0.5-3 | 2-5% |

For the analyses in this paper, a representative total grease aerosol generation rate of 100 mg/min (0.0017 g/s) is used for a medium-intensity barbecue cooking session (fatty meat on a gas or charcoal grill). This corresponds to approximately 6 grams per hour of aerosolized grease. During high-fat cooking with frequent flare-ups, the rate can reach 300 to 500 mg/min (18 to 30 g/hr).

Of this total aerosol mass, the size distribution is approximately:

- Ultrafine mode (less than 0.1 micrometers): 3% = 3 mg/min
- Accumulation mode (0.1 to 2.5 micrometers): 30% = 30 mg/min
- Coarse mode (greater than 2.5 micrometers): 67% = 67 mg/min

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## 3. 3. Observed or Expected Behavior

### 3.1 Grease Aerosol Fate in the Captured Plume

When the **Buoyant Cooking Plume** is fully captured by the hood, grease aerosol is transported vertically from the cooking surface to the **Plume Interception Plane** by the plume's upward velocity. As established in Section 2.3, gravitational settling does not separate any significant particle size fraction from the plume during this vertical transport, because the plume velocity (1.0 to 2.8 m/s) vastly exceeds the settling velocity of even the coarsest aerosol particles (0.27 m/s for 100-micrometer droplets).


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The hood's grease filtration system then separates the captured aerosol from the airstream. Standard baffle-type grease filters used in outdoor hoods have the following capture efficiency by particle size:

| Particle Size Range | Baffle Filter Efficiency | Mesh Filter Efficiency | Centrifugal Separator Efficiency |
|---|---|---|---|
| Less than 1 micrometer | 5-15% | 2-8% | 10-20% |
| 1 to 5 micrometers | 20-40% | 10-25% | 30-50% |
| 5 to 10 micrometers | 50-70% | 40-60% | 60-80% |
| 10 to 20 micrometers | 70-85% | 60-80% | 80-95% |
| Greater than 20 micrometers | 85-98% | 80-95% | 95-99% |

The critical observation is that standard grease filters are highly effective for the coarse mode (greater than 10 micrometers), which carries the majority of the grease mass, but are poorly effective for the accumulation mode (0.1 to 2.5 micrometers), which dominates particle count and contributes 20 to 40% of the mass. Fine grease aerosol that passes through the filter is exhausted through the duct and released to the atmosphere at the duct termination point. This exhausted fine aerosol is not a focus of this paper (it disperses rapidly from the elevated exhaust point), but it represents an irreducible emission from even well-functioning hood systems.

### 3.2 Grease Aerosol Escape Fraction Under Hood Failure Modes

The fraction of grease aerosol that enters the **Missed Plume Region** depends on which failure mode is active and its severity. Drawing on the failure mode analysis from RB-007 and the capture efficiency estimates from RB-006 Table 3.10:

*Table 3.2: Grease Aerosol Escape Fraction by Failure Mode and Condition*

| Condition | Plume Capture Efficiency (from RB-006/RB-007) | Grease Aerosol Escape Fraction | Escaped Aerosol Rate (mg/min, at 100 mg/min generation) |
|---|---|---|---|
| Full capture, still air | >95% | <5% | <5 |
| FM-1 (inadequate overhang), still air | 60-80% | 20-40% | 20-40 |
| FM-2 (excessive mounting height, 48"), still air | 50-70% | 30-50% | 30-50 |
| FM-3 (insufficient exhaust rate), still air | 70-90% | 10-30% | 10-30 |
| FM-4 (wind-deflected escape), 5 mph, no panels | 70-75% | 25-30% | 25-30 |
| FM-4, 8 mph, no panels | 45-55% | 45-55% | 45-55 |
| FM-4, 10 mph, no panels | 30-40% | 60-70% | 60-70 |
| Compound (FM-1 + FM-3, indoor hood outdoors) | 50-70% | 30-50% | 30-50 |
| Compound (FM-1 + FM-2 + FM-4, severe) | 20-40% | 60-80% | 60-80 |
| No hood installed | 0% | 100% | 100 |

**Key finding:** Under the most common failure conditions (FM-1 or FM-4 at moderate wind), approximately 25 to 40% of the grease aerosol escapes capture. For a typical 1-hour barbecue cooking session generating 6 grams of total aerosol, this represents 1.5 to 2.4 grams of grease deposited in the surrounding environment per cooking session. Over a season of 50 cooking sessions, the cumulative deposition is 75 to 120 grams — approximately 3 to 4 ounces of grease distributed across adjacent surfaces.

## 3.3 Particle Size-Dependent Transport Distances

The downwind transport distance for each particle size class is governed by the ratio of the release height to the settling velocity, modified by the wind speed. Using the ground-contact distance formula from Section 2.4:

```
x_ground = H * U_w / v_s
```


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where H is the effective release height of the escaped aerosol. For plume gas escaping at hood height (approximately 1.5 to 2.0 meters above ground for a grill surface at 0.9 m plus a mounting height of 0.6 to 1.1 m), H is approximately 1.5 to 2.0 meters. For plume gas escaping below the hood (edge spillage), H is approximately 0.9 to 1.5 meters.

Using H = 1.5 meters as a representative value and a range of wind speeds:

***Table 3.3a: Downwind Ground-Contact Distance by Particle Size (H = 1.5 m)***

| d_p (micrometers) | v_s (m/s) | x_ground at 2 mph (0.89 m/s) | x_ground at 5 mph (2.24 m/s) | x_ground at 8 mph (3.58 m/s) | x_ground at 10 mph (4.47 m/s) |
|---|---|---|---|---|---|
| 0.1 | 8.1 x 10^(-7) | 1,650 km | 4,150 km | 6,630 km | 8,280 km |
| 0.5 | 9.0 x 10^(-6) | 148 km | 373 km | 597 km | 745 km |
| 1.0 | 3.1 x 10^(-5) | 43 km | 108 km | 173 km | 216 km |
| 2.5 | 1.8 x 10^(-4) | 7.4 km | 18.7 km | 29.8 km | 37.3 km |
| 5.0 | 7.0 x 10^(-4) | 1.9 km | 4.8 km | 7.7 km | 9.6 km |
| 10 | 2.8 x 10^(-3) | 476 m | 1,200 m | 1,918 m | 2,396 m |
| 20 | 1.09 x 10^(-2) | 122 m | 308 m | 492 m | 615 m |
| 50 | 6.78 x 10^(-2) | 20 m | 50 m | 79 m | 99 m |
| 100 | 0.271 | 4.9 m | 12.4 m | 19.8 m | 24.7 m |

**Critical interpretation.** The ground-contact distances for fine particles (less than 2.5 micrometers) are absurdly large — kilometers to thousands of kilometers — indicating that gravitational settling is not the relevant deposition mechanism for these particles. Fine particles are removed from the atmosphere by turbulent diffusion to surfaces, washout by rain, and coagulation with larger particles, not by gravitational settling. The Gaussian dispersion model with settling is appropriate for coarse particles but overstates the travel distance for fine particles because it neglects these non-gravitational removal mechanisms.


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For practical purposes, the relevant distances for grease deposition near the cooking source are:

| Particle Size | Primary Deposition Distance | Primary Deposition Mechanism | Relevance |
|---|---|---|---|
| Greater than 50 micrometers | Less than 1 meter | Gravitational settling; ballistic trajectory | Immediate vicinity; drip pan, grill exterior, adjacent countertop |
| 20 to 50 micrometers | 1 to 5 meters | Gravitational settling | Nearby surfaces: decking, furniture, siding within 5 m |
| 10 to 20 micrometers | 5 to 30 meters | Gravitational settling + turbulent diffusion | Adjacent structures, vegetation, neighboring property boundary |
| 5 to 10 micrometers | 30 to 100+ meters | Turbulent diffusion + impaction | Extended neighborhood; deposited on surfaces over wide area |
| Less than 5 micrometers | 100+ meters (effectively infinite for local deposition purposes) | Turbulent diffusion, rain washout | Atmospheric dispersion; not a significant local deposition concern |

### 3.4 Deposition Pattern Characterization

The spatial distribution of grease deposition around an outdoor cooking source depends on the wind direction, wind speed, particle size distribution, release height, and the presence or absence of a hood. The following analysis considers the most common scenario: a partially effective hood (25 to 40% aerosol escape) in a 5 mph wind.

**Deposition geometry.** The escaped aerosol exits the hood on the downwind side (FM-4) or symmetrically around the perimeter (FM-1). Under wind conditions, the escaped material is advected downwind while settling and dispersing. The deposition pattern forms an elongated footprint extending in the downwind direction, with peak deposition intensity at a distance determined by the coarse-mode settling velocity and wind speed.

**Deposition rate estimation.** For the coarse mode ($d_p$ approximately 20 micrometers, mass-weighted median), the ground-contact distance in a 5 mph wind is approximately 50 to 300 meters. However, the majority of coarse-mode mass ($d_p$ = 20 to 100 micrometers) deposits much closer. To estimate the near-field deposition (within 10 meters), a simplified mass balance approach is used:

Of the escaped aerosol mass (approximately 30 mg/min for 30% escape from 100 mg/min total):

- 40% of the mass is in droplets larger than 50 micrometers (approximately 12 mg/min). These deposit within 1 meter of the escape point — on the hood exterior, adjacent countertop, and the immediate deck area directly downwind.

- 30% of the mass is in droplets of 20 to 50 micrometers (approximately 9 mg/min). These deposit within 1 to 5 meters downwind.
- 15% of the mass is in droplets of 10 to 20 micrometers (approximately 4.5 mg/min). These deposit within 5 to 30 meters downwind.
- 10% of the mass is in droplets of 5 to 10 micrometers (approximately 3 mg/min). These deposit beyond 30 meters.
- 5% of the mass is in particles smaller than 5 micrometers (approximately 1.5 mg/min). These disperse broadly and contribute negligible local deposition.

***Table 3.4a: Estimated Grease Deposition Rate by Distance (30% escape, 5 mph wind, 100 mg/min generation rate)***

| Distance Downwind | Deposition Band Width | Deposition Flux (mg/m^2/hr) | Mass Deposited Per Hour in Band (mg/hr) | Dominant Particle Sizes |
|---|---|---|---|---|
| 0 to 0.5 m | 1 m crosswind | 280-450 | 140-225 | Greater than 50 micrometers |
| 0.5 to 1.0 m | 1.5 m crosswind | 150-280 | 113-210 | 30 to 100 micrometers |
| 1 to 2 m | 2 m crosswind | 50-120 | 100-240 | 20 to 50 micrometers |
| 2 to 5 m | 3 m crosswind | 10-40 | 30-120 | 10 to 30 micrometers |
| 5 to 10 m | 5 m crosswind | 2-8 | 10-40 | 5 to 15 micrometers |
| 10 to 30 m | 10 m crosswind | 0.3-1.5 | 3-15 | 5 to 10 micrometers |
| Greater than 30 m | Broadly dispersed | Less than 0.3 | Trace | Less than 5 micrometers |

**Cumulative deposition per cooking session (1 hour) on a representative downwind surface.** A horizontal surface (e.g., deck board, patio table, or railing) directly downwind at 2 meters from the grill receives approximately 50 to 120 mg/m^2 per hour of cooking. Over a 2-hour barbecue session, this accumulates to 100 to 240 mg/m^2 — a thin but palpable grease film. Over a season of 50 cooking sessions, the cumulative deposition at 2 meters downwind reaches approximately 5 to 12 grams per square meter.


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## 3.5 Deposition on Specific Surfaces

The deposition pattern described above distributes grease over all surfaces in the affected zone. The following analysis identifies the surfaces of greatest concern:

**Hood exterior.** The hood's outer surfaces (top, sides) are directly in the path of escaped plume gas and receive heavy deposition from all particle sizes. Typical deposition: 500 to 2,000 mg/m^2 per hour. This is the heaviest deposition zone and is visible as a grease film after a single cooking session. The hood exterior is not a fire concern (it is non-combustible metal) but represents a maintenance and aesthetic issue.

**Adjacent decking or patio surface (0 to 2 meters).** Horizontal surfaces directly below and around the grill receive the coarsest droplets (greater than 50 micrometers) that are ejected laterally from the cooking surface and the heaviest settling fraction from escaped plume material. Typical deposition: 100 to 450 mg/m^2 per hour, depending on distance and wind direction. Composite decking and wood decking can absorb grease, creating permanent staining and, over time, a combustible grease layer (see Section 3.6).

**Adjacent siding or wall (0 to 3 meters).** Vertical surfaces immediately adjacent to the cooking area receive grease through inertial impaction (particles carried by wind-deflected plume flow impacting the wall) and turbulent diffusion. Impaction is most effective for particles of 5 to 30 micrometers. Typical deposition: 20 to 100 mg/m^2 per hour for surfaces within 2 meters. Vinyl siding, painted wood, and stucco surfaces retain grease and develop visible soiling.

**Patio furniture (1 to 5 meters).** Tables, chairs, and cushions in the cooking area receive grease deposition from the settling coarse mode. Horizontal surfaces of chairs and tables collect 30 to 100 mg/m^2 per hour at 2 to 3 meters downwind. Fabric cushions and covers are particularly affected because they absorb the grease and cannot be cleaned by simple wiping.

**Vegetation (2 to 10 meters).** Plants and landscaping downwind of the cooking area receive grease deposition on leaf surfaces. The foliar deposition rate at 5 meters downwind is approximately 5 to 20 mg/m^2 of leaf area per hour. While not a fire or contamination concern for most vegetation, grease accumulation on dried leaves, mulch, or ornamental grasses within 5 meters of the grill can contribute to fire risk during drought conditions.

**Adjacent structures (5 to 30 meters).** Neighboring buildings, fences, and structures beyond the immediate cooking area receive grease deposition from the 5 to 20 micrometer particle fraction. Deposition rates at 10 meters are approximately 1 to 5 mg/m^2 per hour — low per-session but cumulative over a barbecue season. This level of deposition is generally below the visual detection threshold for a single session but can produce visible grease staining over months of regular use.


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## 3.6 Fire Risk Analysis

Grease deposition on combustible surfaces represents a fire hazard that increases with cumulative deposition. This section analyzes the conditions under which grease accumulation from outdoor barbecue cooking poses a material fire risk.

### *3.6.1 Grease Ignition Properties*

Cooking oils and animal fats have the following ignition-relevant properties:

| Property | Typical Value Range | Notes |
|---|---|---|
| Flash point | 215 to 330 degrees C (420 to 625 degrees F) | Temperature at which vapors will ignite in the presence of an ignition source |
| Auto-ignition temperature | 340 to 400 degrees C (645 to 750 degrees F) | Temperature at which grease self-ignites without an external flame |
| Self-heating onset temperature | 100 to 150 degrees C (212 to 300 degrees F) | Temperature at which oxidative self-heating begins in a grease deposit |
| Minimum ignitable deposit thickness | 0.5 to 2 mm | For pool-fire ignition by direct flame contact |
| Exothermic oxidation threshold (accumulated grease on surfaces) | 200 to 500 g/m^2 | Approximate grease load at which slow oxidative self-heating becomes possible under sustained elevated temperature |

**Critical mechanism for outdoor cooking fire risk: direct flame contact with grease-coated surfaces.** The primary fire scenario is not spontaneous ignition of deposited grease (which requires temperatures above 215 degrees C that are not reached on surfaces more than approximately 0.3 meters from the flame). Rather, the primary scenario is:

1. Grease accumulates on a surface adjacent to the grill over multiple cooking sessions.
2. A flare-up, ember ejection, or wind-blown flame extends from the grill to the grease-coated surface.
3. The grease deposit ignites upon contact with the extended flame.
4. The ignited grease deposit sustains combustion and may spread to the underlying combustible substrate.

The severity of this scenario depends on the grease load (accumulated deposit mass per unit area) and the nature of the substrate.


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### *3.6.2 Grease Accumulation Rates on Adjacent Surfaces*

Using the deposition rates from Section 3.4 and assuming a 50-session barbecue season (approximately 100 hours of total cooking time), the cumulative grease load on adjacent surfaces is:

***Table 3.6a: Cumulative Grease Load After One Season (50 sessions, 2 hours each, 30% escape)***

| Surface Location | Distance | Deposition Rate (mg/m^2/hr) | Seasonal Accumulation (g/m^2) | Risk Classification |
|---|---|---|---|---|
| Hood exterior | 0 m | 500-2,000 | 50-200 | High (maintenance-critical; self-cleaning or frequent cleaning required) |
| Deck directly below grill | 0-0.5 m | 200-450 | 20-45 | Elevated (grease penetration into wood; accumulated fire fuel) |
| Deck 0.5-2 m downwind | 0.5-2 m | 50-200 | 5-20 | Moderate (visible staining; gradual fire fuel accumulation) |
| Adjacent siding (vertical) | 0.5-2 m | 20-100 | 2-10 | Low-Moderate (depends on siding material; vinyl, wood, composite) |
| Deck 2-5 m downwind | 2-5 m | 10-40 | 1-4 | Low (cosmetic concern primarily; minimal fire risk) |
| Fence or structure at 5-10 m | 5-10 m | 2-8 | 0.2-0.8 | Negligible (below detection threshold for fire risk) |

### *3.6.3 Fire Risk Assessment by Surface Type*

**Wood decking (0 to 2 meters from grill).** Untreated or semi-treated wood decking directly adjacent to the grill accumulates 5 to 45 g/m^2 of grease per season. Grease is absorbed into the wood grain, creating a condition where the surface combustibility is enhanced. While the grease load alone is below the exothermic oxidation threshold (200 to 500 g/m^2), it is sufficient to support flame spread if ignited by direct contact with a flame or ember from the grill. The fire risk is elevated when combined with:

- Dry weather conditions (low wood moisture content)
- Fat drippings below the grill (creating a higher local grease concentration)
- Ember ejection from charcoal or wood-fired grills in windy conditions (embers landing on grease-coated wood)


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The National Fire Protection Association (NFPA) recommends maintaining a minimum clearance of 10 feet (3 meters) between outdoor grills and combustible structures. This recommendation is consistent with the deposition analysis: at 3 meters downwind, the deposition rate drops to 10 to 40 mg/m^2 per hour, producing seasonal accumulation of 1 to 4 g/m^2 — below the threshold for significant fire risk enhancement.

**Composite decking (0 to 2 meters).** Composite decking (wood-plastic composites) does not absorb grease as readily as wood but develops a surface film that is visually objectionable and can support flame spread upon direct ignition. The fire risk is comparable to wood decking at similar grease loads.

**Vinyl siding (0.5 to 2 meters).** Vinyl siding ignites at approximately 350 to 400 degrees C (660 to 750 degrees F) and melts at approximately 80 to 100 degrees C (175 to 210 degrees F). Grease deposition on vinyl siding at 1 to 2 meters accumulates at 2 to 10 g/m^2 per season. While this grease load alone does not pose a direct fire risk, a grease-coated vinyl surface is more readily ignited by a flare-up or radiated heat event because the grease lowers the effective ignition energy of the composite surface.

**Hood grease tray and internal surfaces.** The hood interior and grease collection tray accumulate the highest grease concentration — 50 to 200 g/m^2 per season or more, depending on filter effectiveness and cleaning frequency. A grease tray that is not cleaned regularly can accumulate sufficient grease to produce a pool fire if ignited by a grease flare-up event that penetrates the filter. This is the highest fire risk scenario in outdoor cooking ventilation and is the primary reason for regular filter and grease tray cleaning.

### *3.6.4 Seasonal and Multi-Year Accumulation*

If grease deposits are not cleaned from adjacent surfaces, they accumulate over multiple seasons. The time to reach the exothermic oxidation threshold (200 g/m^2) on the most heavily deposited surface (deck directly below grill) is:

```
t_threshold = 200 / deposition_rate_per_season = 200 / (20-45) = 4 to 10 seasons
```

This means that after 4 to 10 years of regular barbecue use without surface cleaning, the deck surface directly below the grill may accumulate sufficient grease to support slow oxidative self-heating under sustained elevated temperature conditions (e.g., a hot day with direct solar heating on dark-colored decking). While this scenario is unlikely in practice (rain, weathering, and cleaning reduce the effective accumulation), it establishes the upper bound of long-term fire risk.


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**More relevant fire timeline:** The ignitable grease film condition — a deposit sufficient to sustain flame spread upon direct contact with a flame or ember — is estimated at approximately 5 to 20 g/m^2. This is reached within 1 to 2 seasons on the deck surface directly below the grill. The practical recommendation is to clean the deck surface within 0.5 meters of the grill after every cooking session, and the surface within 2 meters at least monthly during the grilling season.

### 3.7 Effect of Wind on Grease Deposition Pattern

Wind direction and speed fundamentally control the spatial distribution of grease deposition. The analysis in RB-006 established that **Wind-Affected Plume Behavior** deflects the plume downwind, and the failure mode analysis in RB-007 confirmed that FM-4 (wind-deflected plume escape) produces directional escape on the downwind side of the hood.

**Calm conditions (less than 2 mph).** Grease deposition is approximately symmetric around the grill, with the heaviest concentration directly below and within 1 meter of the grill perimeter. The plume rises vertically and any escaped aerosol settles in a roughly circular pattern around the source. Deposition is concentrated in the immediate vicinity (0 to 1 meter) because the coarse droplets settle quickly and the absence of wind prevents lateral transport.

**Light wind (2 to 5 mph).** The deposition pattern becomes elongated in the downwind direction. The plume is deflected (12 to 20 inches at 30 inches mounting height for a gas medium, per RB-006 Table 3.2b), carrying escaped aerosol downwind. The peak deposition zone shifts from directly below the grill to 1 to 3 meters downwind. Upwind surfaces receive minimal deposition. The downwind surface within 3 meters receives 2 to 4 times the deposition it would receive in calm conditions.

**Moderate wind (5 to 8 mph).** The plume enters the wind-dominated regime (Fr > 1 for most sources at standard mounting heights, per RB-006 Table 3.3). Capture efficiency drops to 45 to 75% (RB-006 Table 3.10). A substantial fraction of grease aerosol escapes downwind. The deposition footprint extends to 5 to 10 meters downwind, with peak deposition at 2 to 5 meters. Coarse droplets (greater than 20 micrometers) are deposited within 5 meters; finer particles are carried beyond 10 meters. Surfaces 5 meters downwind receive deposition rates of 10 to 30 mg/m^2 per hour — sufficient to produce visible staining over a season.

**Strong wind (8 to 15 mph).** The plume is disrupted (Fr > 2 for most sources, per RB-006 Table 3.6). Capture efficiency drops below 50%. The cooking plume is laid over or broken into puffs. Grease aerosol is carried rapidly downwind with minimal vertical rise, resulting in a ground-hugging deposition pattern. Peak deposition shifts to 3 to 8 meters downwind for coarse particles and extends beyond 30 meters for fine particles. Surfaces at the property boundary (10 to 15 meters) can receive measurable deposition. This is the condition with the greatest potential for neighbor-property contamination.


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*Table 3.7: Grease Deposition Pattern Summary by Wind Speed*

| Wind Speed | Deposition Pattern Shape | Peak Deposition Distance | 90% Mass Deposition Zone | Neighbor Property Impact (at 10 m) |
|---|---|---|---|---|
| Calm (less than 2 mph) | Circular, concentric | 0-0.5 m | Within 2 m radius | Negligible |
| Light (2-5 mph) | Elongated ellipse, downwind | 1-3 m downwind | Within 5 m downwind | Trace |
| Moderate (5-8 mph) | Long plume, directional | 2-5 m downwind | Within 10 m downwind | Low but measurable |
| Strong (8-15 mph) | Extended plume, ground-hugging | 3-8 m downwind | Within 20+ m downwind | Measurable; visible over a season |

## 3.8 Aerosol Transport Within the Entrainment Zone

Within the rising **Buoyant Cooking Plume**, grease aerosol is subject to dilution by entrainment of clean ambient air in the **Entrainment Zone**. As the plume rises and entrains ambient air, the grease aerosol concentration decreases inversely with the increasing plume volume.

From RB-001, the plume mass flow rate at height z is:

```
m_dot_p(z) = 0.071 * Q_c^(1/3) * z^(5/3) + 0.0018 * Q_c
```

The grease aerosol mass flow rate is constant (assuming no gravitational separation, as established in Section 2.3), so the aerosol concentration decreases as:

```
C_aerosol(z) = Q_aerosol / m_dot_p(z)
```

For a medium gas grill (Q_c = 8.2 kW) with an aerosol generation rate of 100 mg/min (1.67 x 10^(-3) g/s):


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| Height | m_dot_p (kg/s) | Aerosol Concentration (mg/m^3) | Dilution Factor Relative to Source |
|---|---|---|---|
| Source (z approximately 0) | ~0.010 (estimated initial thermal plume) | ~167 | 1.0 |
| 18" (0.46 m) | 0.043 | 39 | 4.3 |
| 24" (0.61 m) | 0.066 | 25 | 6.6 |
| 30" (0.76 m) | 0.093 | 18 | 9.3 |
| 36" (0.91 m) | 0.124 | 13 | 12.4 |
| 48" (1.22 m) | 0.196 | 8.5 | 19.6 |

By the time the plume reaches a hood at 30 inches, the aerosol concentration has been diluted by a factor of approximately 9 relative to the source level. At 48 inches, the dilution is approximately 20-fold. This dilution does not reduce the total aerosol mass that must be captured (the total mass flow rate of aerosol is unchanged), but it does reduce the concentration at the **Plume Interception Plane**, which affects filter loading rate and the local air quality exposure if the plume escapes.

The aerosol concentration in the escaped plume at 30 inches (approximately 18 mg/m^3 for a gas medium under the assumed generation rate) is relevant for assessing local air quality. For context, the U.S. EPA 24-hour National Ambient Air Quality Standard (NAAQS) for PM2.5 is 35 micrograms per cubic meter (0.035 mg/m^3). The cooking plume concentration at 30 inches is approximately 500 times this standard. Even after substantial dilution by **Open-Boundary Dilution** in the outdoor atmosphere, the escaped plume represents a locally elevated PM2.5 source that contributes to neighborhood-scale air quality degradation during cooking events.

### 3.9 Interaction of Grease Aerosol with Hood Grease Filters

The grease filtration system within the hood is the primary means by which grease aerosol is prevented from entering the duct and exhausting to the atmosphere (in the captured fraction) or accumulating on interior hood surfaces. The performance of grease filters is directly relevant to fire risk and maintenance requirements.

**Filter loading and performance degradation.** As grease accumulates on filter surfaces during cooking, the filter's flow resistance increases and its effective area for flow passage decreases. This increases the pressure drop across the filter, which reduces the delivered CFM of the blower (the blower operates at a higher point on its pressure-flow curve). From RB-007 Section 3.4, this progressive CFM reduction is a trigger for FM-3 (insufficient exhaust rate).


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The rate of filter loading depends on the grease aerosol mass flow intercepted by the filter. For a fully captured plume at 100 mg/min aerosol generation and 60% average filter mass efficiency:

```
Filter loading rate = 100 * 0.60 = 60 mg/min = 3.6 g/hr
```

Over a 2-hour cooking session, each filter element collects approximately 7.2 grams of grease. Over a 10-session month, each filter collects approximately 72 grams (2.5 ounces). Standard manufacturer recommendations to clean or replace grease filters every 1 to 3 months are consistent with this loading rate.

**Fire risk from filter grease accumulation.** A grease-loaded filter exposed to a flare-up event (a burst of flame that penetrates above the cooking grate and reaches the filter surface) can ignite. The auto-ignition temperature of cooking grease (340 to 400 degrees C) is below the temperature of a direct flame impingement event (typically 600 to 900 degrees C). The risk of filter fire is proportional to the grease load on the filter and the frequency and intensity of flare-up events. Regular filter cleaning is the primary mitigation.

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## 4. 4. Implications for Outdoor BBQ Ventilation

### 4.1 Hood Capture Directly Controls Grease Deposition on Adjacent Surfaces

The analysis in Section 3 demonstrates a direct, quantitative relationship between hood capture efficiency and grease deposition on surrounding surfaces. A hood that achieves 95% capture (proper sizing, low mounting, still air) limits grease deposition on adjacent surfaces at 2 meters to approximately 3 to 10 mg/m^2 per hour — a level that is cosmetically negligible and poses no fire risk. A hood that achieves only 50% capture (compound failure mode, moderate wind) increases deposition at 2 meters to approximately 100 to 250 mg/m^2 per hour — producing visible grease staining after a single session and accumulating to fire-relevant levels over a single season.

The implication is that hood capture efficiency is not merely a comfort or odor control parameter — it is a surface contamination and fire risk parameter. Every percentage point of capture failure translates directly to increased grease deposition on adjacent surfaces. The failure modes catalogued in RB-007 are therefore not only ventilation failures but contamination and fire risk failures.

### 4.2 Coarse Mode Dominates Near-Field Deposition; Fine Mode Dominates Far-Field

The bimodal nature of the grease aerosol size distribution creates a two-zone deposition pattern:

**Near-field (0 to 5 meters):** Dominated by the coarse mode (greater than 10 micrometers), which carries the majority of the grease mass and deposits rapidly through gravitational settling. This is where the cosmetic (staining) and fire risk (grease accumulation) consequences are concentrated. Hood capture effectiveness for the coarse mode is high (70 to 98% for standard baffle filters), so effective hood operation dramatically reduces near-field deposition.

**Far-field (greater than 5 meters):** Dominated by the accumulation mode (0.1 to 2.5 micrometers), which carries less total mass but disperses over a much larger area. Far-field deposition is dilute but persistent, contributing to neighborhood-scale air quality and surface soiling. Hood capture effectiveness for the accumulation mode is low (20 to 40% for standard baffle filters), so even a well-functioning hood permits fine aerosol emission through the duct exhaust.

The design implication is that hood sizing and capture performance (addressed in RB-001 through RB-009) primarily reduce near-field grease deposition and fire risk, while filter technology (baffle versus mesh versus electrostatic versus centrifugal) determines the fraction of fine aerosol emitted through the duct. For outdoor installations where neighbor-property air quality is a concern, filter technology selection is the relevant design parameter.

### 4.3 Wind Exposure Converts a Symmetric Problem into a Directional One

In still air, grease deposition is approximately symmetric around the cooking source, and the total deposited mass is spread over a circular area. When wind is present, the deposition footprint becomes directional, concentrating the escaped grease mass on downwind surfaces. A surface directly downwind at 2 meters receives 2 to 4 times the deposition it would receive in calm conditions.

This has a specific design implication: the orientation of the cooking installation relative to adjacent combustible surfaces should consider the prevailing wind direction. If the prevailing wind blows from the grill toward a combustible wall or structure, the grease deposition on that structure is maximized. Conversely, orienting the grill so that the prevailing wind carries escaped plume material away from combustible surfaces and toward non-combustible or easily cleaned surfaces (concrete patio, metal fence) reduces the fire risk.

This recommendation aligns with the hood orientation guidance in RB-006 Section 3.9.4: orient the hood's long axis parallel to the prevailing wind for maximum capture, and position combustible structures upwind (not downwind) of the cooking area.


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## 4.4 Fire Risk Is Concentrated in the Immediate Vicinity and in the Hood Interior

The fire risk analysis in Section 3.6 identifies two primary fire risk zones:

**Zone 1: Hood interior and grease collection system.** The highest grease concentration occurs inside the hood and duct, where the entire captured aerosol mass is concentrated. A grease-loaded filter or overflowing grease tray represents the most acute fire risk. Regular cleaning (filters monthly, grease tray after every session) is the essential mitigation.

**Zone 2: Deck and surfaces within 0.5 meters of the grill.** The heaviest external deposition occurs directly below and immediately around the grill, from both direct fat dripping and coarse-mode aerosol settling. Seasonal accumulation of 20 to 45 g/m^2 on combustible decking creates an elevated ignition risk when combined with flare-up events or ember ejection. Cleaning the immediate deck area after each session and maintaining the NFPA-recommended 10-foot (3-meter) clearance to combustible structures are the primary mitigations.

Beyond 3 meters, seasonal grease accumulation drops below 4 g/m^2, which is below the threshold for significant fire risk enhancement. The NFPA 10-foot clearance recommendation is well-supported by the deposition analysis.

## 4.5 Filter Maintenance Is a Fire Prevention Measure, Not Just a Performance Measure

The analysis in Sections 3.1 and 3.9 demonstrates that grease filter loading is a continuous, session-by-session process. A filter that collects 7 grams of grease per 2-hour session accumulates approximately 70 grams per month of regular use. At this loading rate, the filter's flow resistance increases progressively, reducing delivered CFM and degrading capture efficiency (triggering FM-3 per RB-007). Simultaneously, the accumulated grease on the filter becomes a fire fuel load that can ignite upon flare-up exposure.

Filter maintenance therefore serves three simultaneous functions:

1. **Maintains capture efficiency** by keeping flow resistance low and CFM at design levels.
2. **Reduces fire risk** by removing accumulated grease fuel from the filter surface.
3. **Maintains air quality** by ensuring adequate exhaust flow to capture the plume fully.

Failure to maintain filters degrades all three functions simultaneously, making it the single most consequential maintenance omission in outdoor cooking ventilation.


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# 5. 5. Knowledge Gaps or Opportunities

## 5.1 Well-Established Knowledge

The following aspects of grease aerosol transport and deposition are well-grounded in published aerosol science, combustion research, and atmospheric dispersion literature:

1. **Stokes settling law** for spherical particles in air is a fundamental result of fluid mechanics and is validated against extensive experimental data. The settling velocities in Table 2.3 are reliable for liquid grease droplets in the applicable size range.

2. **The Gaussian plume dispersion model** is the standard engineering tool for atmospheric dispersion of particulate emissions and is validated against decades of field observations. Its application to cooking-generated aerosol at short ranges (10 to 1000 meters) is appropriate.

3. **Cooking aerosol particle size distributions** have been measured in multiple published studies using indoor cooking facilities with controlled conditions. The bimodal-to-trimodal distribution with modes at approximately 0.03, 0.4, and 12 micrometers is consistently reported across studies and cooking types.

4. **Grease ignition properties** (flash point, auto-ignition temperature) are well-characterized in fire safety literature and food chemistry publications.

5. **The z^(-1/3) velocity decay** and z^(5/3) mass flow scaling from RB-001 that govern vertical aerosol transport within the plume are well-validated Heskestad correlations.

## 5.2 Areas of Moderate Uncertainty

1. **Aerosol generation rates specific to outdoor barbecue cooking.** The generation rates in Section 2.6 are derived primarily from indoor cooking studies. Outdoor barbecue cooking — with higher temperatures, direct flame contact, open-air combustion, and different cooking styles — may produce different generation rates and size distributions. The values used are representative but have not been validated for outdoor barbecue-specific conditions.

2. **The coarse mode (greater than 10 micrometers) is the most uncertain.** Indoor cooking aerosol studies typically use instruments optimized for the fine fraction (less than 2.5 micrometers). The coarse droplet fraction (10 to 100 micrometers) is poorly characterized because these droplets are difficult to sample without loss and deposit on sampling equipment surfaces. The mass fraction attributed to the coarse mode (50 to 80%) is estimated from mass balance considerations rather than direct measurement.


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3. **Deposition flux estimates.** The deposition rates in Table 3.4a are engineering estimates derived from the combination of the Gaussian dispersion model, published deposition velocities, and representative generation rates. They have not been validated by field measurement of actual grease deposition around outdoor cooking installations.

4. **Fire risk thresholds.** The grease accumulation levels cited as fire-relevant (5 to 20 g/m^2 for ignitable film, 200 to 500 g/m^2 for self-heating) are drawn from general fire safety literature and grease fire research. These thresholds have not been validated for the specific composition of barbecue-generated grease deposits, which may differ from commercial kitchen grease in fatty acid composition and oxidation state.

### 5.3 Knowledge Gaps Requiring Further Research

1. **Field measurement of grease deposition around outdoor cooking installations.** No published study has measured the spatial distribution of grease deposition around an operating outdoor barbecue with and without a ventilation hood. A field study using deposition plates at calibrated distances and directions from the cooking source, under measured wind conditions, would validate the deposition model and provide the first direct data on outdoor cooking grease contamination patterns.

2. **Outdoor-specific aerosol generation rate measurement.** Controlled measurement of total aerosol mass generation rate and size distribution from representative outdoor cooking scenarios (gas grill, charcoal grill, wood-fired grill, pellet smoker) using standard aerosol instrumentation (cascade impactors, optical particle counters, gravimetric sampling) in outdoor conditions would eliminate the reliance on indoor cooking data.

3. **Long-term grease accumulation and degradation on surfaces.** Grease deposits on outdoor surfaces are subject to weathering (rain washout, UV degradation, microbial decomposition) that reduces the effective accumulation below the gross deposition rate. The net accumulation rate after weathering is unknown. A multi-season study of grease accumulation on representative surface materials (wood decking, composite decking, vinyl siding, concrete) with and without cleaning would quantify the actual fire risk timeline.

4. **Filter efficiency for outdoor cooking aerosol.** Published filter efficiency data are primarily from commercial kitchen testing with standardized cooking loads. The efficiency of standard outdoor hood baffle filters for the specific aerosol produced by barbecue cooking — which may have a different size distribution, grease composition, and moisture content than commercial kitchen aerosol — has not been measured.


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5. **Ember ejection frequency and transport in wind.** For charcoal and wood-fired grills, ember ejection in windy conditions is a direct ignition source for grease-coated surfaces. The frequency, size, and transport distance of ejected embers as a function of wind speed have not been characterized for outdoor cooking sources.

6. **Health exposure assessment for escaped cooking plume.** The PM2.5 concentration in the escaped plume (approximately 18 mg/m^3 at 30 inches per Section 3.8) is highly elevated relative to ambient air quality standards. The health exposure of outdoor cooks, nearby residents, and bystanders to escaped cooking plume aerosol is a knowledge gap that extends beyond the ventilation scope of this program but is relevant to public health.

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## 6. 6. Diagram Mapping Notes (Text Only)

The following diagram descriptions are aligned with the Diagram Standard v2.1 canonical diagram types and should be produced by the Diagram & Visual Communication Agent.

### Diagram 6.1: Grease Aerosol Size Distribution and Settling Velocity (Diagram Type 2 — Quantitative Chart)

**Purpose:** Show the bimodal particle size distribution of cooking grease aerosol alongside the Stokes settling velocity curve, with regime annotations.

**Content:**

- Dual Y-axis chart. X-axis: particle diameter (log scale, 0.01 to 100 micrometers).
- Left Y-axis: normalized mass distribution (dM/d(log d_p)). Three modes shown: ultrafine peak at 0.03 micrometers, accumulation peak at 0.4 micrometers, coarse peak at 12 micrometers.
- Right Y-axis: Stokes settling velocity (log scale, 10^(-6) to 1 m/s). Monotonically increasing curve (v_s proportional to d_p^2).
- Horizontal reference lines on the right Y-axis at: u_0 at 30 inches for gas medium (1.99 m/s) — "Plume velocity at 30-inch hood height"; u_0 at 48 inches for charcoal kettle (1.07 m/s) — "Weakest plume at 48 inches".
- All settling velocities fall well below both plume velocity references, confirming that no particle size settles out of the plume.
- Vertical reference line at d_p = 2.5 micrometers labeled "PM2.5 boundary"
- Vertical reference line at d_p = 10 micrometers labeled "PM10 boundary"

- Annotations for each mode: ultrafine ("Dominates particle number; negligible mass; passive tracer"), accumulation ("20-40% of mass; PM2.5 fraction; longest atmospheric residence time"), coarse ("50-80% of mass; settles rapidly; deposits within meters of source").
- Figure caption: "Figure 11.1: Grease aerosol particle size distribution (mass-weighted) from outdoor barbecue cooking, overlaid with the Stokes gravitational settling velocity. All settling velocities are orders of magnitude below the Buoyant Cooking Plume velocity at standard hood heights, confirming that all particle sizes are transported to the Plume Interception Plane without gravitational separation."

### Diagram 6.2: Grease Deposition Footprint in Plan View (Diagram Type 3 — Spatial Layout)

**Purpose:** Show the spatial pattern of grease deposition around an outdoor cooking source for calm and windy conditions.

**Content:**

- Two plan-view diagrams side by side:
  - Left: calm conditions (less than 2 mph). Concentric contour rings centered on the grill, showing deposition flux decreasing radially. Contours at 200, 50, 10, and 2 mg/m^2/hr. Approximately circular pattern with slight asymmetry due to hood shadow.
  - Right: 5 mph wind from the left. Elongated contour pattern extending to the right (downwind). Peak deposition shifted 1-3 meters downwind. Contours compressed upwind and extended downwind. Deposition extends to 10+ meters downwind.
- Grill location marked at center, hood outline shown above grill.
- Adjacent structures (deck boundary, fence, siding) shown at representative distances (2 m, 5 m, 10 m).
- Color gradient: red (heavy deposition, greater than 100 mg/m^2/hr), orange (moderate, 10-100), yellow (light, 1-10), green (trace, less than 1).
- Wind arrow on right panel.
- Figure caption: "Figure 11.2: Grease deposition footprint in plan view for 30% plume escape at 100 mg/min aerosol generation. Left: calm conditions produce symmetric deposition concentrated within 2 meters. Right: 5 mph wind produces directional deposition extending 10+ meters downwind, with peak deposition at 1-3 meters. Surfaces directly downwind receive 2-4 times the calm-conditions deposition rate."


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### Diagram 6.3: Particle Transport Distance by Size Class (Diagram Type 2 — Quantitative Chart)

**Purpose:** Show the downwind distance at which particles of each size class deposit at ground level, for a representative wind speed.

**Content:**

- X-axis: particle diameter (log scale, 1 to 100 micrometers)
- Y-axis: ground-contact distance (log scale, 1 m to 10 km)
- Curves for wind speeds of 2, 5, 8, and 10 mph (using H = 1.5 m)
- Horizontal reference lines at: "Property boundary (10 m)"; "NFPA recommended clearance (3 m)"; "Adjacent deck (2 m)"
- Annotation: "Particles smaller than 5 micrometers travel beyond the scale of this chart — they disperse into the atmosphere and are not relevant to local surface deposition."
- Annotation: "Particles larger than 50 micrometers deposit within 1-5 meters regardless of wind speed."
- Figure caption: "Figure 11.3: Downwind ground-contact distance for grease aerosol particles as a function of diameter, for four wind speeds. The release height is 1.5 meters (typical cooking installation height above ground). Coarse particles (greater than 20 micrometers) deposit within the immediate cooking area; intermediate particles (5-20 micrometers) can reach adjacent structures; fine particles (less than 5 micrometers) disperse broadly."

### Diagram 6.4: Grease Accumulation Timeline and Fire Risk Thresholds (Diagram Type 2 — Quantitative Chart)

**Purpose:** Show the cumulative grease accumulation on adjacent surfaces over a barbecue season, with fire risk threshold annotations.

**Content:**

- X-axis: number of cooking sessions (0 to 100, representing two seasons)
- Y-axis: cumulative grease load (g/m^2, 0 to 50)
- Curves for:
  - Deck directly below grill (0-0.5 m): steepest accumulation
  - Deck 1-2 m downwind: moderate accumulation
  - Siding at 1-2 m: lower accumulation


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    - Deck 3-5 m downwind: slow accumulation
- Horizontal reference lines at:
    - 5 g/m^2: "Ignitable film threshold (flame-contact ignition possible)"
    - 20 g/m^2: "Heavy grease load (enhanced flame spread if ignited)"
    - 200 g/m^2: "Exothermic oxidation threshold (theoretical; not reached at these distances)"
- Annotations showing when each surface reaches the 5 g/m^2 threshold
- Assumption note: "30% plume escape, 100 mg/min generation rate, 2-hour sessions, no cleaning."
- Figure caption: "Figure 11.4: Cumulative grease accumulation on adjacent surfaces over repeated cooking sessions, with fire risk thresholds. The deck surface directly below the grill reaches the ignitable film threshold within 10-25 sessions. At 3-5 meters downwind, the threshold is not reached within a typical 50-session season."

### Diagram 6.5: Hood Capture Efficiency Versus Grease Deposition Relationship (Diagram Type 2 — Quantitative Chart)

**Purpose:** Show the direct quantitative relationship between hood capture efficiency and the grease deposition rate on a representative downwind surface.

**Content:**

- X-axis: hood capture efficiency (0% to 100%)
- Y-axis: grease deposition rate on deck at 2 meters downwind (mg/m^2/hr, 0 to 300)
- Single decreasing curve from maximum deposition at 0% capture to near-zero at 100% capture
- Reference points annotated: "No hood (0%): 250 mg/m^2/hr"; "Typical FM-1+FM-4 compound failure (50%): 125 mg/m^2/hr"; "Good outdoor capture (85%): 38 mg/m^2/hr"; "Excellent capture (95%): 13 mg/m^2/hr"
- Shaded zones: red (greater than 100 mg/m^2/hr: "Visible staining per session; seasonal fire risk"); yellow (10-100: "Gradual staining; multi-season fire risk"); green (less than 10: "Negligible deposition; no fire risk")
- Figure caption: "Figure 11.5: Relationship between hood capture efficiency and grease deposition rate on a horizontal surface 2 meters downwind. Every 10 percentage points of capture improvement reduces deposition by approximately 25 mg/m^2/hr. Achieving greater than 90% capture reduces deposition below the level that produces visible staining or fire risk."

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# 7. Appendix A: Standard Ambient Conditions Used in All Calculations

| Parameter | Symbol | Value | Units |
|---|---|---|---|
| Ambient temperature | T_inf | 293 | K (20 degrees C / 68 degrees F) |
| Gravitational acceleration | g | 9.81 | m/s^2 |
| Ambient air density | rho_a | 1.20 | kg/m^3 |
| Dynamic viscosity of air | mu | 1.81 x 10^(-5) | Pa*s |
| Mean free path of air | lambda | 0.066 | micrometers |
| Grease droplet density | rho_p | 900 | kg/m^3 |
| Specific heat of air | c_p | 1.00 | kJ/(kg*K) |

# 8. Appendix B: Key Parameters from Dependency Papers

| Quantity | Value | Source |
|---|---|---|
| Plume centerline velocity, Gas Medium at 30" | 1.99 m/s | RB-001 Table 3.5 |
| Plume centerline velocity, Charcoal Kettle at 48" | 1.07 m/s | RB-001 Table 3.5 |
| Plume mass flow, Gas Medium at 30" | 0.093 kg/s (168 CFM) | RB-001 Table 3.7 |
| Plume capture diameter, Gas Medium at 30" | 1.05 m (41") | RB-001 Table 3.6 |
| Wind deflection, Gas Medium at 30", 5 mph | 12" (0.30 m) | RB-006 Table 3.2b |
| Critical wind for 25% escape, Gas Medium at 30" | 6.7 mph | RB-006 Table 3.4a |
| Capture efficiency, standard hood, 5 mph, no panels | 70-75% | RB-006 Table 3.10 |
| Capture efficiency, standard hood, 8 mph, no panels | 45-55% | RB-006 Table 3.10 |
| Capture efficiency, side panels + rear wall, 5 mph | >95% | RB-006 Table 3.10 |
| FM-1 still-air capture, indoor hood outdoors | 60-80% | RB-007 Section 3.2 |
| FM-3 trigger: installed CFM less than 609 CFM at 30" | FM-3 active | RB-007 Section 3.4 |
| Gust factor, standard | 1.7 | RB-006 Section 2.6 |
| NFPA recommended clearance, grill to combustible structure | 10 feet (3 m) | NFPA 1 Fire Code |

## 9. Appendix C: Glossary Terms Used in This Paper

All terms below are used as defined in Glossary v1.1 of the Outdoor Ventilation Standard.

1. **Buoyant Cooking Plume** — The thermally driven column of heated gas, combustion byproducts, aerosolized grease particulates, and entrained ambient air rising from an outdoor cooking source. The primary vehicle for vertical transport of grease aerosol from the cooking surface to the hood.
2. **Entrainment Zone** — The plume boundary region where ambient air is drawn into the plume, diluting grease aerosol concentration as the plume rises.
3. **Near-Field Plume Region** — The zone immediately above the cooking surface where grease aerosol is generated at highest concentration and the plume has not yet been substantially diluted by entrainment.
4. **Velocity Decay** — The reduction of plume centerline velocity with height. Governs the plume's ability to transport aerosol vertically to the hood; the velocity vastly exceeds the settling velocity of all relevant aerosol sizes.
5. **Capture Envelope** — The spatial volume around the hood within which grease aerosol-laden plume gas is intercepted and extracted. Aerosol outside the Capture Envelope enters the Missed Plume Region.
6. **Effective Capture Area** — The portion of the hood face through which grease-laden plume gas is actually ingested. Reduced by non-uniform velocity distribution and ambient air short-circuiting.
7. **Plume Interception Plane** — The horizontal plane at hood height where grease aerosol is either captured by the hood or escapes into the Missed Plume Region.
8. **Momentum-Limited Capture** — A failure condition where the hood's suction is insufficient to ingest grease-laden plume gas at the hood edges, allowing peripheral aerosol to escape.
9. **Missed Plume Region** — The spatial volume occupied by escaped plume gas and grease aerosol that was not captured by the hood. The Missed Plume Region is the source of all grease deposition on adjacent surfaces.
10. **Open-Boundary Dilution** — The progressive dispersal of escaped grease aerosol into the unbounded outdoor atmosphere. Unlike indoor environments, there is no secondary containment or recirculation.
11. **Wind-Affected Plume Behavior** — The deflection, widening, and disruption of the plume by ambient wind, which converts escaped grease aerosol from a symmetric, vertically rising column into a directional, wind-advected plume that deposits preferentially on downwind surfaces.

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