United States
Environmental Protection Agency

Office of Chemical Safety and
Pollution Prevention

Draft Risk Evaluation for N-Methylpyrrolidone (2-Pyrrolidinone, 1 Methyl-) (NMP)

Supplemental Information on Occupational Exposure Assessment

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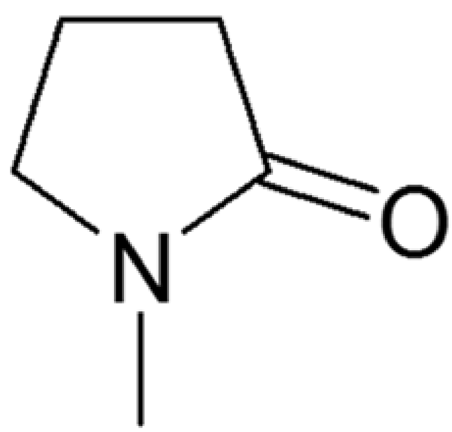

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ABBREVIATIONS

ACGIH	American Conference of Government Industrial Hygienists
AIA	Aerospace Industries Association
AIHA	American Industrial Hygiene Association
AP-42	Compilation of Air Pollutant Emissions Factors
APF	Assigned Protection Factor
BLS	Bureau of Labor Statistics
CAA	Clean Air Act
CARB	California Air Resources Board
CASRN	Chemical Abstracts Service Registry Number
CBI	Confidential Business Information
CDR	Chemical Data Reporting
CFR	Code of Federal Regulations
cm^2	Centimeters squared
CSPA	Consumer Specialty Products Association
DOD	Department of Defense
DOEHRS-IH	Defense Occupational and Environmental Health Readiness System – Industrial Hygiene
ECETOC	European Center for Ecotoxicology and Toxicology of Chemicals
ECHA	European Chemicals Agency
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ESD	Emission Scenario Documents
EU	European Union
EVOH	Ethylene vinyl alcohol (gloves)
FDA	Food and Drug Administration
FFEM	FUJIFILM Electronic Materials
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
FR	Federal Register
g	grams
GBL	Gamma-butyrolactone
GS	Generic Scenario
HERO	Health & Environmental Research Online
HHE	Health Hazard Evaluation
hr	Hour
HVLP	High-Volume Low-Pressure
IBC	Intermediate bulk container
IFA	German Institute for Occupational Safety and Health
kg	Kilogram(s)
kPa	kilopascal
L	Liter(s)
lb	Pound
LEV	Local Exhaust Ventilation
LPG	Liquefied Petroleum Gas
m^3	Cubic Meter(s)
MEMA	Motor & Equipment Manufacturers Association
mg	Milligram(s)
MMA	Monomethylamine

mmHg	Millimeter(s) of Mercury
s	Seconds
SDS	Safety Data Sheet
NABTU	North America's Building Trades Unions
NAICS	North American Industry Classification System
NEMA	National Electrical Manufacturers Association
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NIOSH	National Institute of Occupational Safety and Health
NKRA	Not Known or Reasonably Ascertainable
NMP	N-Methylpyrrolidone
NPDES	National Pollutant Discharge Elimination System
OAQPS	Office of Air Quality Planning and Standards
OARS	Occupational Alliance for Risk Science
OECD	Organisation for Economic Co-operation and Development
OEL	Occupational Exposure Limit
OES	Occupational Exposure Scenario
ONU	Occupational Non-User
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
PBPK	Physiologically Based Pharmacokinetic (Modeling)
PBZ	Personal Breathing Zone
PEL	Permissible Exposure Limit
PF	Problem Formulation
POTW	Publicly Owned Treatment Works
PNOR	Particulates Not Otherwise Regulated
PPE	Personal Protective Equipment
ppm	Part(s) per Million
PPS	Polyphenylene Sulfide
QC	Quality Control
RA	Risk Assessment
RCRA	Resource Conservation and Recovery Act
RDF	Refuse-Derived Fuel
REL	Recommended Exposure Limit
RIVM	The Netherlands' National Institute for Public Health and the Environment
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act
SIA	Semiconductor Industry Association
SOC	Standard Occupational Classification
SOCMI	Synthetic Organic Chemical Manufacturing Industry
SUSB	Statistics of U.S. Businesses
TLV	Threshold Limit Value
TRA	Targeted Risk Assessment (tool)
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TWA	Time-Weighted Average
U.S.	United States
UV	Ultraviolet
USDA	U.S. Department of Agriculture

VOC	Volatile Organic Compound
WEEL	Workplace Environment Exposure Limit

1 INTRODUCTION

This document supports occupational exposure assessment in the "Risk Evaluation for N-Methylpyrrolidone (2-Pyrrolidinone, 1 Methyl-) (NMP)."

1.1 Overview

For the purpose of this assessment, EPA considered occupational exposure of the total workforce of exposed users and non-users, which include but are not limited to male and female workers of reproductive age who are >16 years of age. Female workers of reproductive age are >16 to less than 50 years old. Adolescents (>16 to <21 years old) are a small part of this total workforce. The occupational exposure assessment is applicable to and covers the entire workforce who are exposed to NMP.

EPA evaluated acute and chronic exposures to workers and occupational non-users (ONUs) by dermal and inhalation routes in association with NMP use in industrial and commercial applications, which are shown in Table 1-1. Oral exposure via incidental ingestion of inhaled vapor/mist/dust will be considered as discussed in the "Risk Evaluation for N-Methylpyrrolidone (2-Pyrrolidinone, 1 Methyl-) (NMP)."

EPA assessed these exposures by inputting exposure parameters into a physiologically based pharmacokinetic (PBPK) model, which is described in Appendix I of the Risk Evaluation document. Parameter development for each occupational exposure scenario assessed are described in Section 2.

For each scenario, EPA distinguishes exposures for workers and ONUs when possible. Normally, a primary difference between workers and ONUs is that workers may handle chemical substances and have direct dermal contact with liquid chemicals that they handle, while ONUs are working in the general vicinity of workers but do not handle the assessed chemical substances and do not have direct dermal contact with liquid chemicals being handled by the workers. EPA expects that ONUs may often have lower inhalation exposures than workers since they may be further from the exposure source than workers. For inhalation, if EPA cannot distinguish ONU exposures from workers, EPA assumes that ONU inhalation may be less than the inhalation estimates for workers.

1.2 Scope

Workplace exposures have been assessed for the following industrial and commercial uses of NMP, also referred to as occupational exposure scenarios (OES):

1. Manufacturing
2. Repackaging
3. Chemical Processing, Excluding Formulation
4. Incorporation into a Formulation, Mixture or Reaction Product
5. Application of Paints, Coatings, Adhesives and Sealants
6. Printing and Writing
7. Metal Finishing
8. Removal of Paints, Coatings, Adhesives, and Sealants
9. Cleaning
10. Automotive Car Servicing
11. Laboratory Use
12. Electronics Manufacturing
13. Soldering
14. Fertilizer Application
15. Wood Preservatives
16. Recycling and Disposal

These are mapped to the conditions of use listed in the Risk Evaluation document in the table below.

Table 1-1. Crosswalk of Conditions of Use Listed to Occupational Exposure Scenarios Assessed in the Risk Evaluation

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
Manufacture	Domestic Manufacture	Domestic Manufacture	Section 2.1 - Manufacturing
	Import	Import	Section 2.2 - Repackaging
Processing	Processing as a reactant or intermediate	Intermediate in Plastic Material and Resin Manufacturing and in Pharmaceutical and Medicine Manufacturing	Section 2.3 - Chemical Processing, Excluding Formulation
		Other	
	Incorporated into formulation, mixture or reaction product	Adhesives and sealant chemicals in Adhesive Manufacturing	Section 2.4 - Incorporation into Formulation, Mixture, or Reaction Product
		Anti-adhesive agents in Printing and Related Support Activities	
		Paint additives and coating additives not described by other codes in Paint and Coating Manufacturing; and Print Ink Manufacturing	
		Processing aids not otherwise listed in Plastic Material and Resin Manufacturing	
		Manufacturing; Primary Metal Manufacturing; Soap, Cleaning Compound and Toilet Preparation Manufacturing; Transportation Equipment Manufacturing; All Other Chemical Product and Preparation Manufacturing; Printing and Related Support Activities; Services; Wholesale and Retail Trade	
		Surface active agents in Soap, Cleaning Compound and Toilet Preparation Manufacturing	
Processing	Incorporated into formulation, mixture or reaction product	Plating agents and surface treating agents in Fabricated Metal Product Manufacturing	Section 2.4 - Incorporation into Formulation, Mixture, or Reaction Product
		Solvents (which become part of product formulation or mixture) in Electrical Equipment, Appliance and Component Manufacturing; Other Manufacturing; Paint and Coating Manufacturing; Print Ink Manufacturing; Soap, Cleaning Compound and Toilet Preparation Manufacturing; Transportation Equipment Manufacturing; All Other Chemical Product and Preparation Manufacturing; Printing and Related Support Activities; Wholesale and Retail Trade	
		Other uses in Oil and Gas Drilling, Extraction and Support Activities; Plastic Material and Resin Manufacturing; Services	
	Incorporated into article	Lubricants and lubricant additives in Machinery Manufacturing	Section 2.5 - Metal Finishing

Life Cycle Stage	**Category** [a]	**Subcategory** [b]	**Occupational Exposure Scenario**
		Paint additives and coating additives not described by other codes in Transportation Equipment Manufacturing	Section 2.5 - Application of Paints, Coatings, Adhesives, and Sealants
		Solvents (which become part of product formulation or mixture), including in Textiles, Apparel and Leather Manufacturing	Section 2.4 - Incorporation into Formulation, Mixture, or Reaction Product
Processing	Incorporated into article	Other, including in Plastic Product Manufacturing	Section 2.3 - Chemical Processing, Excluding Formulation
	Recycling	Recycling	Section 2.16 - Recycling and Disposal
	Repackaging	Wholesale and Retail Trade	Section 2.2 - Repackaging
Distribution in commerce	Distribution	Distribution in commerce	Activities related to distribution (e.g., loading, unloading) are considered throughout the life cycle, rather than using a single distribution scenario.
Industrial, commercial, and consumer use	Paints and coatings	Paint and coating removers	Section 2.6 - Removal of Paints, Coatings, Adhesives, and Sealants
		Adhesive removers	
		Lacquers, stains, varnishes, primers and floor finishes	Section 2.7 - Application of Paints, Coatings, Adhesives, and Sealants
		Powder coatings (surface preparation)	
	Paint additives and coating additives not described by other codes	Use in Computer and Electronic Product Manufacturing, Construction, Fabricated Metal Product Manufacturing, Machinery Manufacturing, Other Manufacturing, Paint and Coating Manufacturing, Primary Metal Manufacturing, Transportation Equipment Manufacturing, Wholesale and Retail Trade	
	Solvents (for cleaning or degreasing)	Use in Electrical Equipment, Appliance and Component Manufacturing.	Section 2.8 - Electronics Manufacturing
	Ink, toner, and colorant products	Printer ink	Section 2.9 - Printing and Writing
		Inks in writing equipment	
	Processing aids, specific to petroleum production	Petrochemical Manufacturing	Section 2.3 - Chemical Processing, Excluding Formulation
Industrial, commercial, and consumer use	Adhesives and sealants	Adhesives and sealant chemicals including binding agents	Section 2.7 - Application of Paints, Coatings, Adhesives, and Sealants
		Single component glues and adhesives, including lubricant adhesives	
		Two-component glues and adhesives, including some resins	

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
		Soldering materials	Section 2.10 - Soldering
	Other uses	Anti-freeze and de-icing products	Section 2.11 - Commercial Automotive Serving
		Automotive care products	
		Lubricants and greases	
		Metal products not covered elsewhere	Section 2.5 - Metal Finishing
		Laboratory chemicals	Section 2.12 - Laboratory Use
		Lithium ion batteries	Section 2.8 - Electronics Manufacturing
		Cleaning and furniture care products, including wood cleaners, gasket removers	Section 2.13 - Cleaning
		Other uses in Oil and Gas Drilling, Extraction and Support Activities	Section 2.3 - Chemical Processing, Excluding Formulation
		Lubricant and lubricant additives, including hydrophilic coatings	Section 2.5 - Metal Finishing
		Fertilizer and other agricultural chemical manufacturing - processing aids and solvents	Section 2.14 - Fertilizer Application
		Pharmaceutical and Medicine Manufacturing - functional fluids (closed systems)	Section 2.3 - Chemical Processing, Excluding Formulation
		Wood preservatives	Section 2.15 - Wood Preservatives
Disposal	Disposal	Industrial pre-treatment	Section 2.16 - Recycling and Disposal
		Industrial wastewater treatment	
		Publicly owned treatment works (POTW)	
		Underground injection	
		Landfill (municipal, hazardous or other land disposal)	
		Incinerators (municipal and hazardous waste)	
		Emissions to air	

[a] These categories of conditions of use appear in the Life Cycle Diagram, reflect CDR codes, and broadly represent conditions of use of NMP in industrial and/or commercial settings.
[b] These subcategories reflect more specific uses of NMP

1.3 Components of the Occupational Exposure Assessment

The occupational exposure assessment of each use comprises the following components:

- **Process Description:** A description of the use, including the role of the chemical in the use; process vessels, equipment, and tools used during the use; and descriptions of the worker activities, including an assessment for potential points of worker exposure.
- **Number of Sites:** An estimate of the number of sites that use the chemical for the given use.

- **Number of Workers and Occupational Non-Users:** An estimate of the number of workers and occupational non-users potentially exposed to the chemical for the given use.
- **PBPK Input Parameter Determination:** A development of a set of central tendency and a set of high-end PBPK input parameters for each occupational exposure scenario within a use, accounting for both inhalation and dermal exposure.

1.4 Approach and Methodology for Occupational Exposures

EPA reviewed data such as general facility data (e.g., process descriptions, NMP concentration data), inhalation monitoring data (i.e., personal exposure monitoring data and area monitoring data), and environmental release data, found in published literature. Literature sources were evaluated using the evaluation strategies laid out in Appendix D of the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018a). Results of the evaluations are in the supplemental files titled "Risk Evaluation for N-Methylpyrrolidone (NMP), Systematic Review Supplemental File: Data Quality Evaluation for Occupational Exposure and Release Data. Docket EPA-HQ-OPPT-2019-0236" and "Risk Evaluation for N-Methylpyrrolidone (2-Pyrrolidinone, 1-Methyl-) Systematic Review Supplemental File: Data Quality Evaluation of Environmental Releases and Occupational Exposure Common Sources. Docket EPA-HQ-OPPT-2019-0236."

Each data source received an overall confidence of high, medium, low or unacceptable. For the risk evaluation, EPA used the data of the highest quality. Data of lower rated quality may be used to supplement analyses. Data that were found to be unacceptable were not used for risk assessment purposes. Overall confidence ratings for the data used in this document (i.e., high, medium, low or unacceptable) are included in Section 2 and the tables in Appendix A.

1.4.1 Process Description

EPA performed a literature search to find descriptions of processes involved in each use to identify worker activities that could potentially result in occupational exposures. Where process descriptions were unclear or not available, EPA referenced relevant Emission Scenario Documents (ESDs) or Generic Scenarios (GSs). Process descriptions for each use can be found in Section 2.

1.4.2 Number of Sites, Workers, and ONUs

Where available, EPA used CDR data to provide a basis to estimate the numbers of sites, workers, and occupational non-users (ONUs). EPA supplemented the available CDR data with U.S. economic data using the following method:

1. Identify the North American Industry Classification System (NAICS) codes for the industry sectors associated with these uses.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' (BLS) Occupational Employment Statistics (OES) data (U.S. BLS, 2016).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census' Statistics of US Businesses (SUSB) (citation) data on total employment by 6-digit NAICS.
4. Use market penetration data to estimate the percentage of employees likely to be using NMP instead of other chemicals.
5. Combine the data generated in Steps 1 through 4 to produce an estimate of the number of employees using NMP in each industry/occupation combination, and sum these to arrive at a total estimate of the number of employees with exposure.

Market penetration data for NMP are not readily available at this time; therefore, site, worker, and ONU estimates do not take this into account and likely overestimate the number of sites, workers, and ONUs potentially exposed to NMP. Where end-use sector is not clear, relevant GSs and ESDs are used to estimate the number of sites and workers, such as for metal finishing.

1.4.3 PBPK Input Parameter Determination

For each occupational exposure scenario, PBPK modeling requires a set of input parameters related to both dermal and inhalation exposures. The occupational exposure parameters and information needed for the PBPK modeling are the following:

- NMP weight fraction in the liquid product;
- Total skin surface area in contact with the liquid product;
- Glove protection factor (if applicable);
- Duration of dermal contact with the liquid product;
- Air concentration for inhalation and vapor-through-skin exposure; and
- Body weight of the exposed worker.

EPA assumed that the skin of the hands was exposed dermally to NMP at the specified liquid weight fraction and skin surface area and that there was simultaneous exposure by inhalation and vapor-through-skin absorption for unobstructed skin areas. As described below, air concentrations were adjusted to duration of contact of liquid on the skin, which is assumed to be removed by cleaning at the end of the work period. Acute scenarios assumed 1 day of exposure and chronic scenarios assumed 5 days of exposure per week.

EPA used literature sources for estimating many of these occupational exposure parameters. EPA used modeling or generic assumptions when data were not available. For most PBPK input parameters, EPA did not find enough data to determine statistical distributions of the actual exposure parameters and concentrations. Within the distributions, central tendencies describe 50^{th} percentile or the substitute that most closely represents the 50^{th} percentile. The high-end of a distribution describes the range of the distribution above 90th percentile (U.S. EPA, 1992). Ideally, EPA would use the 50th and 95th percentiles for each parameter. Where these statistics were unknown, the mean or mid-range (mean is preferable to mid-range) served as substitutes for 50th percentile and the high-end of ranges served as a substitute for 95th percentile. However, these substitutes were highly uncertain and not ideal substitutes for the percentiles. EPA could not determine whether these substitutes were suitable to represent statistical distributions of real-world scenarios.

For each occupational exposure scenario, EPA developed two sets of PBPK input parameters, one representative of *central tendency* conditions and one representative of *high-end* conditions. To generate each central tendency scenario result, EPA used a group of all central tendency input parameter values relevant to the scenario. To generate each high-end scenario result, EPA used a group of mostly high-end input parameter values relevant to the scenario except body weight, which is a median value. Using mostly high-end input values is a plausible approach to estimate a high-end PBPK result for the periods of acute and chronic exposures of 1 to 5 days.

A central tendency is assumed to be representative of occupational exposures in the center of the distribution for a given use. For risk evaluation, EPA may use the 50^{th} percentile (median), mean (arithmetic or geometric), mode, or midpoint values of a distribution as representative of the central tendency scenario. EPA's preference is to provide the 50^{th} percentile of the distribution. However, if the full distribution is not known, EPA may assume that the mean, mode, or midpoint of the distribution represents the central tendency depending on the statistics available for the distribution.

A high-end is assumed to be representative of occupational exposures that occur at probabilities above the 90th percentile but below the exposure of the individual with the highest exposure (U.S. EPA, 1992). For risk evaluation, EPA provided high-end results at the 95th percentile, where available. If the 95th percentile is not available, EPA may use a different percentile greater than or equal to the 90th percentile but less than or equal to the 99.9th percentile, depending on the statistics available for the distribution. If the full distribution is not known and the preferred statistics are not available, EPA may estimate a maximum or bounding estimate in lieu of the high-end.

1.4.3.1 General Approach

This section discusses EPA's general approach for data selection. EPA follows the following hierarchy in selecting data and approaches for estimating air concentrations:

1. Monitoring data:
   a. Personal and directly applicable
   b. Area and directly applicable
   c. Personal and potentially applicable or similar
   d. Area and potentially applicable or similar
2. Modeling approaches:
   a. Surrogate monitoring data
   b. Fundamental modeling approaches
   c. Statistical regression modeling approaches
3. Occupational exposure limits:
   a. Company-specific occupational exposure limits (OELs) (for site-specific exposure assessments, e.g., there is only one manufacturer who provides to EPA their internal OEL but does not provide monitoring data)
   b. Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL)
   c. Voluntary limits (American Conference of Governmental Industrial Hygienists [ACGIH] Threshold Limit Value [TLV], National Institute for Occupational Safety and Health [NIOSH] Recommended Exposure Limits [RELs], Occupational Alliance for Risk Science (OARS) workplace environmental exposure level [WEEL] [formerly by AIHA])

Within each level of the hierarchy, EPA used the data with the highest overall confidence rating from EPA's systematic review process. Note that EPA did not rate EPA models used to estimate air concentrations; where these models are used, the overall confidence rating is listed as "not applicable". EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

Exposures are calculated from the datasets provided in the sources depending on the size of the dataset. For datasets with six or more data points, central tendency and high-end exposures were estimated using the 50th percentile and 95th percentile. For datasets with three to five data points, central tendency exposure was calculated using the 50th percentile and the maximum was presented as the high-end exposure estimate. For datasets with two data points, the midpoint was presented as a midpoint value and the higher of the two values was presented as a higher value. Finally, data sets with only one data point presented the value as a what-if exposure. For datasets including exposure data that were reported as below the limit of detection (LOD), EPA estimated the exposure concentrations for these data, following EPA's *Guidelines for Statistical Analysis of Occupational Exposure Data* (EPA, 1994). which recommends using the $\frac{LOD}{\sqrt{2}}$ if the geometric standard deviation of the data is less than 3.0 and $\frac{LOD}{2}$ if the geometric standard deviation is 3.0 or greater. Specific details related to each occupational exposure scenario can be found in Section 2.

Air concentrations may be a *point estimate* (i.e., a single descriptor or statistic, such as central tendency or high-end) or a *full distribution*. EPA will consider three general approaches for estimating air concentrations:

- Deterministic calculations: EPA will use combinations of point estimates of each model parameter to estimate a central tendency and high-end for air concentration. EPA will document the method and rationale for selecting parametric combinations to be representative of central tendency and high-end.

- Probabilistic (stochastic) calculations: EPA will pursue Monte Carlo simulations using the full distribution of each parameter to calculate a full distribution of the air concentration results and selecting the 50^{th} and 95^{th} percentiles of this resulting distribution as the central tendency and high-end, respectively.

- Combination of deterministic and probabilistic calculations: EPA may have full distributions for some parameters but point estimates of the remaining parameters. For example, EPA may pursue Monte Carlo modeling to estimate exposure concentrations, but only have point estimates of working years of exposure, exposure duration and frequency, and lifetime years. In this case, EPA will document the approach and rationale for combining point estimates with distribution results for estimating central tendency and high-end results.

EPA follows the following hierarchy in selecting data and approaches for estimating other dermal input parameters:

1. Monitoring data (in general, for weight fractions of NMP, glove usage information, and exposure durations).
2. Industry data:
   a. Data provided directly by industry (i.e., public comments, reports written by the company where the data originates from, safety datasheets [SDSs])
   b. Industry data from an indirect source (i.e., government documents, other risk assessment reports, online vendors [for weight fractions of NMP])
3. Values from the 2011 edition of EPA's Exposure Factors Handbook (U.S. EPA, 2011).
4. Assumptions

1.4.3.2 Approach for this Risk Evaluation

For most exposure parameters, EPA did not find enough data to determine statistical distributions of the actual exposure parameters. As described in Section 1.4.3, ideally, EPA would like to know 50th and 95th percentiles for each parameter. However, where these percentiles were unavailable, EPA used substitutes such as mid-ranges or high-ends. These substitutes were highly uncertain and not ideal substitutes for the percentiles. EPA could not determine whether these values were suitable to represent statistical distributions of real-world scenarios.

Parameters were selected for the most sensitive populations: pregnant women and females of reproductive age who may become pregnant.

1.4.3.2.1 Weight Fraction of NMP

EPA determined the weight fraction of NMP in various products through information provided in the available literature, previous risk assessments and the 2017 NMP Market Profile (Abt, 2017). This Market Profile was prepared in part by searching Safety Data Sheets (SDSs) of products that contain NMP and compiling the associated name, use, vendor and NMP concentration associated with each of these products. Where a data point was provided as range of NMP concentrations for a certain product (e.g., paints and coatings), EPA utilized the mid-range (middle) and high-end (maximum) weight fractions to estimate potential exposures. Where multiple data points for a given type of product (e.g., paints and coatings) were available, EPA estimated exposures using the central tendency (50^{th} percentile) and high-end (95^{th} percentile) NMP concentrations.

1.4.3.2.2 Skin Surface Area

For both consumer and occupational dermal exposure assessments, EPA used skin surface area values both for the hands of females and the hands of males, obtained from the 2011 edition of EPA's Exposure Factors Handbook (Table 7-13) (U.S. EPA, 2011). These values overestimate exposures for younger members of the workforce whose hand surface areas would be smaller. One exception is for the OES that includes Writing, 1 cm^2 was assumed based on a literature estimate for writing inks (Australian Government Department of Health, 2016). For the remainder of the occupational dermal exposure assessment, EPA used the following values:

- high-end value, which represents two full hands exposed to a liquid: 890 cm^2 (female), 1,070 cm2 (males)
- central tendency value, which is half of two full hands (equivalent to one full hand) exposed to a liquid and represents only the palm-side of both hands exposed to a liquid: 445 cm^2 (females), 535 (males)

ONUs are not expected to have direct contact with NMP-based liquid products unless an incident (e.g., spill) were to occur. However, PBPK modeling of ONU (no liquid contact) used a skin surface area value of 0.1 cm^2 (about 0.1% of values used for occupational users) for liquid exposure to prevent a division by zero error in model equations.

For dermal exposure to vapor for both occupational users and ONUs, the PBPK modeled up to 25% of the total skin surface area, corresponding to the face, neck, arms and hands, as exposed to and capable of absorbing vapors, minus any area covered by personal protection equipment (PPE). This area, which is programmed into the PBPK model, is not a variable input value.

1.4.3.2.3 Glove Usage

EPA also made assumptions about glove use and associated protection factors (PFs). Where workers wear gloves, workers are exposed to NMP-based product that penetrates the gloves, including potential seepage through the cuff from improper donning of the gloves, permeation of NMP through the glove material, and the gloves may occlude the evaporation of NMP from the skin. Where workers do not wear gloves, workers are exposed through direct contact with NMP.

Overall, EPA understands that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. Some sources indicate that workers wear chemical-resistant gloves (Meier et al., 2013; OECD, 2009; NICNAS, 2001), while others indicate that workers likely wear gloves that provide a lower protection factor (RIVM, 2013). No information on employee training was found. Data on the prevalence of glove use is not available for most uses of NMP. One anecdotal survey of glove usage among workers performing graffiti removal indicates that most workers wear gloves, although the glove materials varied and were sometimes not protective (U.S. EPA, 2015b). Prior to the initiation of this risk evaluation, EPA had gathered information in support of understanding glove use for handling pure NMP and for paint and coatings removal using NMP formulations. This information may be generally useful for a broader range of uses of NMP and is presented for illustrative purposes in Appendix E of the Risk Evaluation. SDSs found by EPA recommend glove use. Initial literature review suggests that there is unlikely to be sufficient data to justify a specific probability distribution for effective glove use for a chemical or industry. Instead, the impact of effective glove use is explored by considering different protection factors, which are further discussed below and compiled in Table 1-2.

Gloves only offer barrier protection until the chemical breaks through the glove material. Using a conceptual model, Cherrie (2004) proposed a glove workplace protection factor (PF) – the ratio of estimated uptake through the hands without gloves to the estimated uptake though the hands while wearing gloves: this protection factor is driven by glove usage practices and by flux, which varies with time. The ECETOC TRA v3 model represents the protection factor of gloves as a fixed, assigned protection factor equal to 5, 10, or 20 (Marquart et al., 2017). When assuming glove use, EPA assumed protections factors using this strategy. Given the limited state of knowledge about the protection afforded by gloves in the workplace, it is reasonable to utilize the PF values of the ECETOC TRA v3 model (Marquart et al., 2017), rather than attempt to derive new values.

For each occupational exposure scenario, EPA used judgement to predict the likelihood of the use of gloves based on the characteristics described in Table 1-2 below. For OESs with only industrial sites, EPA assumes that workers are likely to wear protective gloves and have basic training on the proper usage of these gloves, corresponding to a protection factor of 10 for both the central tendency and high-end exposure scenarios. In high-end scenarios that include both commercial and industrial sites, EPA assumes that either no gloves are used or, if gloves are used, that glove material may not be protective, each of which corresponds to a protection factor of 1. For these same scenarios, EPA assesses a central tendency scenario assuming the use of gloves with minimal to no employee training, corresponding to a protection factor of 5. As indicated in Table 1-2, use of protection factors above 1 is valid only for glove materials that have been tested for permeation against the NMP-containing liquids associated with the condition of use. EPA has not found information that would indicate specific activity training (e.g., procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur in industrial OESs, so the PF of 20 is not assumed for any central tendency or high-end estimates. EPA also considered potential dermal exposure in cases where exposure is occluded. If occlusion were to occur, contact duration would be extended and glove protection factors could be reduced, although such extensions and reductions could not be quantified for this evaluation due to lack of data.

Table 1-2. Glove Protection Factors for Different Dermal Protection Strategies from ECETOC TRA v3

Dermal Protection Characteristics	Setting	Protection Factor, PF
a. No gloves used, or any glove / gauntlet without permeation data and without employee training	Industrial and Commercial Uses	1
b. Gloves with available permeation data indicating that the material of construction offers good protection for the substance		5
c. Chemically resistant gloves (i.e., as *b* above) with “basic” employee training		10

Dermal Protection Characteristics	Setting	Protection Factor, PF
d. Chemically resistant gloves in combination with specific activity training (e.g., procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur	Industrial Uses Only	20

1.4.3.2.4 Duration of Dermal Contact

Where available, EPA utilized exposure durations from the available task-based inhalation monitoring data. No dermal duration data was found. In lieu of dermal duration data or task-based durations from inhalation monitoring data, EPA assumed a minimum duration of 1 hour/day, which is a reasonable assumption considering the initial contact time with the formulation containing NMP plus the time after direct contact when the thin film evaporates from and absorbs into the skin. EPA assumed a high-end value of 8 hours/day (i.e., a full shift). As a central tendency estimate, EPA assumed a mid-range value of 4 hours/day (the calculated mid-point of 4.5 was rounded to 4 hours/day). The low-end and high-end values are consistent with EPA's documented standard model assumptions for occupational dermal exposure modeling (U.S. EPA, 1991).

1.4.3.2.5 Air Concentration for Inhalation and Vapor-through-Skin Exposure

EPA reviewed workplace inhalation monitoring data collected by government agencies such as OSHA and NIOSH, and monitoring data found in published literature (i.e., personal exposure monitoring data and area monitoring data). Data were evaluated using the evaluation strategies laid out in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018a). Where available, EPA used air concentration data and estimates found in government or published literature sources to serve as inputs to the PBPK modeling for occupational exposures to NMP. There is not a known correlation between weight fraction of NMP in the material being handled / used and the concentration of NMP in air. Where air concentration data were not available, data for the use of NMP in similar but different work activities (surrogate approach) or modeling estimates were used. Details on which approaches and models EPA used are included in Section 2 for the applicable OESs and discussion of the uncertainties associated with these approaches and models is included in Section 3.2.

Inhalation data sources did not usually indicate whether NMP exposure concentrations were for occupational users or nearby occupational non-users. In these cases, EPA assumed that inhalation exposure data were applicable for a combination of users and nearby occupational non-users (ONUs); EPA used the same inhalation exposure estimates for both occupational users and ONUs. While some ONUs may have lower inhalation exposures than users, especially when they are further away from the source of exposure, EPA assumed that ONUs that may be near workers handling NMP.

For PBPK modeling, the duration of inhalation exposure must equal the duration of dermal exposure. Therefore, where EPA did not have exposure durations from task-based monitoring data, EPA adjusted air concentrations by multiplying by a ratio of duration of the air concentration averaging time to duration of dermal exposure to liquid, which is discussed above.

Few literature sources indicate the use of respirators for reducing worker exposures to NMP by inhalation. Therefore, EPA central tendency and high-end scenarios do not incorporate protection factors for respirator use. Regarding respirator use, only one of the NMP studies containing worker inhalation data specified the type of respirator used by the workers in the study. This respirator, a half mask air-purifying respirator with organic vapor cartridges (Kiefer, 1994), is classified as having an assigned protection factor (APF) of 10. Therefore, EPA conducted additional modeling representing scenarios below central tendency for the use of respirators providing an APF of 10. This modeling reduces inhalation concentrations by a factor of 10 as intended when this type of respirator is used in accordance with OSHA's Respiratory Protection standard (29 CFR 1910.134). While respirators with other APFs may be used, EPA only included this APF in additional modeling. The results of this additional modeling are shown in Section 4 of the Risk Evaluation.

1.4.3.2.6 Body Weight

Both the consumer and occupational dermal exposure assessments used the 50th percentile body weight value for pregnant women in their first trimester, which is 74 kg, and for males, which is 88 kg, for both the central tendency and high-end exposure scenarios. EPA obtained this value from the 2011 edition of EPA's Exposure Factors Handbook (Table 8-29) (U.S. EPA, 2011).

2 Engineering Assessment

The following sections will contain process descriptions and the specific details (worker activities, analysis for determining number of workers, exposure assessment approach and results, release sources, media of release, and release assessment approach and results) from the assessment for each release/exposure scenario.

2.1 Manufacturing

2.1.1 Process Description

NMP can be manufactured using multiple reaction pathways and relevant different processing steps. One method involves reaction of butyrolactone with an excess of pure or aqueous methylamine in a high-pressure tube (NCBI, 2017; NIH, 2017; Harreus et al., 2011; TURI, 1996). This reaction is shown in Figure 2-1 and is taken from (Anderson and Liu, 2000). This exothermic reaction takes place under adiabatic conditions and produces a reaction product containing NMP that is subsequently distilled to purify the produced NMP. This method of manufacturing results in a 97% yield of NMP (Harreus et al., 2011).

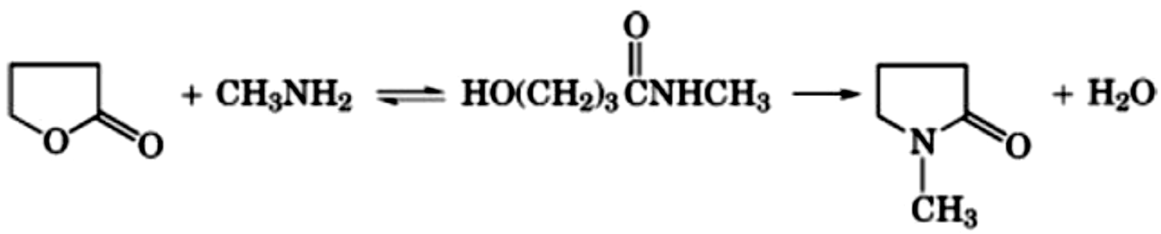

Figure 2-1. NMP Manufacturing Under Adiabatic Conditions

Another similar process for manufacturing NMP involves reacting gamma-butyrolactone (GBL) and monomethylamine (MMA), as shown in Figure 2-2 (Johnson Matthey Process Technologies, 2017). This reaction is non-catalyzed and takes place in two stages. The first stage produces a long-chain amide that is cyclized, then dehydrated to form NMP during the second stage of the reaction. The reaction product that contains NMP is then distilled to purify the NMP.

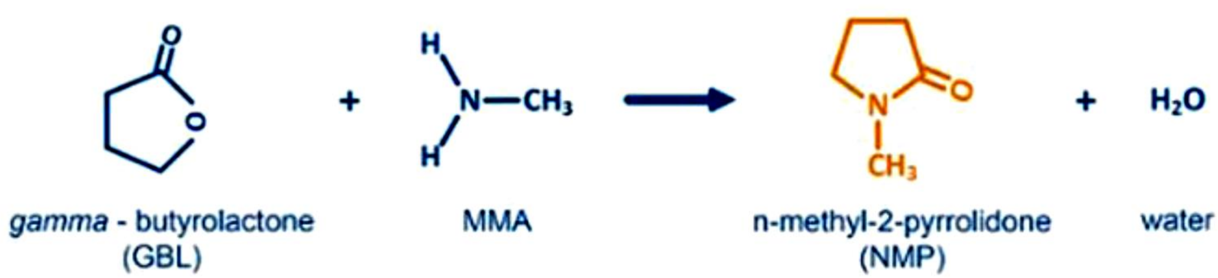

Figure 2-2. NMP Manufacturing Using Gamma-Butyrolactone (GBL) and Monomethylamine (MMA)

Other methods of NMP manufacturing include high pressure synthesis from acetylene and formaldehyde (NIH, 2017; TURI, 1996) carbonylation of allylamine (Harreus et al., 2011), and hydrogenation of maleic anhydride or succinic acid and methylamine (Mitsubishi Chemical, 2017; NIH, 2017).

Methods of manufacturing may depend on the specifications for the end product. For example, higher purities of NMP are generally required for electronic applications (U.S. EPA, 2017b).

2.1.2 Exposure Assessment

2.1.2.1 Worker Activities

Workers are potentially exposed to NMP during the manufacture of NMP from sampling, equipment maintenance, cleaning activities, and loading NMP into containers (RIVM, 2013). These activities are all potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

The 2013 Netherlands' National Institute for Public Health and the Environment (RIVM) *Proposal for Restriction - NMP* report indicates that the production, storage, and bulk transfers of NMP are all conducted within closed systems (RIVM, 2013). In addition, this report indicates that bulk transfers of NMP may occur with either open or closed transfer lines. Filling of smaller containers is expected to occur at dedicated filling points equipped with ventilation.

The RIVM *Annex XV Proposal for a Restriction - NMP* report indicates that sites that manufacture NMP are expected to implement local exhaust ventilation (LEV) and wear proper chemical-specific personal protective equipment, including appropriate gloves (RIVM, 2013). Specifically, workers wear gloves with an assigned protection factor (APF) of 5 (80 percent exposure reduction) (RIVM, 2013). EPA did not find information that indicates the extent that engineering controls and worker PPE are used at facilities that manufacture NMP in the United States.

ONUs include employees that work at the sites where NMP is manufactured, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the manufacturing of NMP.

2.1.2.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed to NMP at manufacturing sites using 2016 CDR data (where available), 2016 TRI data (where available), Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The method for estimating number of workers from the Bureau of Labor Statistics' OES data and U.S. Census' SUSB data is detailed in Appendix B.1. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

The 2016 CDR non-CBI results identify a total of 33 sites that manufacture, import, or both manufacture and import NMP (U.S. EPA, 2016a). Of these 33 sites, five sites report domestic manufacture of NMP and an additional six sites claim the domestic manufacture/import activity field as either CBI or withheld.[1] To try to determine whether the remaining six CDR sites were manufacturers or importers, EPA mapped the sites to 2016 TRI data using the facility names and addresses but did not find these sites in 2016 TRI (reporting releases of NMP) (U.S. EPA, 2016b). EPA assumed that these six sites for which the activity could not be determined through CDR or TRI may import or manufacture NMP. Therefore, there may be up to 11 sites that domestically manufacture NMP.

Of these 11 sites, one site reports that there are at least 50 but fewer than 100 workers potentially exposed to NMP, three sites report that there are at least 100 but fewer than 500 workers potentially exposed to NMP, and one site reports that there are at least 500 but fewer than 1,000 workers potentially exposed to NMP. The remaining sites claim number of worker estimates as CBI. EPA compiled these worker estimates in Table 2-1.

In addition to worker estimates from the 2016 CDR results, EPA compiled the number of workers and ONUs for NAICS code 325199 in Table 2-1 using data obtained from the BLS. To determine the number of workers potentially exposed, EPA used one less than the range of number of workers reported in the 2016 CDR for the manufacturing sites that reported worker information as non-CBI. For the CDR submissions that claimed number of workers as CBI and for the additional sites identified per 2016 TRI data, EPA used the number of workers estimate from the BLS data for NAICS code 325199. To determine the number of ONUs potentially exposed, EPA used the ratio of ONUs to workers from BLS data multiplied by the total number of workers estimated with BLS and CDR data. Note that these estimates may be overestimates of the actual number of employees potentially exposed to NMP.

Table 2-1. US Number of Establishments and Employees for Manufacturing

Source	Number of Establishments	Number of Workers per Site	Number of ONUs per Site
(U.S. BLS, 2016) data for NAICS 325199, All Other Basic Organic Chemical Manufacturing	Not included in this estimate	39 [a]	18 [a]
2016 CDR results indicate up to 11 sites manufacture NMP	1	at least 50 but fewer than 100 [b]	Unknown – used BLS estimate
	3	at least 100 but fewer than 500 [b]	
	1	at least 500 but fewer than 1,000 [b]	
	6	Unknown – used BLS estimate	
Total establishments and number of potentially exposed workers and ONUs = [c]	**11**	**2,800**	**200**[d]

a – Rounded to the nearest whole number.
b – EPA uses one less than the upper end of this range for worker calculations (i.e., for "at least 50 but fewer than 100 workers, EPA assumes 99 workers).
c – Totals may not add exactly due to rounding to two significant figures.
d – EPA used the number of ONUs per site from BLS data to calculate the total number of ONUs using CDR estimate for number of sites.

[1] Manufacturers (including importers) are required to report under CDR if they meet certain production volume thresholds, generally 25,000 lb or more of a chemical substance at any single site. Reporting is triggered if the annual reporting threshold is met during any of the calendar years since the last principal reporting year. In general, the reporting threshold remains 25,000 lb per site. However, a reduced reporting threshold (2,500 lb) now applies to chemical substances subject to certain TSCA actions. https://www.epa.gov/chemical-data-reporting/how-report-under-chemical-data-reporting

2.1.2.3 Occupational Exposure Assessment Methodology

In the occupational exposure assessment for this scenario, EPA assesses potential exposure from the loading of various containers (i.e., drums, tank trucks, rail cars) with pure NMP. While EPA does expect that workers may perform additional activities during this scenario, such as sampling or maintenance work, EPA expects that loading activities present the largest range of potential exposures.

2.1.2.3.1 Inhalation

Due to limited relevance and quality of monitoring data and modeling estimates for manufacturing of NMP found in the published literature, EPA used modeling estimates with the highest data quality for this use, as further described below.

Limited monitoring data for the manufacture of NMP are available based on the information searched at the time of preparation of this report. The one source with monitoring data (IFA, 2010), is for the storing and conveying of NMP; however, no additional details on these data were provided so EPA did not use these data. Modeled inhalation exposure concentrations during the manufacturing of NMP were included in the RIVM *Annex XV Proposal for a Restriction – NMP* report, specifically in the context of closed- and open-system transfers of NMP. The proposal report indicated closed system transfers are likely for manufacturing of NMP. EPA modeled potential worker inhalation exposures during the loading of bulk storage containers (i.e., tank trucks and rail cars) and drums using a common loading model developed by EPA and compared them to the modeled exposures in the RIVM *Annex XV Proposal for a Restriction - NMP* report. EPA's modeled exposure concentrations for loading NMP into bulk containers are similar in value and the same order of magnitude as those modeled by RIVM for closed-system NMP transfers. EPA's modeled exposure concentrations for loading NMP into drums are the same magnitude but higher in value than those modeled by RIVM for open-system NMP transfers. EPA's modeled exposure concentrations represent a larger range of potential inhalation exposure concentrations than those presented by RIVM. EPA assessed the range of occupational inhalation exposures modeled by EPA for this scenario. The discussed inhalation monitoring data as well as the RIVM and EPA's modeled exposure concentrations are summarized and further explained in Appendix A.1.

The inhalation exposure concentrations modeled by EPA for loading of 100% NMP are summarized into the input parameters used for the PBPK modeling in Table 2-2. The container loading models used by EPA calculate short-term exposure concentrations, with the exposure duration equal to the duration of the loading event (for bulk containers, typical case is 0.5 hours for loading tank trucks and worst-case is 1 hour for loading rail cars; for drums, 20 containers are loaded per hour and the duration was determined based on the throughput of NMP at a site [refer to Appendix A.1 for further explanation]) and number of loading events per day. EPA calculated the 8-hour TWA exposures as the weighted average exposure during an entire 8-hour shift, assuming zero exposure during the remainder of the shift.

The *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* involves deterministic modeling and the *Drum Loading and Unloading Release and Inhalation Exposure Model* involves probabilistic modeling. See Appendix B.2 and B.3 for additional details on the bulk container loading modeling and the drum loading modeling, respectively.

Table 2-2. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Manufacturing

Work	Parameter	Full-Shift NMP	Duration-Based	Source	Data

Activity	Characterization	Air Concentration (mg/m³, 8-hour TWA)	NMP Air Concentration (mg/m³)		Quality Rating
Loading NMP into bulk containers	Central tendency (50th percentile)	0.047	0.76 (duration = 0.5 hour)	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model (U.S. EPA, 2013a)*	Not applicable[a]
	High-end (95th percentile)	0.19	1.52 (duration = 1 hour)		
Loading NMP into drums	Central tendency (50th percentile)	0.427	1.65 (duration = 2.06 hour)	*EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model (U.S. EPA, 2013a)*	
	High-end (95th percentile)	1.51	5.85 (duration = 2.06 hour)		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

2.1.2.3.2 Dermal

Table 2-3 summarizes the parameters used to assess dermal exposure during the manufacturing of NMP. EPA assesses dermal exposure to NMP at the specified concentration weight fraction, skin surface area, and exposure duration, based on the methodology described below. During the manufacturing of NMP, workers are potentially exposed during sampling, maintenance, and loading (packaging) activities. For this scenario, EPA assessed dermal exposures during the loading of pure NMP into bulk containers and into drums. See below for additional information.

NMP Weight Fraction

For this scenario, EPA gathered NMP concentration data from the non-CBI 2016 CDR results and literature. The 2016 CDR results include four submissions with non-CBI concentration data that indicate NMP is manufactured at least 90 weight percent NMP (U.S. EPA, 2016a). Because CDR reporting is in ranges, the category for at least 90 weight percent includes those products that are between 90 and 100 weight percent. The RIVM *Annex XV Proposal for a Restriction - NMP* report indicates that manufactured NMP is sold at a purity of at least 80 weight percent and up to 100 weight percent (RIVM, 2013). Other sources indicate manufactured NMP is sold at a purity of 99.8 (TURI, 1996) and up to 100 weight percent NMP per 2012 CDR (U.S. EPA, 2012). All underlying data from these sources have an overall confidence rating of high. Based on this information, EPA assesses dermal exposures at 100 weight percent NMP, as a likely exposure scenario.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Because NMP manufacturing occurs at industrial sites, EPA expects that the use of gloves is likely (RIVM, 2013). Workers are likely to wear protective gloves and have basic training on the proper usage of these gloves, corresponding to a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3. Thus, EPA assesses a protection factor 10 for both the central tendency and high-end scenarios for this scenario. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

For the loading of bulk containers, EPA assesses an exposure duration of half an hour and one hour, based on the typical and worst-case scenarios assessed for inhalation exposures during the loading of a tank truck and rail car, respectively. For loading of drums, EPA modeled the exposure duration to be 2.06 hours, based on annual NMP throughput at each site (determined from the production volume and number of sites from 2016 CDR), 250 days of operation per year, and a loading rate of 20 drums per hour. Refer to Appendix A.1 for additional information on this exposure duration calculation.

Table 2-3. Summary of Parameters for Worker Dermal Exposure to Liquids During Manufacturing

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Loading NMP into bulk containers	Central Tendency	10	1	445 (f) 535 (m)	0.5	74 (f) 88 (m)
	High-end	10	1	890 (f) 1,070 (m)	1	
Loading NMP into drums	Central Tendency	10	1	445 (f) 535 (m)	2.06	74 (f) 88 (m)
	High-end	10	1	890 (f) 1,070 (m)	2.06	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.1.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-4.

The numeric parameters corresponding to the characterizations presented in Table 2-4 are summarized in Table 2-5. These are the inputs used in the PBPK model.

Table 2-4. Characterization of PBPK Model Input Parameters for Manufacturing of NMP

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Loading of bulk containers	Central tendency (50th percentile)	Duration calculated by model	1-hand	Yes	N/A - 100% is assumed for both exposure scenarios
High-end	Loading of drums	High-end (95th percentile)	Duration calculated by model	2-hand	Yes	N/A - 100% is assumed for both exposure scenarios

Table 2-5. PBPK Model Input Parameters for Manufacturing of NMP

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	0.76	0.5	445 (f) 535 (m)	10	1	74 (f) 88 (m)
High-end	5.85	2.06	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.1.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.2 Repackaging

2.2.1 Process Description

In general, commodity chemicals are imported into the United States in bulk via water, air, land, and intermodal shipments (Tomer and Kane, 2015). These shipments take the form of oceangoing chemical tankers, railcars, tank trucks, and intermodal tank containers. Chemicals shipped in bulk containers may be repackaged into smaller containers for resale, such as drums or bottles. Domestically manufactured commodity chemicals may be shipped within the United States in liquid cargo barges, railcars, tank trucks, tank containers, intermediate bulk containers (IBCs)/totes, and drums. Both imported and domestically manufactured commodity chemicals may be repackaged by wholesalers for resale; for example, repackaging bulk packaging into drums or bottles.

The exact shipping and packaging methods specific to NMP are not known. For this risk evaluation, EPA assesses the repackaging of NMP from bulk packaging to drums at wholesale repackaging sites (see Figure 2-3).

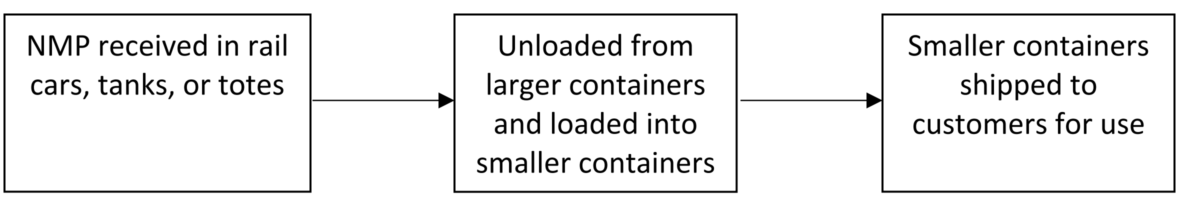

Figure 2-3. General Process Flow Diagram for Repackaging

This scenario includes the repackaging of both pure NMP and formulations containing NMP.

2.2.2 Exposure Assessment

2.2.2.1 Worker Activities

During repackaging, workers are potentially directly exposed while connecting and disconnecting hoses and transfer lines to containers and packaging to be unloaded (e.g., railcars, tank trucks, totes), intermediate storage vessels (e.g., storage tanks, pressure vessels), and final packaging containers (e.g., drums, bottles). These activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors. Workers are also potentially directly exposed through the same pathways to incidental leaks or spills. Workers near loading racks and container filling stations are potentially exposed to fugitive emissions from equipment leaks and displaced vapor as containers are filled.

The RIVM *Annex XV Proposal for a Restriction - NMP* report recommends that workers conducting repackaging activities wear gloves with an assigned protection factor (APF) of 5 (80 percent exposure reduction) (RIVM, 2013). This report also indicates that LEV may be employed but is not customary. EPA did not find information that indicates the extent that engineering controls and worker PPE are used at facilities that repackage NMP in the United States.

ONUs include employees that work at the site where NMP is repackaged, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for repackaging include supervisors, managers, and tradesmen that may be in the repackaging area but do not perform tasks that result in the same level of exposures as repackaging workers.

2.2.2.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed to NMP at repackaging sites using 2016 CDR data (where available), 2016 TRI data (where available), Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The method for estimating number of workers from the Bureau of Labor Statistics' OES data and U.S. Census' SUSB data is detailed in Appendix B.1. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

The 2016 CDR non-CBI results identify a total of 33 sites that manufacture, import, or both manufacture and import NMP (U.S. EPA, 2016a). Of these 33 sites, there are at least 22 and up to 29 sites that manufacture NMP, with the exact number unknown due to CBI claims.[2] EPA assumes that the sites claiming CBI may either import or domestically manufacture NMP. Of these 29 sites, eight submissions report that NMP is imported and never at the site. EPA assumes that these eight sites do not conduct repackaging activities. Of the remaining 21 sites, EPA mapped these sites to 2016 TRI data and found that one of these sites does not repackage NMP, one site does repackage NMP, and the remaining sites were not identified in TRI (EPA assumes these sites repackage NMP). Thus, EPA assumes 20 sites import and repackage NMP, per 2016 CDR results. Of the 21 import and repackaging sites, six sites report that there are fewer than 10 workers potentially exposed to NMP, one site reports at least 10 but fewer than 25 workers, five sites report at least 50 but fewer than 100 workers, and one site reports that there are at least 100 but fewer than 500 workers potentially exposed to NMP. The remaining sites claim number of workers estimates as CBI or not known or reasonably ascertainable. EPA compiled these worker estimates in Table 2-6.

[2] Manufacturers (including importers) are required to report under CDR if they meet certain production volume thresholds, generally 25,000 lb or more of a chemical substance at any single site. Reporting is triggered if the annual reporting threshold is met during any of the calendar years since the last principal reporting year. In general, the reporting threshold remains 25,000 lb per site. However, a reduced reporting threshold (2,500 lb) now applies to chemical substances subject to certain TSCA actions. https://www.epa.gov/chemical-data-reporting/how-report-under-chemical-data-reporting

EPA determined additional sites that potentially repackage NMP using 2016 TRI results. Specifically, EPA first identified the sites reporting operations under NAICS code 424690, Other Chemical and Allied Products Merchant Wholesalers, and removed those sites that reported to and are captured in the 2016 CDR results. EPA then identified those sites that report repackaging operations occur, leaving 12 sites.

In addition to worker estimates from the 2016 CDR results, EPA compiled the number of workers and ONUs for NAICS code 424690 in Table 2-6 using data obtained from the BLS. To determine the number of workers potentially exposed, EPA used the one less than the range of number of workers reported in the 2016 CDR for the sites that reported worker information as non-CBI. For the CDR submissions that claimed number of workers as CBI and for the additional sites identified per 2016 TRI data, EPA used the number of workers estimate from the BLS data for NAICS code 424690. To determine the number of ONUs potentially exposed, EPA used the ratio of ONUs to workers from BLS data multiplied by the total number of workers estimated with BLS and CDR data. Note that these estimates may be overestimates of the actual number of employees potentially exposed to NMP.

Table 2-6. US Number of Establishments and Employees for Repackaging

Source	Number of Establishments	Number of Workers per Site	Number of ONUs per Site
(U.S. BLS, 2016) data for NAICS 424690, Other Chemical and Allied Products Merchant Wholesalers	Not included in this estimate	1 [a]	1 [a]
Per 2016 CDR results, there are up to 29 sites that import (21 sites with NMP at the site and 8 with NMP never at site). Per 2016 TRI data, one of these sites does not repackage, one site does repackage, and the remaining sites were not identified in the TRI. EPA assumes the unidentified sites repackage NMP. Thus, 20 sites repackage NMP.	6	fewer than 10 [b]	Unknown – used BLS estimate
	1	at least 10 but fewer than 25 [b]	
	5	at least 50 but fewer than 100 [b]	
	1	at least 100 but fewer than 500 [b]	
	7	Unknown – used BLS estimate	
The 2016 TRI identifies 43 sites reporting operations under NAICS code 424690. Excluding those sites included in the 2016 CDR and only including those reporting repackaging operations results in 12 sites.	12	Unknown – not reported in TRI – used BLS estimate	
Total establishments and number of potentially exposed workers and ONUs = [c]	**32** [d]	**1,100**	**14** [e]

a – Rounded to the nearest whole number. Exact values are 1.3 workers and 0.45 ONUs.
b – EPA uses one less than the upper end of this range for worker calculations (i.e., for "at least 50 but fewer than 100 workers, EPA assumes 99 workers).
c – Totals may not add exactly due to rounding to two significant figures.
d – EPA assumes the sum of sites reported in 2016 CDR and 2016 TRI.
e – EPA used the number of ONUs from BLS data to calculate the total number of ONUs based on the number of sites per CDR.

2.2.2.3 Occupational Exposure Assessment Methodology

2.2.2.3.1 Inhalation

EPA compiled the same monitoring and modeled exposure concentration data for this scenario as for manufacturing. These data are summarized in Appendix A.2. As described in the previous scenario, Section 2.1.2.3.1, due to limited relevance and quality of monitoring data and modeling estimates found in the published literature, EPA used modeling estimates with the highest data quality for this use, as further described below.

EPA only found one source with monitoring data on the storing and conveying of NMP, which did not include details on worker activities, sample locations, or sampling times. EPA also summarized in Appendix A.2 the modeled inhalation exposure concentrations during the manufacturing of NMP, for closed- and open-system transfers of NMP, that were presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013).

Consistent with the approach EPA took in Section 2.1.2.3.1 for the manufacture of NMP, EPA modeled potential worker inhalation exposures during the unloading of bulk storage containers and drums using EPA models. Details on this modeling approach are presented in Appendix A.2. EPA's modeled exposure concentrations represent a larger range of potential inhalation exposure concentrations than those presented by RIVM; thus, EPA uses these modeled exposures in lieu of using the monitoring data or modeled exposure in the RIVM *Annex XV Proposal for a Restriction - NMP* report. The inhalation monitoring data as well as the RIVM and EPA's modeled exposure concentrations are summarized and further explained in Appendix A.2.

The inhalation exposure concentrations modeled by EPA for unloading of 100% NMP are summarized into the input parameters used for the PBPK modeling in Table 2-7. The container unloading models used by EPA calculates short-term exposure concentrations, with the exposure duration equal to the duration of the unloading event (for bulk containers, typical case is 0.5 hours for unloading tank trucks and worst-case is 1 hour for unloading rail cars; for drums, 20 containers are unloaded per hour and the duration was determined based on the throughput of NMP at a site [refer to Appendix A.2 for further explanation]) and number of loading events per day. EPA calculated the 8-hour TWA exposures to as the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift.

The *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* involves deterministic modeling and the *Drum Loading and Unloading Release and Inhalation Exposure Model* involves probabilistic modeling. See Appendix B.2 and B.3 for additional details on the bulk container unloading modeling and the drum unloading modeling, respectively.

Table 2-7. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure Repackaging

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Unloading NMP from bulk containers	Central tendency (50th percentile)	0.047	0.76 (duration = 0.5 hour)	*Tank Truck and Railcar Loading and Unloading Release and Inhalation*	Not applicable[a]
	High-end (95th percentile)	0.19	1.52 (duration = 1 hour)		

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m³, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m³)	Source	Data Quality Rating
				Exposure Model (U.S. EPA, 2013a)	
Unloading NMP from drums	Central tendency (50th percentile)	0.427	1.65 (duration = 2.06 hour)	*EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model (U.S. EPA, 2013a)*	
	High-end (95th percentile)	1.51	5.85 (duration = 2.06 hour)		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

2.2.2.3.2 Dermal

Table 2-8 summarizes the parameters used to assess dermal exposure during the repackaging of NMP and formulations containing NMP. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below. During the importation and repackaging of NMP, EPA assessed dermal exposures during the unloading of pure NMP from bulk containers and drums. See below for additional information.

NMP Weight Fraction

For this scenario, EPA gathered NMP concentration data from the non-CBI 2016 CDR results and literature. The 2016 CDR results include 20 submissions with non-CBI concentration data that indicate NMP is imported in formulations as low as less than one weight percent NMP and up to 90 to 100 weight percent NMP (U.S. EPA, 2016a). One public comment indicates that NMP is imported in a primer formulation at five weight percent NMP (Haas, 2017). Another source indicates NMP is imported at a purity of 100 weight percent NMP (U.S. EPA, 2012; TURI, 1996). The underlying data from all sources have overall confidence ratings of high. Based on this information, using the midpoint when concentration data is available in a range, EPA calculated the 50th percentile weight percent of NMP in imported products to be 95 weight percent. Based on the high 50th percentile NMP concentration and EPA's expectation that bulk commodity chemicals are more likely to be repackaged over formulations containing NMP (i.e., pure NMP is more likely to be repackaged than formulations with lower NMP concentrations), EPA assesses dermal exposures at 100 weight percent NMP.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Because repackaging of NMP occurs at industrial sites, EPA expects that the use of gloves is likely (RIVM, 2013). Workers are likely to wear protective gloves and have basic training on the proper usage of these gloves, corresponding to a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3. Thus, EPA assesses a protection factor 10 for both the central tendency and high-end scenarios for this scenario. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

For the unloading of bulk containers, EPA assesses a central tendency exposure duration of half an hour, based on the typical scenario assessed for inhalation exposures during the unloading of a tank truck and rail car, respectively. For unloading of drums, EPA modeled the exposure duration to be 2.06 hours, based on annual NMP throughput at each site (determined from the production volume and number of sites from 2016 CDR), 250 days of operation per year, and an unloading rate of 20 drums per hour. Refer to Appendix A.2 for additional information on this exposure duration calculation.

Table 2-8. Summary of Parameters for Worker Dermal Exposure to Liquids During Repackaging

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Unloading NMP from bulk containers	Central Tendency	10	1	445 (f) 535 (m)	0.5	74 (f) 88 (m)
	High-end	10	1	890 (f) 1,070 (m)	1	
Unloading NMP from drums	Central Tendency	10	1	445 (f) 535 (m)	2.06	74 (f) 88 (m)
	High-end	10	1	890 (f) 1,070 (m)	2.06	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.2.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-9.

The numeric parameters corresponding to the characterizations presented in Table 2-9 are summarized in Table 2-10. These are the inputs used in the PBPK model.

Table 2-9. Characterization of PBPK Model Input Parameters for Repackaging

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Unloading NMP from bulk containers	Central tendency (50th percentile)	Duration calculated by model	1-hand	Yes	N/A - 100% is assumed for both exposure scenarios
High-end	Unloading NMP from drums	High-end (95th percentile)	Duration calculated by model	2-hand	Yes	N/A - 100% is assumed for both exposure scenarios

Table 2-10. PBPK Model Input Parameters for Repackaging

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	0.76	0.5	445 (f) 535 (m)	10	1	74 (f) 88 (m)
High-end	5.85	2.06	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.2.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.3 Chemical Processing, Excluding Formulation

2.3.1 Process Description

This scenario includes the use of NMP for processing activities other than formulation (i.e., non-incorporative processing). Specifically, this may include the use of NMP as an intermediate, as a media for synthesis, extractions, and purifications, or as some other type of processing aid. EPA identified the following industries that use NMP in this manner (U.S. EPA, 2016a; RIVM, 2013):

- Agricultural chemical manufacturing
- Petrochemical manufacturing
- Pharmaceutical manufacturing
- Polymer product manufacturing
- Miscellaneous chemical manufacturing

2.3.1.1 Agricultural Chemical Manufacturing

NMP is used for the manufacturing of agricultural chemicals, including fertilizers, fungicides, insecticides, herbicides, and other types of pesticides (Abt, 2017; U.S. EPA, 2017b; RIVM, 2013). NMP is used in the synthesis of active ingredients for agricultural chemicals (Roberts, 2017; RIVM, 2013). A public comment to the NMP risk evaluation docket from the NMP Producers Group details that NMP is used as a solvent in the production of a fertilizer additive that prevents the volatilization of urea in fertilizer formulations (Roberts, 2017). The NMP Producers Group indicates that the amount of NMP in the final fertilizer formulation is minimal (<0.1 percent). The RIVM *Annex XV Proposal for a Restriction - NMP* report also indicates that, when NMP is used in the synthesis of active ingredients, it is not expected to be in the final agricultural chemical formulation (RIVM, 2013).

NMP is also used in the formulation of agricultural chemicals such that it is present in the final agricultural chemical formulation. Formulation activities are assessed in Section 2.4 of this risk evaluation.

2.3.1.2 Petrochemical Manufacturing

NMP is used as a petrochemical processing aid in a variety of applications including extraction of aromatic hydrocarbons from lube oils; separation and recovery of aromatic hydrocarbons from mixed hydrocarbon feedstocks; recovery of acetylenes, olefins and diolefins; removal of sulfur compounds from and dehydration of natural gas and refinery gases (Anderson and Liu, 2000).

NMP is used both for the extraction of unwanted aromatics from lube oils and the recovery of hydrocarbons from feedstocks, via extractive distillation (ERM, 2017; MacRoy, 2017; NIH, 2017; RIVM, 2013; ECHA, 2011). NMP is favorable for the extractive distillation of hydrocarbons because hydrocarbons are highly soluble in NMP, and the use of NMP for extraction does not lead to the formation of azeotropes.

Extractive distillation involves distillation in the presence of a solvent (or mixture of solvents) that acts as a separating agent, displaying both a selectivity for and the capacity to solubilize components in a mixture to be separated (Doherty and Knapp, 2004). Solvents interact differently with the components of the mixture to be separated, thereby altering their relative volatility and allowing them to be separated. Solvents are added near the top of the extractive distillation column and the mixture to be separated is added at a second feed point further down the column. The component with the higher volatility in the presence of a solvent is distilled overhead as the distillate and components with lower volatility are removed with the solvent in the column bottoms. The solvent is then separated from other components of the mixture, generally through distillation in a second column, and then recycled back to the extractive distillation column (Doherty and Knapp, 2004).

Other uses of NMP in petrochemical processing involve using NMP to absorb specific compounds, then separating the NMP from the absorbed compounds, similar to the extractive distillation process (Anderson and Liu, 2000). Examples of absorptive processes include NMP use in the recovery of acetylenes, olefins and diolefins; removal of sulfur compounds from natural and refinery gases; and the dehydration of natural gas (MacRoy, 2017; NIH, 2017; RIVM, 2013; Anderson and Liu, 2000).

Absorption using a solvent, such as NMP, generally involves two towers, an absorption tower and a removal tower. The mixture to be separated and the solvent are first introduced into the absorption tower. The solvent then absorbs the miscible compound and this heavier stream leaves in the bottoms of the column. The solvent mixture is then sent to another column where the absorbed compound is recovered from the solvent. The solvent may undergo further processes, such as scrubbing, to be fully regenerated before being recycled back into the absorption column (Gannon and Schaffer, 2003).

2.3.1.3 Pharmaceutical Manufacturing

NMP is used as a solvent and extraction medium for the manufacture and formulation of pharmaceuticals (ECHA, 2011). The RIVM *Annex XV Proposal for a Restriction - NMP* report indicates that NMP may be a reaction medium for the synthesis of antibiotics (RIVM, 2013). When NMP functions as a reaction medium, it is not expected to be present above residual quantities in the final product.

NMP may also be used in controlled release delivery systems for human and veterinary drugs, where NMP is used as a solvent in which a biodegradable polymer housing the active drug is dissolved (RIVM, 2013).

NMP has also historically been used as an excipient in pharmaceuticals, with potential function as a transdermal enhancer (RIVM, 2013). However, the use of NMP in this function has since been banned (NMP Producers Group, 2006).

2.3.1.4 Polymer Manufacturing

NMP is also used the polymer industry as a polymerization media for a variety of polymers.

NMP is used as a polymerization media for the manufacturing of polyphenylene sulfide (PPS) and other high-temperature polymers such as polyethersulfones, polyamideimides and polyaramids (Materials, 2017; NIH, 2017; U.S. EPA, 2015b; RIVM, 2013). One public comment indicates that NMP is present at below 17 ppm in produced PPS (Materials, 2017). Another public comment indicates that NMP may be present at up to 1,500 ppm in resin pellets up to seven percent in resin powders (Roberts, 2017). EPA expects that these quantities of NMP are driven off in subsequent compounding of the resins, which is assessed in Section 2.4 of this risk evaluation.

Similarly, NMP is used as a processing aid in the production of polymer membranes (Roberts, 2017; RIVM, 2013). Polymer membranes are produced by immersion precipitation in which a solution of polymer, solvents, and other additives is immersed in a water bath to produce a polymer-based film from which the solvent is removed into the water bath. This film is isolated and solidified to produce the desired membrane that can be applied in gas separations, filtrations, and desalination processes (RIVM, 2013). Further, a public comment on the NMP risk evaluation docket indicates polymer particles dispersed in NMP may be imported into the US for the production of polymer film via a gravure process (Anonymous, 2017). NMP is not present in the produced polymer membranes and films in appreciable quantities (Anonymous, 2017; Roberts, 2017).

NMP is particularly useful for the dissolving and repolymerization of difficult to dissolve polymers (ACC, 2017; RIVM, 2013). NMP can be used to dissolve polymers at elevated temperatures and precipitate them to form beads and pellets (ACC, 2017). Additionally, NMP is used in this capacity to produce high-performance polymers that are used for ballistic protection by dissolving the polymer and allowing reaction between an amine group and a carboxylic acid halide group before polymerization (RIVM, 2013). Again, NMP is not expected to be present above residual quantities in these products (RIVM, 2013).

Finally, a comment on the NMP risk evaluation docket indicates that NMP can be used in the polymer manufacturing industry as a polymerization inhibitor (Kemira, 2018). Specifically, NMP is used in additives containing phenothiazine. According to this public comment, these additives can contain NMP at 35 or 65 weight percent. In the case of uncontrolled polymerization, these additives are injected into the reaction vessels to cease the polymerization reaction and prevent vessel ruptures. This comment indicates that, if these additives are uses, NMP is not expected to be present in the final polymer articles.

2.3.1.5 Miscellaneous

NMP may be used in additional industries as a chemical intermediate. The exact process operations involved during the use of NMP as a chemical intermediate are dependent on the final product that is being synthesized. For NMP use as a chemical intermediate, operations would typically involve unloading NMP from transport containers and feeding it into reaction vessel(s), where the NMP would either react fully or to a lesser extent. Following completion of the reaction, the produced substance may or may not be purified further, thus removing unreacted NMP (if present). The reacted NMP is not expected to be released to the environment or to present a potential for worker exposure. Any unreacted NMP presents potential sources of release or exposure.

2.3.2 Exposure Assessment

2.3.2.1 Worker Activities

During the use of NMP as a reactant or other processing aid, workers are potentially exposed while unloading NMP into intermediate storage or processing vessels, quality sampling of the NMP prior to use, fugitive emissions from equipment leaks, and from maintenance and cleaning activities. These activities are all potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors. For polymer processing, workers have further potential inhalation exposure to NMP vapors during drying of the polymers as the NMP may evaporate as the produced polymer is further processed or the NMP may be driven off with elevated temperatures (RIVM, 2013).

These processes are likely to be partially or fully closed operations, to avoid solvent losses (Roberts, 2017; RIVM, 2013) and due to the nature of the processes (i.e., extractions and other purification processes are conducted in closed columns). One public comment indicates that workers who handle solutions containing NMP wear a chemical resistant jacket, gloves, goggles, and a face shield (Kemira, 2018). The RIVM *Annex XV Proposal for a Restriction - NMP* report recommends that workers within these chemical processing industries wear gloves with an assigned protection factor (APF) of 5 (80 percent exposure reduction) (RIVM, 2013). EPA did not find additional information on the use of engineering controls and worker PPE at facilities that use NMP in non-incorporative processing operations.

ONUs include employees that work at the site where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs include supervisors, managers, and tradesmen that may be in the processing area but do not perform tasks that result in the same level of exposures as workers.

2.3.2.2 Number of Potentially Exposed Workers

The use of NMP for non-incorporative processing operations may occur in many industries. EPA determined the industries likely to use NMP for non-incorporative processing operations from the following sources: the non-CBI 2016 CDR results for NMP (U.S. EPA, 2016a), 2016 TRI data (U.S. EPA, 2016b), and the process descriptions in Section 2.3.1.

In the 2016 CDR, one submission reported processing of NMP as an intermediate in the plastic material and resin manufacturing and pharmaceutical and medicine manufacturing industries (U.S. EPA, 2016a). EPA identified three additional reported uses that EPA assessed in this scenario, including the use of NMP as a processing aid in the following industries: petrochemical manufacturing (reported by two submitters); pesticide, fertilizer, and other agricultural chemical manufacturing (reported by one submitter); and, plastic material and resin manufacturing (reported by one submitter). Half of these submissions report fewer than 10 sites that use NMP in non-incorporative activities, with the remaining half reporting at least 10 but fewer than 25 sites. These submissions report varying estimates of the number of workers potentially exposed. Due to the variability in the CDR reported values for number of sites and workers and uncertainty in the basis of the CDR submitter estimates for downstream processers, EPA estimated sites from 2016 TRI data and workers using data from the BLS and U.S. Census Bureau.

EPA reviewed the 2016 TRI data for sites that use NMP as a reactant or as a chemical processing aid. Based on the 2016 TRI data, 94 unique sites use NMP as a reactant and/or chemical processing aid. EPA compiled the primary NAICS codes for these sites in Table 2-11. EPA determined the number of workers using the related SOC codes from BLS data that are associated with the primary NAICS codes listed in Table 2-11. The method for estimating number of workers from the Bureau of Labor Statistics' OES data and U.S. Census' SUSB data is detailed in Appendix B.1.

Table 2-11. US Number of Establishments and Employees for Chemical Processing, Excluding Formulation

2016 NAICS	2016 NAICS Title	Number of Establishments per 2016 TRI	Number of Workers per Site per BLS, 2016 and SUSB, 2015 Data [a]	Number of ONUs per Site per BLS, 2016 and SUSB, 2015 data [a]
313310	Textile and Fabric Finishing Mills	1	7	3
313320	Fabric Coating Mills	1	9	4
322299	All Other Converted Paper Product Manufacturing	1	21	3
323111	Commercial Printing (except Screen and Books)	1	2	1
323120	Support Activities for Printing	1	2	1
324110	Petroleum Refineries	4	170	75
325110	Petrochemical Manufacturing	1	64	30
325130	Synthetic Dye and Pigment Manufacturing	3	26	12
325199	All Other Basic Organic Chemical Manufacturing	7	39	18
325211	Plastics Material and Resin Manufacturing	6	27	12
325212	Synthetic Rubber Manufacturing	1	25	11
325220	Artificial and Synthetic Fibers and Filaments Manufacturing	1	47	21
325320	Pesticide and Other Agricultural Chemical Manufacturing	3	25	7
3254	Pharmaceutical and Medicine Manufacturing	9	41	25
325510	Paint and Coating Manufacturing	3	14	5
325520	Adhesive Manufacturing	1	18	7
325992	Photographic Film, Paper, Plate, and Chemical Manufacturing	1	19	6
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	3	14	5
3261	Plastics Product Manufacturing	7	18	5
331420	Copper Rolling, Drawing, Extruding, and Alloying	3	32	10
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	2	8	2
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	2	9	4
334400	Semiconductor and Other Electronic Component Manufacturing	12	30	27
334516	Analytical Laboratory Instrument Manufacturing	1	15	16
335911	Storage Battery Manufacturing	1	54	20
336100	Motor Vehicle Manufacturing	11	235	99
336300	Motor Vehicle Parts Manufacturing	3	51	15
339112	Surgical and Medical Instrument Manufacturing	1	34	11
339999	All Other Miscellaneous Manufacturing	3	5	1

2016 NAICS	2016 NAICS Title	Number of Establishments per 2016 TRI	Number of Workers per Site per BLS, 2016 and SUSB, 2015 Data [a]	Number of ONUs per Site per BLS, 2016 and SUSB, 2015 data [a]
Total establishments and number of potentially exposed workers and ONUs [b]=		***94***	***5,400***	***2,500***

a – Rounded to the nearest whole number.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.3.2.3 Occupational Exposure Assessment Methodology

2.3.2.3.1 Inhalation

EPA compiled inhalation monitoring data and modeled exposure concentrations for the use of NMP in non-incorporative processing activities in Appendix A.3. The monitoring data included in this appendix lacks data on worker activities, the function of NMP within the industry of use, and the sampling duration; thus, EPA does not use these monitoring data. Due to limited relevance and quality of monitoring data and modeling estimates for chemical processing with NMP found in the published literature, EPA used modeling estimates with the highest data quality for this use, as described below.

In addition to the monitoring data, EPA compiled in Appendix A.3 the modeled NMP inhalation exposure data that were presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These modeled inhalation exposure concentrations are for the use of NMP as a process solvent or reagent in an industrial setting and include scenarios for closed processing systems with various levels of enclosure as well as the handling of NMP at both ambient and elevated temperatures.

Because the modeled exposure concentrations do not include loading and unloading operations, which EPA expects to be a significant source of potential worker exposure, EPA modeled potential worker inhalation exposure concentrations for the unloading of NMP from bulk containers (i.e., tank trucks and rail cars) and drums. This modeling is consistent with the methodology described in Section 2.1.2.3.1 for the manufacturing of NMP. The *Drum Loading and Unloading Release and Inhalation Exposure Model* involves probabilistic modeling. Additional details on this modeling approach are presented in Appendix A.3.

EPA used the short-term inhalation exposure concentration that EPA modeled during unloading of drums containing 100% NMP as input to the PBPK model for short-term worker inhalation exposures. The exposure duration for this short-term exposure scenario is the duration of the unloading event (20 drums are unloaded per hour and the duration was determined based on the throughput of NMP at a site [refer to Appendix A.3 for further explanation]). These estimates are summarized in Table 2-12. EPA calculated the 8-hour TWA exposures to as the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. See Appendix B.3 for additional details on the drum unloading modeling.

Table 2-12. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Chemical Processing, Excluding Formulation

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Unloading liquid NMP from drums	Central tendency (50th percentile)	0.075	1.65 (duration = 0.36 hr)	*Drum Loading and Unloading Release and Inhalation Exposure Model* (U.S. EPA, 2013a)	Not applicable[a]
	High-end (95th percentile)	0.265	5.85 (duration = 0.36 hr)		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

2.3.2.3.2 Dermal

Table 2-13 summarizes the parameters used to assess dermal exposure during the use of NMP in non-incorporative processing activities. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below. During the non-incorporative processing of NMP, workers are potentially exposed during sampling, maintenance, unloading, and loading (packaging) activities. For this scenario, EPA assessed dermal exposures during the unloading of pure NMP from drums. See below for additional information.

NMP Weight Fraction

For this scenario, EPA gathered NMP concentration data from the non-CBI 2016 CDR results, public comments, and literature. The 2016 CDR results include seven submissions that indicate NMP is used as an intermediate or non-incorporative processing aid (U.S. EPA, 2016a). Six of these submissions provide non-CBI concentration data, all indicating that NMP is used at 90 weight percent or greater. Based on this information, EPA expects that chemical processors assessed in this scenario are likely to purchase pure NMP and add to various processes in the amounts needed to achieve the desired concentration for the process operation. Thus, EPA assesses dermal exposures for this scenario at 100 weight percent NMP. This data has an overall confidence rating of high.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Because processing of NMP occurs at industrial sites, EPA expects that the use of gloves is likely (RIVM, 2013). Workers are likely to wear protective gloves and have basic training on the proper usage of these gloves, corresponding to a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3. Thus, EPA assesses a protection factor 10 for both the central tendency and high-end scenarios for this scenario. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

For unloading drums, EPA modeled the exposure duration to be 0.36 hours, based on the annual NMP throughput at each site (determined by dividing the 2016 CDR production volume by the number of sites for this and the Incorporation into Formulation, Mixture, or Reaction Product scenario), 250 days of operation per year, and an unloading rate of 20 drums per hour. Refer to Appendix A.3 for additional information on this exposure duration calculation.

Table 2-13. Summary of Parameters for Worker Dermal Exposure to Liquids During Chemical Processing, Excluding Formulation

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Unloading liquid NMP from drums	Central Tendency	10	1	445 (f) 535 (m)	0.36	74 (f) 88 (m)
	High-End	10	1	890 (f) 1,070 (m)	0.36	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.3.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-14.

The numeric parameters corresponding to the characterizations presented in Table 2-14 are summarized in Table 2-15. These are the inputs used in the PBPK model.

Table 2-14. Characterization of PBPK Model Input Parameters for Chemical Processing, Excluding Formulation

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Unloading drums	Central tendency (50^{th} percentile)	Duration calculated by model	1-hand	Yes	N/A - 100% is assumed for both exposure scenarios
High-end	Unloading drums	High-end (95^{th} percentile)	Duration calculated by model	2-hand	Yes	N/A - 100% is assumed for both exposure scenarios

Table 2-15. PBPK Model Input Parameters for Chemical Processing, Excluding Formulation

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	1.65	0.36	445 (f) 535 (m)	10	1	74 (f) 88 (m)
High-end	5.85	0.36	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.3.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.4 Incorporation into Formulation, Mixture, or Reaction Product

2.4.1 Process Description

Incorporation into a formulation, mixture or reaction product refers to the process of mixing or blending of several raw materials to obtain a single product or preparation. The uses of NMP that may require incorporation into a formulation include adhesives, sealants, paints, coatings, inks, metal finishing chemicals, cleaning and degreasing products, agricultural products, and petrochemical products including lube oils. NMP-specific formulation processes were not identified; however, several ESDs published by the OECD and Generic Scenarios published by EPA have been identified that provide general process descriptions for these types of products.

The formulation of coatings and inks typically involves dispersion, milling, finishing and filling into final packages (OECD, 2010a, c). Adhesive formulation involves mixing together volatile and non-volatile chemical components in sealed, unsealed or heated processes (OECD, 2009). Sealed processes are most common for adhesive formulation because many adhesives are designed to set or react when exposed to ambient conditions (OECD, 2009). Lubricant formulation typically involves the blending of two or more components, including liquid and solid additives, together in a blending (OECD, 2017).

As described in Section 2.3.1.1, NMP is used in the formulation of agricultural products. While the majority of these products are liquids, the NMP Producers Group provided a public comment to the NMP risk evaluation docket indicating that a fertilizer additive is used to produce granular fertilizer products (Roberts, 2017). According to this public comment, the fertilizer additive containing NMP is used in both liquid and granular fertilizer products and the blending of both the liquid and granular fertilizers takes place in enclosed process equipment. The concentration of the NMP in the final fertilizer product is expected to be less than 0.1 percent (Roberts, 2017). The “Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP” document and 2017 market profile on NMP also identify a granular fungicide product containing less than five weight percent NMP (Abt, 2017; U.S. EPA, 2017b).

As described in Section 2.3.1.4, NMP is used for the production of polymeric resins and may be present in residual quantities from below 17 ppm (Materials, 2017) up to seven weight percent in the produced resin (Roberts, 2017). The residual of seven percent is indicated for resin powders (Roberts, 2017). After production, resins are typically compounded to produce a masterbatch. According to 2016 TRI data on NMP, the compounding of resins is likely to occur at resin production sites, as opposed to at separate compounding sites. In compounding, the polymer resin is blended with additives and other raw materials to form a masterbatch in either open or closed blending processes (U.S. EPA, 2014). After compounding, the resin is fed to an extruder where is it converted into pellets, sheets, films or pipes (U.S. EPA, 2014). These resin pellets and other shapes are then converted into final plastic articles, generally by melting and forming or extruding, at plastic converting sites.

2.4.2 Exposure Assessment

2.4.2.1 Worker Activities

During the formulation of products containing NMP, workers are potentially exposed to NMP during unloading of NMP, sampling, maintenance activities, and drumming or loading formulated products containing NMP (RIVM, 2013). These activities are all potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

Several public comments to the NMP risk evaluation docket and literature sources report the use of closed formulation processes. A public comment from FUJIFILM Electronic Materials (FFEM), which formulates NMP products for the electronics industries, indicates that formulation is completed in an enclosed process (Fujifilm, 2017a). The NMP Producers Group provided a public comment indicating that the blending of both liquid and granular fertilizers takes place in enclosed process equipment (Roberts, 2017). Another comment from a coating and adhesive formulator indicates that products are batch manufactured in an enclosed process (ACC, 2017). However, this comments also indicates that metering of additives containing NMP may be done from open containers.

The Plastics Compounding GS indicates compounding of plastics may be done in either open or enclosed vessels (U.S. EPA, 2014). The RIVM *Annex XV Proposal for a Restriction - NMP* report on

NMP indicates that formulation might or might not occur in closed processes and that formulation may occur at elevated temperatures (RIVM, 2013). Another source on the formulation of paint stripping products indicates that formulation of could be open or closed; however, closed processes are preferred because they prevent solvent loss and mitigate exposures (White and Bardole, 2004).

Public comments indicate that respirators are used to prevent worker exposures to NMP (Roberts, 2017). One public comment includes information from a formulator of coatings and adhesives, which indicates that workers at that site wear full face respirators when handling NMP (ACC, 2017). One formulator of products containing NMP indented for use in the electronics industry specifies that workers wear PPE, including safety glasses, impervious gloves, and protective clothing with respirators, if needed (Fujifilm, 2017a). Other literature sources indicate that workers generally wear safety glasses, impervious gloves, and designated work clothes or overalls (Bader et al., 2006; NICNAS, 2001). The RIVM *Annex XV Proposal for a Restriction - NMP* report recommends that workers within these formulation industries wear gloves with an assigned protection factor (APF) of 5 (80 percent exposure reduction) (RIVM, 2013).

ONUs include employees that work sites where NMP is blended into formulations, but they do not directly handle the chemical and are therefore expected to have lower exposures. ONUs for formulation sites include supervisors, managers, and tradesmen that may be in the processing area, but do not perform tasks that result in the same level of exposures as production workers.

2.4.2.2 Number of Potentially Exposed Workers

Formulation of NMP-based formulations, mixtures, and reaction products is widespread, occurring in many industries. EPA determined the industries likely to conduct formulation activities using NMP from the following sources: the non-CBI 2016 CDR results for NMP (U.S. EPA, 2016a), 2016 TRI data (U.S. EPA, 2016b), the 2017 market profile for NMP (Abt, 2017), the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b), and public comments on the NMP risk evaluation docket.

In the 2016 CDR, 18 submissions reported processing of NMP by incorporation into a formulation, mixture, or reaction product (U.S. EPA, 2016a). More than half of these submissions report fewer than 10 sites that use NMP in incorporative activities, with the remaining submissions reporting a higher estimate of sites or Not Known or Reasonably Ascertainable (NKRA). These submissions report varying estimates of the number of workers potentially exposed, from fewer than 10 workers up to at least 500 but fewer than 1,000 workers. Due to the variability in the CDR reported values for number of sites and workers and uncertainty in the basis of the CDR submitter estimates for downstream processers, EPA estimated sites from 2016 TRI data and workers using data from the BLS and U.S. Census Bureau.

EPA reviewed the 2016 TRI data for sites that use NMP as a formulant. Based on the 2016 TRI data, 94 unique sites use NMP as a formulant. EPA compiled the primary NAICS codes for these sites in Table 2-16. EPA determined the number of workers using the related SOC codes from BLS analysis that are associated with the primary NAICS codes listed in Table 2-16. The method for estimating number of workers from the Bureau of Labor Statistics' OES data and U.S. Census' SUSB data is detailed in Appendix B.1.

Table 2-16. US Number of Establishments and Employees for Incorporation into Formulation, Mixture, or Reaction Product

2016 NAICS	2016 NAICS Title	Number of Establishments per 2016 TRI	Number of Workers per Site per BLS, 2016 and SUSB, 2015 Data [a]	Number of ONUs per Site per BLS, 2016 and SUSB, 2015 data [a]
313320	Fabric Coating Mills	1	9	4
323111	Commercial Printing (except Screen and Books)	1	2	1
324191	Petroleum Lubricating Oil and Grease Manufacturing	1	20	9
325110	Petrochemical Manufacturing	1	64	30
325130	Synthetic Dye and Pigment Manufacturing	1	26	12
325180	Other Basic Inorganic Chemical Manufacturing	1	25	12
325199	All Other Basic Organic Chemical Manufacturing	5	39	18
325211	Plastics Material and Resin Manufacturing	9	27	12
325212	Synthetic Rubber Manufacturing	1	25	11
325220	Artificial and Synthetic Fibers and Filaments Manufacturing	1	47	21
325311	Nitrogenous Fertilizer Manufacturing	1	17	5
325314	Fertilizer (Mixing Only) Manufacturing	1	10	3
325320	Pesticide and Other Agricultural Chemical Manufacturing	9	25	7
325412	Pharmaceutical Preparation Manufacturing	1	44	27
325510	Paint and Coating Manufacturing	17	14	5
325520	Adhesive Manufacturing	4	18	7
325611	Soap and Other Detergent Manufacturing	2	19	4
325612	Polish and Other Sanitation Good Manufacturing	1	17	4
325910	Printing Ink Manufacturing	2	13	4
325992	Photographic Film, Paper, Plate, and Chemical Manufacturing	4	19	6
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	12	14	5
3261	Plastics Product Manufacturing	2	18	5
326291	Rubber Product Manufacturing for Mechanical Use	1	43	7
331300	Alumina and Aluminum Production and Processing	1	33	13
331420	Copper Rolling, Drawing, Extruding, and Alloying	2	32	10
339112	Surgical and Medical Instrument Manufacturing	1	34	11
424690	Other Chemical and Allied Products Merchant Wholesalers	3	1	0
562211	Hazardous Waste Treatment and Disposal	7	9	5
562920	Materials Recovery Facilities	1	2	2
Total establishments and number of potentially exposed workers and ONUs [b]=		***94***	***1,900***	***720***

a – Rounded to the nearest whole number.

b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.4.2.3 Occupational Exposure Assessment Methodology

2.4.2.3.1 Inhalation

EPA compiled inhalation monitoring data and modeled exposure concentration data for the incorporation of NMP into a formulation, mixture, or reaction product in Appendix A.4. EPA favors the use of monitoring data over modeled data, thus EPA used the monitoring data with the highest data quality to assess exposure for this use, as described below.

Appendix A.4 includes NMP personal monitoring data during the formulation of adhesives, for workers engaged in maintenance, cleaning, and packaging activities, which is summarized in Table 2-17. These data also included area monitoring data in production and shipping areas, which is summarized in Table 2-18. EPA cannot distinguish ONU exposures from worker exposures from the data in Table 2-17 and Table 2-18. EPA used the data in Table 2-17 for inhalation exposure inputs to the PBPK model, as described in Section 2.4.3.

In addition to this monitoring data, EPA compiled in Appendix A.4 the modeled NMP inhalation exposure data that were presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013); however, EPA did not use modeled data from the RIVM *Annex XV Proposal for a Restriction - NMP* report because EPA used monitoring data to assess these exposures. Consistent with the modeling EPA described in Section 2.3.2.3.1 for the chemical processing (excluding formulation) of NMP, EPA modeled potential worker inhalation exposures during the unloading of bulk storage containers and drums containing 100% NMP. The *Drum Loading and Unloading Release and Inhalation Exposure Model* involves probabilistic modeling. EPA used the inhalation exposure concentrations that EPA modeled during unloading of drums containing pure NMP as input to the PBPK model for central tendency worker exposure. The exposure duration for this short-term exposure scenario is the duration of the unloading event (20 drums are unloaded per hour and the duration was determined based on the throughput of NMP at a site [refer to Appendix A.4 for further explanation]). EPA calculated the 8-hour TWA exposures to as the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. See Appendix B.3 for additional details on the drum unloading modeling.

In addition to the formulation of liquid products, EPA identified formulation activities that may result in potential worker exposures to particulates containing NMP. Specifically, these include plastics compounding and blending of granular fertilizers, as described in Section 2.4.1. To determine potential worker inhalation exposure to solids containing NMP, EPA used the OSHA permissible exposure limit (PEL) for total particulates not otherwise regulated (PNOR) of 15 mg/m^3 as an 8-hour TWA and NMP concentration data in the products EPA identified as solids containing NMP that undergo formulation. EPA does not use these exposure concentrations as input to the PBPK model because the PBPK model does not account for solids, and the range of input parameters for the other exposure scenarios capture these concentrations. See Appendix A.4 for additional details on this assessment.

Table 2-17. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Incorporation into Formulation, Mixture, or Reaction Product

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration	Duration-Based NMP Air Concentration	Source	Data Quality Rating
		(mg/m^3, 8-hour TWA)	(mg/m^3)		

Liquid – unloading drums	Central tendency (50th percentile)	0.075	1.65 (duration = 0.36 hr)	*Drum Loading and Unloading Release and Inhalation Exposure Model*	Not applicable[a]
Liquid - Maintenance, bottling, shipping, loading	High-end (95th percentile)	12.8	No data	(Bader et al., 2006)	High
Solid – loading into drums	Central tendency (50th percentile)	0.75	No data	OSHA PNOR PEL and NMP concentration data	Not applicable
	High-end (95th percentile)	0.96	No data		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

Table 2-18. Summary of Area Monitoring During Incorporation into Formulation, Mixture, or Reaction Product

Scenario	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Liquid - Maintenance, bottling, shipping, loading	Central tendency	0.2	0.2	(Bader et al., 2006)	High
	High-end	3	3		

2.4.2.3.2 Dermal

Table 2-19 summarizes the parameters used to assess dermal exposure during the incorporation of NMP into formulations, mixtures, and reaction products. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below. During the formulation of NMP, workers are potentially exposed during sampling, maintenance, unloading, and loading activities. For this scenario, EPA assessed dermal exposures during the unloading of pure NMP from drums. In addition, because NMP may be formulated into solid products, EPA assessed the loading of solid formulations containing NMP into drums.

NMP Weight Fraction

NMP is most likely received at formulation sites in pure form (i.e., 100 weight percent NMP), before it is unloaded by workers and formulated into products with various NMP concentrations. For this scenario, EPA gathered NMP concentration data in formulated products from the non-CBI 2016 CDR results, public comments to the NMP risk evaluation docket, the 2017 market profile for NMP, the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document, and literature. The underlying data from these sources have overall confidence ratings ranging from medium to high. The 2016 CDR results include 36 submissions that indicate NMP is used for formulation in various industries, which formulate product ranging from at least one weight percent up to at least 90 weight percent NMP (U.S. EPA, 2016a). EPA reviewed the remaining data sources for the concentration of NMP in various formulations, including the products identified in all subsequent scenarios except recycling and disposal. These products identify that NMP is present in formulations ranging from 0.06 weight percent NMP up to 100 weight percent NMP (for industrial cleaning solvents). For this scenario, EPA conservatively assessed dermal exposures during the unloading of pure NMP from drums, which is the activity from which workers are potentially exposed to the highest concentration of NMP.

Note that EPA also determined separate typical and worst-case NMP concentrations from seven identified solid formulations (resins and granular agricultural products). EPA calculated the central tendency (50th percentile) weight percent of NMP in solid formulations to be 5 weight percent and the worst-case (95th percentile) to be 6.4 weight percent NMP.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Because processing of NMP occurs at industrial sites, EPA expects that the use of gloves is likely (RIVM, 2013). Workers are likely to wear protective gloves and have basic training on the proper usage of these gloves, corresponding to a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3. Thus, EPA assesses a protection factor 10 for both the central tendency and high-end scenarios for this scenario. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

For unloading of drums containing NMP, EPA modeled the exposure duration to be 0.36 hours, based on the annual NMP throughput at each site (determined by dividing the 2016 CDR production volume by the number of sites for this and the previous scenario), 250 days of operation per year, and an unloading rate of 20 drums per hour. Refer to Appendix A.4 for additional information on this exposure duration calculation. EPA used this an exposure duration of 8 hours for the maintenance, bottling, shipping, and loading of NMP because the exposure concentrations are 8-hour TWA values.

Table 2-19. Summary of Parameters for Worker Dermal Exposure to Liquids During Incorporation into Formulation, Mixture, or Reaction Product

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Liquid - Unloading drums	Central Tendency	10	1	445 (f) 535 (m)	0.36	74 (f) 88 (m)
Liquid - Maintenance, bottling, shipping, loading	High-End	10	1	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.4.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-20. EPA only presents these scenarios for handling of liquid NMP, to present the most conservative assessment of potential exposures.

The numeric parameters corresponding to the characterizations presented in Table 2-20 are summarized in Table 2-21. These are the inputs used in the PBPK model.

Table 2-20. Characterization of PBPK Model Input Parameters for Incorporation into Formulation, Mixture, or Reaction Product

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Liquid - Drum unloading	Central tendency (50th percentile)	Duration calculated by model	1-hand	Yes	N/A - 100% is assumed for both exposure scenarios
High-end	Liquid - Maintenance, bottling, shipping, loading	High-end (95th percentile)	Duration calculated by model	2-hand	Yes	N/A - 100% is assumed for both exposure scenarios

Table 2-21. PBPK Model Input Parameters for Incorporation into Formulation, Mixture, or Reaction Product

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Liquid – Drum unloading	1.65	0.36	445 (f) 535 (m)	10	1	74 (f) 88 (m)
High-end	Liquid – Maintenance, bottling, shipping, loading	12.8	8	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.4.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.5 Metal Finishing

2.5.1 Process Description

EPA's "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document indicates that NMP is used in metal finishing operations (U.S. EPA, 2017b). Metal finishing is a broad term used in industry to include a wide variety of processes that alter the surface of metal substrates, such as cleaning, coating, etching, and invasive quality testing.

Prior to any metal finishing process, the surfaces of metal substrates must first be cleaned to remove grease and other surface contamination (OECD, 2004). Following cleaning, the substrates may then be conditioned or activated, which involves the use of a dilute acid to neutralize any remaining alkaline cleaner used in the cleaning process and to dissolve any tarnish or oxide film on the surface of the metal substrates. Further, to produce the required surface smoothness or texture, facilities often use polishing and other abrasive techniques. NMP is expected to be used in these types of surface preparation processes.

In addition to surface preparation, the Consumer Specialty Products Association (CSPA) submitted a public comment to EPA's NMP docket indicating that NMP is used as a penetrant for inspection of metals, specifically on metal parts such as those used in turbines and bridges, among other types of parts (Brown and Bennett, 2017). Penetrants contain dyes and are used to identify defects in metal parts, such as those from fatigue and welding cracks. Specifically, once parts are machined and assembled, penetrant is applied to the surface of the metal, where it migrates into cracks and other surface defects. The metal parts are then visually inspected for defects, frequently under an ultraviolet light where fluorescent penetrant dyes are more visible, and then the penetrant is cleaned from the metal part (Center, 2017).

The specific process steps depend on the type of substrate with application methods including: dip or immersion, spray, roll, and brush application.

Based on the above information, EPA expects NMP is used in surface preparation and invasive testing of metal parts. Therefore, EPA assesses the following distinct occupational exposure scenarios for this scenario:

- Spray application
- Dip application
- Brush application

NMP may also be used in coatings that are applied to metal parts; however, coating processes with NMP-based products are covered in Section 2.5.

2.5.2 Exposure Assessment

2.5.2.1 Worker Activities

Workers are potentially exposed to NMP in metal finishing formulations during multiple activities, including quality testing of formulations, transferring the formulations into application equipment (if used), applying the formulation to a substrate, and maintenance and cleaning activities. These activities are all potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

During application of metal finishing formulations, workers may manually apply the formulation with a variety of application techniques, including spray application from a handheld spray gun or can, brush application, and dipping. All types of application are potential exposure points for workers. Some application methods may be automated, which reduces the potential for worker exposures. For example, for larger metal parts, machinery may be used to dip these parts into metal finishing formulations. If the dip application apparatus has an enclosed reservoir, this reduces the potential for NMP vapors to escape and become available for worker inhalation exposure. The extent of automated application processes and use of open versus closed systems in the various industries that conduct metal finishing operations is unknown.

The German Institute for Occupational Safety and Health (IFA) compiled monitoring data for multiple industries that use NMP, including foundries (IFA, 2010). EPA has not identified information describing how NMP is used at the foundry companies that were included in this monitoring data compilation. However, EPA believes these operations are most likely to fall within this scenario. These data include samples from facilities that employ LEV, indicating that this engineering control is sometimes used at facilities that conduct metal finishing operations. EPA did not find information regarding the frequency of use of this or other engineering controls nor that for worker PPE in the various industries that may conduct metal finishing operations.

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.5.2.2 Number of Potentially Exposed Workers

Application of NMP-based metal finishing products may occur in multiple industries. EPA determined the industries likely to use NMP for metal finishing from the non-CBI 2016 CDR results for NMP (U.S. EPA, 2016a), the Scope of the Risk Evaluation for N-Methylpyrrolidone (U.S. EPA, 2017c), and the public comment from the CSPA (Brown and Bennett, 2017).

The exact industries that distinctly perform metal finishing operations are unknown. EPA compiled the associated NAICS codes for the identified industries in Table 2-22. EPA determined the number of workers associated with each industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based metal finishing products and the number of employees within an establishment exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based metal finishing products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during metal finishing.

Table 2-22. US Number of Establishments and Employees for Metal Finishing

Industry	Source	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers per Site [a]	Number of ONUs per Site [a]
Primary Metal Manufacturing	(IFA, 2010)	331100	Iron and Steel Mills and Ferroalloy Manufacturing	603	55	21
		331200	Steel Product Manufacturing from Purchased Steel	667	34	10
		331300	Alumina and Aluminum Production and Processing	529	37 [b]	15 [b]
		331400	Nonferrous Metal (except Aluminum) Production and Processing	964	28	10
		331500	Foundries	1,770	18	10
Fabricated Metal Product Manufacturing	(U.S. EPA, 2016a)	332100	Forging and Stamping	2,467	11	5
		332200	Cutlery and Handtool Manufacturing	1,194	8	3
		332300	Architectural and Structural Metals Manufacturing	12,309	11	4
		332400	Boiler, Tank, and Shipping Container Manufacturing	1,575	21	8
		332500	Hardware Manufacturing	599	12	4
		332600	Spring and Wire Product Manufacturing	1,196	11	4
		332700	Machine Shops; Turned Product; and Screw, Nut, and Bolt Manufacturing	23,083	2	2
		332800	Coating, Engraving, Heat Treating, and Allied Activities	5,732	11	4
		332900	Other Fabricated Metal Product Manufacturing	6,612	12	6
Turbine Manufacturing	(Brown and Bennett, 2017)	333600	Engine, Turbine, and Power Transmission Equipment Manufacturing	1,073	30	17
Total establishments and number of potentially exposed workers and ONUs = [c]				***60,000***	***530,000***	***190,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)

a – Rounded to the nearest whole number.

b – No 2016 BLS data was available for this NAICS. Number of relevant workers per site and ONUs per site within this NAICS were calculated using the ratios of relevant workers and ONUs to the number of total employees at the 3-digit NAICS level.

c – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.5.2.3 Occupational Exposure Assessment Methodology

2.5.2.3.1 Inhalation

Appendix A.5 summarizes the inhalation monitoring data for NMP-based metal finishing application that EPA compiled from published literature sources, including 8-hour TWA, short-term, and partial shift sampling results. This appendix also includes EPA's rationale for inclusion or exclusion of these data in the risk evaluation, as well as description of any modeling approaches used by EPA to assess exposures in this scenario. In summary, where available, EPA used the monitoring data for metal finishing or surrogate monitoring data for the use of NMP during Application of Paints, Coatings, Adhesives, and Sealants and Cleaning that had the highest quality rating to assess exposure. Where monitoring data was unavailable for an application type, EPA used modeling estimates with the highest data quality to assess exposure. This is further described below.

EPA found limited data on the application of metal finishing chemicals, thus assesses spray application using the data from Application of Paints, Coatings, Adhesives, and Sealants (refer to Section 2.5) as surrogate (surrogate work activities using NMP) for this scenario. EPA used data for dip cleaning from the Cleaning scenario (refer to Section 2.10) as surrogate (surrogate work activities using NMP) for this scenario. Finally, EPA used a modeled exposure for the brush application of a substance containing NMP that was presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report. The personal breathing zone monitoring data and the modeled exposures are summarized in Table 2-23. The area monitoring data are summarized in Table 2-24. EPA cannot distinguish ONU exposures from worker exposures from the data in Table 2-23 and Table 2-24. EPA used the data in Table 2-23 for inhalation exposure inputs to the PBPK model, as described in Section 2.5.3.

Table 2-23. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Metal Finishing

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8- hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Spray Application	Low-end (of range)	0.040	0.040 (duration = 4 hr)	(NIOSH, 1998)	High
	Mean	0.530	0.530 (duration = 4 hr)		
	High-end (of range)	4.51	4.51 (duration = 4 hr)		
Dip Application	Central tendency (50th percentile)	0.990	No data	Surrogate data (surrogate work activities using NMP) from: (RIVM, 2013; Nishimura et al., 2009; Bader et al., 2006) (IFA, 2010; Xiaofei et al., 2000)	Medium to high
	High-end (95th percentile)	2.75	No data		
Brush Application	Single estimate	4.13	No data	(RIVM, 2013)	High

Table 2-24. Summary of Area Monitoring During Metal Finishing

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Spray Application	Low-end	0.040	0.040 (duration = 4 hr)	(NIOSH, 1998)	High
	Mean	0.140	0.140 (duration = 4 hr)		
	High-end	0.530	0.530 (duration = 4 hr)		

2.5.2.3.2 Dermal

Table 2-25 summarizes the parameters used to assess dermal exposure during application of metal finishing formulations containing NMP. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

NMP Weight Fraction

Neither the 2017 Market Profile for NMP (Abt, 2017) nor the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) identified metal finishing products containing NMP. The 2012 and 2016 CDR results indicate industrial and commercial categories of use for "metal products not covered elsewhere." These categories of use indicate that the weight concentration of NMP in formulation is greater than 60 percent but less than 90 percent. Due to lack of additional information, EPA assesses a low-end weight fraction of 0.6 and a high-end weight fraction of 0.9. Because metal finishing products can be applied with multiple different methods (e.g., spray and brush), EPA assesses these weight fractions for all application methods in this scenario. These data have overall confidence ratings of high.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. EPA did not find information on the use of gloves within the metal finishing industries. Thus, EPA assesses that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the commercial nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-25. Summary of Parameters for Worker Dermal Exposure to Liquids During Metal Finishing

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
All forms of application listed above	Central Tendency	5	0.6	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.9	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.5.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-26.

The numeric parameters corresponding to the characterizations presented in Table 2-26 are summarized in Table 2-27. These are the inputs used in the PBPK model.

Table 2-26. Characterization of PBPK Model Input Parameters for Metal Finishing

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Spray application	Mean	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Spray application	High-end (of range)	Assumed 8 hours	2-hand	No	High-end
Central Tendency	Dip application	Central tendency (50th percentile)	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Dip application	High-end (95th percentile)	Assumed 8 hours	2-hand	No	High-end
Central Tendency	Brush application	Single estimate	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Brush application	Single estimate	Assumed 8 hours	2-hand	No	High-end

Table 2-27. PBPK Model Input Parameters for Metal Finishing

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Spray application	0.530	4	445 (f) 535 (m)	5	0.6	74 (f) 88 (m)
High-end	Spray application	4.51	8	890 (f) 1,070 (m)	1	0.9	74 (f) 88 (m)

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m³)	Exposure Duration (hr)	Skin Surface Area Exposed (cm²) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Dip application	1.98	4	445 (f) 535 (m)	5	0.6	74 (f) 88 (m)
High-end	Dip application	2.75	8	890 (f) 1,070 (m)	1	0.9	74 (f) 88 (m)
Central Tendency	Brush application	8.26	4	445 (f) 535 (m)	5	0.6	74 (f) 88 (m)
High-end	Brush application	4.13	8	890 (f) 1,070 (m)	1	0.9	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm² for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.5.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.6 Removal of Paints, Coatings, Adhesives, and Sealants

2.6.1 Process Description

EPA's 2017 market profile of NMP identified that NMP may be used in removers for paints, coatings, and adhesives (Abt, 2017). Similar to the 2015 EPA Assessment on Paint Stripper Use (U.S. EPA, 2015b), this risk evaluation considers two different occupational exposure scenarios within this category of use: miscellaneous stripping, which is assumed to occur mostly indoors, and graffiti removal, which is assumed mostly outdoor but may include partially enclosed spaces, such as outdoor escalators and elevators. EPA makes this distinction based on the specificity of the available monitoring data.

The typical process for removal of paints and coatings, including graffiti removal, from substrates first includes optional preparation of surfaces via cleaning and sanding (U.S. EPA, 2015b). This preparation is to ensure that the removal product will stick to the coating to be removed. Following surface preparation, the paint and coating removal product is applied to the surface of the substrate via hand-held brush, tank dipping, spray application, pouring, wiping, or rolling. Depending on whether removal is performed industrially or commercially, users may purchase paint and coating removal products in 55-gallon drums or in common, commercially available containers that range from 1 liter to 5 gallons (U.S. EPA, 2015b).

Paint stripper application methods can include brushing, spraying, dipping, and wiping (White and Bardole, 2004). The particular application method is dependent on the size and location of the substrate. For example, for walls and floors, the removal product is typically applied with a handheld brush. For furniture, the furniture pieces are generally dipped into a tank containing the removal product, or the removal product is applied by brushing or spraying. After application, the stripper is allowed to set and soften the old coating (U.S. EPA, 2015b). The old coating is then removed by scraping, brushing, wiping, or mechanically buffering or sanding. Once the old coating is removed, the substrate may be washed with water or solvent to remove any remaining portions of the old coating and prepare the surface for a new coating, if one is to be applied.

2.6.2 Exposure Assessment

2.6.2.1 Worker Activities

During paint and coating removal, workers may manually apply the removal product to the surface of the substrate. Once the paint and coating removal product is applied to the substrate and allowed to set, workers will likely manually remove the old coating. Both these worker activities are potential sources of worker exposure, through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

EPA did not find information on the customary engineering controls and worker PPE used in the paint, coating, and graffiti removal industries; however, some resources list suggested engineering controls and worker PPE that may be used during paint, coating, and graffiti removal. Graffiti removal is typically performed outdoors, while paint and coating removal may occur indoors or outdoors. Should removal activities occur indoors, the area may be mechanically ventilated (U.S. EPA, 2013b). Workers may wear respirators to reduce potential exposure to NMP vapors. Workers may wear gloves that are resistant to NMP, which include butyl rubber and laminated polyethylene or ethylene vinyl alcohol (EVOH) gloves.

The 2015 EPA (U.S. EPA, 2015b) for NMP assesses exposures considering the use of gloves that have an exposure reduction efficiency of 90 percent and the use of respirators with an assigned protection factor (APF) of 10 (U.S. EPA, 2015b). The RA also assesses exposures without consideration for gloves or respirators, as EPA had not identified information indicating these PPE are generally implemented across all industries that conduct paint and coating removal.

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.6.2.2 Number of Potentially Exposed Workers

The 2015 EPA Assessment on Paint Stripper Use (U.S. EPA, 2015b) identified the following industries that are likely to conduct paint stripping activities:

- Professional contractors;
- Bathtub refinishing;
- Automotive refinishing;
- Furniture refinishing;
- Art restoration and conservation;
- Aircraft paint stripping;
- Ship paint stripping; and
- Graffiti removal.

EPA's additional research does not indicate that this list of industries has changed since publication of the 2015 Paint Stripper Risk Assessment. EPA determined the number of workers associated with each industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). These data are summarized in Table 2-28. The number of establishments within each industry that use NMP-based removal products and the number of employees within an establishment exposed to NMP-based removal products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based removal products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during paint and coating removal.

Table 2-28. US Number of Establishments and Employees for Removal of Paints, Coatings, Adhesives, and Sealants

Occupational Exposure Scenario	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site [a]	Number of ONUs per Site [a]
Miscellaneous Paint, Coating, Adhesive, and Sealant Removal	238320	Painting and Wall Covering Contractors	31,943	4	0
	238330	Flooring Contractors	14,601	4	0
	811121	Automotive Body, Paint and Interior Repair and Maintenance	33,648	3	0
	811420	Reupholstery and Furniture Repair	3,720	1	1
	711510	Independent Artists, Writers and Performers	25,205	1	0
	712110	Museums	5,125	1	0
	336411	Aircraft Manufacturing	321	187	159
	336611	Ship building and repairing	674	62	22
Graffiti Removal	Unknown				
Total number of establishments, workers, and ONUs potentially exposed [b]			***120,000***	***410,000***	***100,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest worker.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.6.2.3 Occupational Exposure Assessment Methodology

EPA evaluated potential worker exposures through PBPK modeling. The PBPK model was used to calculate internal doses of NMP using a set of parameters determined from literature or through standard assumptions, as described below.

2.6.2.3.1 Inhalation

Appendix A.6 summarizes the inhalation monitoring data for NMP-based paint and coating removal that EPA compiled from published literature sources, including 8-hour TWA, short-term, and partial shift sampling results. This appendix also includes EPA's rationale for inclusion or exclusion of these data in the risk evaluation. EPA used the available monitoring data with the highest data quality to assess exposure for this use.

The available monitoring data for paint and coating removal are summarized into low-end (lowest concentration), high-end (highest concentration), and mean or mid-range values in Table 2-29. Note that, where possible, EPA prefers to present a central tendency (based on 50th percentile) and worst-case (based on 95th percentile) exposure scenario. However, due to lack of data, EPA summarized the data into low-end, high-end, and mid-range or mean.

EPA's research for this risk evaluation did not result in additional 8-hour TWA data points from the *2015 TSCA Work Plan Chemical Risk Assessment N-Methylpyrrolidone: Paint Stripping Use* (U.S. EPA, 2015b). The data presented in Table 2-29 are the input parameters used for the PBPK modeling for workers and ONUs, respectively. Note that, due to lack of specificity in the monitoring data, EPA assumes the data are representative of both workers and ONUs.

Table 2-29. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Removal of Paints, Coatings, Adhesives, and Sealants

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Miscellaneous paint, coating, adhesive, and sealant removal	Low-end (of range)	1.0	6.1 (duration = 1 hr)	(U.S. EPA, 2015b)	High
	Mid-range	32.5	13.2 (duration = 1 hr)		
	High-end (of range)	64	280 (duration = 1 hr)		
Graffiti removal	Low-end	0.03	No data	(U.S. EPA, 2015b)	High
	Mean	1.01	No data		
	High-end	4.52	No data		

2.6.2.3.2 Dermal

Table 2-30 summarizes the parameters used to assess dermal exposure during paint and coating removal. EPA assumed that the skin was exposed dermally to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below.

NMP Weight Fraction

The 2015 EPA Assessment on Paint Stripper Use (U.S. EPA, 2015b) identified the weight percent of NMP in paint and coating removal products as ranging from 25 up to 100. EPA identified additional paint stripping and graffiti removal products in the 2017 market profile on NMP and "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (Abt, 2017; U.S. EPA, 2017b). This data identified multiple commercial and industrial grade paint, coating, and graffiti removers that contain NMP at weight fractions ranging from 1 to 100 weight percent NMP. With these data, EPA determined a typical and worst-case estimate of NMP concentration in these products, calculated as the 50th percentile and 95th percentile, respectively. Where NMP concentration was provided in a range, EPA used the midpoint of the range for the calculations. Based on these data, for miscellaneous paint, coating, adhesive, and sealant removal, the typical NMP concentration is 30.5 weight percent and the worst-case NMP concentration is 69.5 weight percent. For graffiti removal, the typical NMP concentration is 50 weight percent and the worst-case NMP concentration is 61.25 weight percent. The underlying data used for these estimates have overall confidence ratings ranging from medium to high.

For the remaining dermal parameters, skin surface area, exposure duration, and body weight, EPA uses the same methodology for both miscellaneous removal and graffiti removal, as described below.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. The 2015 EPA (U.S. EPA, 2015b) for NMP assesses exposures considering the use of gloves that have an exposure reduction efficiency of 90 percent, equal to a protection factor of 10 (U.S. EPA, 2015b). The RA also assesses exposures without consideration for gloves or respirators, as EPA had not identified information indicating these PPE are generally implemented across all industries that conduct paint and coating removal. Consistent with the RA and due to the wide-spread use of NMP-based paint and coating removal products, EPA assumes that no gloves are used for the worst-case exposure scenario, corresponding to a protection factor of 1. The 2015 EPA (U.S. EPA, 2015b) assumed that, if gloves were worn, they provided a protection factor of 10. However, for this risk evaluation, EPA considers the potential for employee training on proper glove usage. No information on employee training was found, but due to the commercial nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

For paint and coating removal, EPA found inhalation exposure monitoring data indicating an exposure duration of one hour. EPA uses this duration as a central tendency scenario. For a high-end scenario, as described in Section 1.4.3.2.4, EPA assumes eight hours. For graffiti removal, EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-30. Summary of Parameters for PBPK Modeling of Worker Dermal Exposure to Liquids During Removal of Paints, Coatings, Adhesives, and Sealants

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Miscellaneous paint, coating, adhesive, and sealant removal	Central Tendency	5	0.305	445 (f) 535 (m)	1	74 (f) 88 (m)
	High-End	1	0.695	890 (f) 1,070 (m)	8	
Graffiti removal	Central Tendency	5	0.5	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.6125	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.6.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-31.

The numeric parameters corresponding to the characterizations presented in Table 2-31 are summarized in Table 2-32. These are the inputs used in the PBPK model.

Table 2-31. Characterization of PBPK Model Input Parameters for Removal of Paints, Coatings, Adhesives, and Sealants

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Miscellaneous paint, coating, adhesive, and sealant removal	Mid-range	Based on 1-hour TWA data	1-hand	Yes	Central Tendency
High-end	Miscellaneous paint, coating, adhesive, and sealant removal	High-end (of range)	Assumed 8 hours	2-hand	No	High-end
Central Tendency	Graffiti removal	Mean	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Graffiti removal	High-end (of range)	Assumed 8 hours	2-hand	No	High-end

Table 2-32. PBPK Model Input Parameters for Removal of Paints, Coatings, Adhesives, and Sealants

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Miscellaneous paint, coating, adhesive, and sealant removal	13.2	1	445 (f) 535 (m)	5	0.305	74 (f) 88 (m)
High-end	Miscellaneous paint, coating, adhesive, and sealant removal	64	8	890 (f) 1,070 (m)	1	0.695	74 (f) 88 (m)
Central Tendency	Graffiti removal	2.02	4	445 (f) 535 (m)	5	0.5	74 (f) 88 (m)
High-end	Graffiti removal	4.52	8	890 (f) 1,070 (m)	1	0.6125	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.6.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.7 Application of Paints, Coatings, Adhesives, and Sealants

2.7.1 Process Description

Based on information identified in the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and 2016 CDR reporting, NMP is used as a solvent in a wide variety of industrial, commercial, and consumer paints, coatings, adhesives, and sealants (U.S. EPA, 2017b, 2016a). The application methods vary with the specific use.

Several OECD ESDs and EPA generic scenarios provide general process descriptions and worker activities for industrial and commercial uses. The ESD on Radiation Curable Coatings, Inks, and Adhesives indicates that, before application onto substrates, paint and coating formulations may be diluted and are then charged into application equipment (OECD, 2011). Typical coating applications include manual application with roller or brush, air spray systems, airless and air-assisted airless spray systems, electrostatic spray systems, electrodeposition/electrocoating and autodeposition, dip coating, curtain coating systems, roll coating systems, and supercritical carbon dioxide systems (OECD, 2011). After application, solvent-based coatings typically undergo a drying stage in which the solvent evaporates from the coating (OECD, 2011).

The OECD ESD for Use of Adhesives (OECD, 2015) provides general process descriptions and worker activities for industrial adhesive uses. Liquid adhesives are unloaded from containers into the coating reservoir, applied to a flat or three-dimensional substrate, and the substrates are then joined and allowed to cure (OECD, 2015). The majority of adhesive applications include spray, roll, curtain, and syringe or bead application (OECD, 2015). For solvent-based adhesives, the volatile solvent (in this case NMP) evaporates during the curing stage (OECD, 2015). Based on EPA's knowledge of the industry, EPA expects similar process descriptions, worker activities, and application methods for sealant products as those described above.

Based on the types of paint, coating, adhesive, and sealant products listed in the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) and 2017 market profile on NMP (Abt, 2017), EPA could not clearly distinguish the relevant application methods for these NMP-based products. Due to the potential widespread industrial and commercial use of NMP-based coating products, EPA expects that the majority of application methods described above are relevant. Therefore, EPA assesses the following distinct occupational exposure scenarios for this scenario:

- Spray application
- Roll or curtain application
- Dip application
- Brush or roller application
- Syringe or bead application

2.7.2 Exposure Assessment

2.7.2.1 Worker Activities

Workers are potentially exposed to NMP in paint, coating, adhesive, and sealant formulations during quality testing of formulations, transferring the formulations into application equipment, applying the formulation to a substrate, and maintenance and cleaning activities (Meier et al., 2013; OECD, 2011; NICNAS, 2001). These activities are all potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors or paint, coating, adhesive, and sealant mists containing NMP. Workers have further potentially inhalation exposure to NMP vapors during curing or drying of solvent-borne formulations as the NMP evaporates from the applied formulations.

During application of paints, coatings, adhesives, and sealants, workers may manually apply the formulation with a variety of application techniques, including spray application from a handheld spray gun or can, brush or roller application, dipping, or syringe/bead application. All types of application are potential exposure points for workers. However, the application of the paint, coating, adhesive, and sealant formulations may be automated using automated spray equipment, roll/curtain equipment, or dip application equipment. The potential for worker exposure during automated application depends on the type of system used, specifically whether the system is open or closed. For example, automated spray application may occur in an enclosed booth equipped with an air filtration or water curtain system to capture overspray, limiting the potential for worker exposure (NICNAS, 2001). Alternatively, spray application may be automated but occur in only a semi-enclosed or open space, which increases the potential for worker exposures. The extent to which closed application systems is used in the various industries that apply NMP-based paints, coatings, adhesives, and sealants is unknown.

The 2011 ESD on Application of Radiation Curable Coatings, Inks, and Adhesives indicates that typical PPE may include protective clothing, gloves, safety shoes, and respiratory protection, as needed (OECD, 2011). Additional sources indicate that it is common practice for workers to wear chemical-resistant gloves (Meier et al., 2013; OECD, 2009; NICNAS, 2001). The RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013) assesses exposure scenarios that account for the use of local exhaust ventilation (LEV) (using a 90 percent exposure reduction), gloves (using an 80 percent or a 95 percent exposure reduction), and, in some cases, a respirator with assigned protection factors (APFs) of 5 (80 percent exposure reduction) or 20 (95 percent exposure reduction).

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.7.2.2 Number of Potentially Exposed Workers

Application of NMP-based paints, coatings, adhesives, and sealants are widespread, occurring in many industries. EPA determined the industries likely to use NMP in paints, coatings, adhesives, and sealants from the following sources: the non-CBI 2016 CDR results for NMP (U.S. EPA, 2016a), the 2017 market profile for NMP (Abt, 2017), and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b).

In addition, EPA received public comments on the NMP risk evaluation docket indicating NMP is used in paints, coatings, adhesives, and / or sealants in the following industries:

- Aerospace manufacturing industry (Riegle, 2017)

- Automotive manufacturing industry (ACC, 2017; Alliance of Automobile Manufacturers, 2017)
- Electronics manufacturing (National Electrical Manufacturers Association, 2017; Thomas, 2017)
- Semiconductor manufacturing (Fujifilm, 2017a; Isaacs, 2017)
- Construction (architectural coatings) (Davis, 2017; NABTU, 2017)

The industries that distinctly perform the various methods of paint, coating, adhesive, and sealant application (e.g., spray, dip, roll) are unknown. EPA assumes that all industries may perform all methods of application. EPA compiled the associated NAICS codes for the identified industries in Table 2-33. EPA determined the number of workers associated with each industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based paint, coating, adhesive, and sealant products and the number of employees within an establishment exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based paint, coating, adhesive, and sealant products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during paint, coating, adhesive, and sealant application.

Table 2-33. US Number of Establishments and Employees for Application of Paints, Coatings, Adhesives, and Sealants

Industry	Industry Source	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers per Site [a]	Number of ONUs per Site [a]
Construction and Flooring	(Abt, 2017; U.S. EPA, 2017b, 2016a)	238320	Painting and Wall Covering Contractors	31,943	4	0
		238330	Flooring Contractors	14,601	4	0
Primary Metal Manufacturing	(U.S. EPA, 2016a)	331100	Iron and Steel Mills and Ferroalloy Manufacturing	603	53	18
		331200	Steel Product Manufacturing from Purchased Steel	667	28	7
		331300	Alumina and Aluminum Production and Processing	529	33 [b]	13 [b]
		331400	Nonferrous Metal (except Aluminum) Production and Processing	964	22	7
		331500	Foundries	1,770	18	10
Fabricated Metal Product Manufacturing	(Abt, 2017; U.S. EPA, 2017b, 2016a)	332100	Forging and Stamping	2,467	10	4
		332200	Cutlery and Handtool Manufacturing	1,194	7	3
		332300	Architectural and Structural Metals Manufacturing	12,309	10	3
		332400	Boiler, Tank, and Shipping Container Manufacturing	1,575	19	6
		332500	Hardware Manufacturing	599	12	4
		332600	Spring and Wire Product Manufacturing	1,196	10	3
		332700	Machine Shops; Turned Product; and Screw, Nut, and Bolt Manufacturing	23,083	2	1
		332800	Coating, Engraving, Heat Treating, and Allied Activities	5,732	8	2
		332900	Other Fabricated Metal Product Manufacturing	6,612	12	5
Machinery Manufacturing	(U.S. EPA, 2017b, 2016a)	333100	Agriculture, Construction, and Mining Machinery Manufacturing	3,094	20	9
		333200	Industrial Machinery Manufacturing	3,262	8	6
		333300	Commercial and Service Industry Machinery Manufacturing	2,014	14	6
		333400	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing	1,776	31	8
		333500	Metalworking Machinery Manufacturing	6,527	4	4
		333600	Engine, Turbine, and Power Transmission Equipment Manufacturing	1,073	30	17
		333900	Other General Purpose Machinery Manufacturing	6,048	13	7

Industry	Industry Source	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers per Site [a]	Number of ONUs per Site [a]
Computer and Electronic Product Manufacturing	(Abt, 2017; U.S. EPA, 2017b, 2016a)	334100	Computer and Peripheral Equipment Manufacturing	1,091	12 [b]	12 [b]
		334200	Communications Equipment Manufacturing	1,369	13	14
		334300	Audio and Video Equipment Manufacturing	486	6 [b]	6 [b]
		334400	Semiconductor and Other Electronic Component Manufacturing	3,979	30	27
		334500	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing	5,231	17	18
		334600	Manufacturing and Reproducing Magnetic and Optical Media	521	6 [b]	6 [b]
Electrical Equipment, Appliance, and Component Manufacturing	(U.S. EPA, 2016a)	335100	Electric Lighting Equipment Manufacturing	1,104	17	5
		335200	Household Appliance Manufacturing	303	102	20
		335300	Electrical Equipment Manufacturing	2,124	28	12
		335900	Other Electrical Equipment and Component Manufacturing	2,140	23	8
Transportation Equipment Manufacturing	(Abt, 2017; U.S. EPA, 2017b, 2016a)	336100	Motor Vehicle Manufacturing	340	235 [b]	99 [b]
		336200	Motor Vehicle Body and Trailer Manufacturing	1,917	41	7
		336300	Motor Vehicle Parts Manufacturing	5,088	51	15
		336400	Aerospace Product and Parts Manufacturing	1,811	75	64
		336500	Railroad Rolling Stock Manufacturing	243	35	15
		336600	Ship and Boat Building	1,541	36	13
Wholesale and Retail Trade	(U.S. EPA, 2016a)	424690	Other Chemical and Allied Products Merchant Wholesalers	9,517	1	0
Total establishments and number of potentially exposed workers and ONUs = [c]				***170,000***	***2,000,000***	***910,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)

a – Rounded to the nearest whole number.

b – No 2016 BLS data was available for this NAICS. Number of relevant workers per site and ONUs per site within this NAICS were calculated using the ratios of relevant workers and ONUs to the number of total employees at the 3-digit NAICS level.

c – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.7.2.3 Occupational Exposure Assessment Methodology

2.7.2.3.1 Inhalation

Appendix A.7 summarizes the inhalation monitoring data for NMP-based paint, coating, adhesive, and sealant application that EPA compiled from published literature sources, including 8-hour TWA, short-term, and partial shift sampling results. EPA also compile modeled exposure data in this appendix. Where available for the various types of application, EPA used monitoring data or surrogate monitoring data for the use of NMP during Cleaning that had the highest quality rating to assess exposure. Where monitoring data was unavailable for an application type, EPA used modeling estimates with the highest data quality to assess exposure. This is further described below and in Appendix A.7.

EPA used monitoring data presented in Appendix A.7 to determine the PBPK model inputs for inhalation exposures during spray application. EPA did not find inhalation monitoring data on roll coating with NMP-containing formulations, thus used data from *EPA/OPPT's UV Roll Coating Model* in conjunction with NMP concentration data to determine inputs to the PBPK model for roll coating in this scenario. The *EPA/OPPT UV Roll Coating Model* involved deterministic modeling. EPA found limited data on the dip application of paints, coatings, adhesives, and sealants, thus EPA used data for dip cleaning with NMP from the Cleaning scenario (refer to Section 2.10) as surrogate (surrogate work activities using NMP) for this scenario. EPA used a modeled exposure for the brush application of a substance containing NMP that was presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report. The personal breathing zone monitoring data and the modeled exposures are summarized in Table 2-34. The area monitoring data are summarized in Table 2-35. EPA cannot distinguish ONU exposures from worker exposures from the data in Table 2-34 and Table 2-35. EPA used the data in Table 2-34 for inhalation exposure inputs to the PBPK model, as described in Section 2.7.3.

Table 2-34. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Application of Paints, Coatings, Adhesives, and Sealants

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Spray Application	Low-end (of range)	0.04	0.04 (duration = 4 hr)	(NIOSH, 1998)	High
	Mean	0.53	0.53 (duration = 4 hr)		
	High-end (of range)	4.51	4.51 (duration = 4 hr)		
Roll / Curtain Application	Central tendency (50th percentile)	0.03	No data	*EPA/OPPT UV Roll Coating Model*	Not applicable[a]
	High-end (95th percentile)	0.19	No data		
Dip Application	Central tendency (50th percentile)	0.99	No data	Surrogate data (surrogate work activities using NMP) from: (RIVM, 2013; IFA, 2010; Nishimura	Medium to high
	High-end (95th percentile)	2.75	No data		

				et al., 2009; Bader et al., 2006; Xiaofei et al., 2000)	
Roller / Brush and Syringe / Bead Application	Single estimate	4.13	No data	(RIVM, 2013)	High

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

Table 2-35. Summary of Occupational Non-User Inhalation Exposure During Application of Paints, Coatings, Adhesives, and Sealants

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Spray Application	Low-end	0.04	0.04 (duration = 4 hr)	(NIOSH, 1998)	High
	Mean	0.14	0.14 (duration = 4 hr)		
	High-end	0.53	0.53 (duration = 4 hr)		
Roll / Curtain Application	No data	No data	No data	No data	Not applicable
	No data	No data	No data	No data	Not applicable
Dip Application	No data	No data	No data	No data	Not applicable
	No data	No data	No data	No data	Not applicable
Roller / Brush and Syringe / Bead Application	No data	No data	No data	No data	Not applicable

2.7.2.3.2 Dermal

Table 2-36 summarizes the parameters used to assess dermal exposure during application of paints, coatings, adhesives, and sealants containing NMP. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below.

NMP Weight Fraction

EPA gathered paint, coating, adhesive, and sealant product concentration from a variety of sources, including 2017 market profile for NMP (Abt, 2017), the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b), public comments to the NMP risk evaluation docket, and published literature (U.S. EPA, 2017b; RIVM, 2013; Muenter and Blach, 2010; NICNAS, 2001, 1998). The overall confidence rating of the data from these sources range from medium to high.

EPA identified multiple paint, coating, adhesive, and sealant products containing NMP. Note that some data points are not for one specific product but are estimated ranges of the expected NMP concentration in paints, coatings, adhesives, and sealants. Where NMP concentration was provided in a range, EPA used the midpoint of the range for the calculations of typical and worst-case NMP concentration described below. NMP concentrations in paints, coatings, adhesives, and sealants range from 0.06 weight percent NMP up to 90 weight percent NMP. With these data, EPA determined a typical and worst-case estimate of NMP concentration in these products, calculated as the 50^{th} percentile and 95^{th} percentile, respectively. Based on these data, the typical NMP concentration is 2 weight percent and the worst-case NMP concentration is 53.4 weight percent.

Skin Surface Area and Glove Usage
As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Due to the wide-spread commercial and industrial use of NMP-based paints, coatings, adhesives, and sealants, EPA assumes that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. Some sources indicate that workers wear chemical-resistant gloves (Meier et al., 2013; OECD, 2009; NICNAS, 2001), while others indicate that workers likely wear gloves that provide a lower protection factor (RIVM, 2013). No information on employee training was found. Based on this information and the widespread use of NMP in this scenario, EPA assesses a central tendency scenario assuming the use of gloves with minimal to no employee training, corresponding to a protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration
EPA found inhalation monitoring data for spray application indicating an exposure duration of four hours. EPA did not find additional data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-36. Summary of Parameters for Worker Dermal Exposure to Liquids During Application of Paints, Coatings, Adhesives, and Sealants

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
All forms of application listed above	Central Tendency	5	0.02	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.534	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.7.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-37.

The numeric parameters corresponding to the characterizations presented in Table 2-37 are summarized in Table 2-38. These are the inputs used in the PBPK model.

Table 2-37. Characterization of PBPK Model Input Parameters for Application of Paints, Coatings, Adhesives, and Sealants

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Spray application	Mean	Based on 4-hour TWA data	1-hand	Yes	Central Tendency
High-end	Spray application	High-end (of range)	Based on 8-hour TWA data	2-hand	No	High-end
Central Tendency	Roll / curtain application	Central tendency (50th percentile)	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Roll / curtain application	High-end (95th percentile)	Based on 8-hour TWA data	2-hand	No	High-end
Central Tendency	Dip application	Central tendency (50th percentile)	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Dip application	High-end (95th percentile)	Based on 8-hour TWA data	2-hand	No	High-end
Central Tendency	Brush application	Single estimate	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Brush application	Single estimate	Based on 8-hour TWA data	2-hand	No	High-end

Table 2-38. PBPK Model Input Parameters for Application of Paints, Coatings, Adhesives, and Sealants

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Spray application	0.53	4	445 (f) 535 (m)	5	0.02	74 (f) 88 (m)
High-end	Spray application	4.51	8	890 (f) 1,070 (m)	1	0.534	74 (f) 88 (m)
Central Tendency	Roll / curtain application	0.06	4	445 (f) 535 (m)	5	0.02	74 (f) 88 (m)
High-end	Roll / curtain application	0.19	8	890 (f) 1,070 (m)	1	0.534	74 (f) 88 (m)

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Dip application	1.98	4	445 (f) 535 (m)	5	0.02	74 (f) 88 (m)
High-end	Dip application	2.75	8	890 (f) 1,070 (m)	1	0.534	74 (f) 88 (m)
Central Tendency	Brush application	8.26	4	445 (f) 535 (m)	5	0.02	74 (f) 88 (m)
High-end	Brush application	4.13	8	890 (f) 1,070 (m)	1	0.534	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.7.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.8 Electronic Parts Manufacturing

2.8.1 Process Description

Within the electronics industries, NMP serves multiple functions, including:

- As a binder solvent in the assembly of lithium-ion batteries (Mitsubishi Chemical, 2017; Argonne National Laboratory, 2015; RIVM, 2013)
- Solvent for the cleaning of electronic parts, including semiconductor wafer cleaning (Isaacs, 2017; NIH, 2017; RIVM, 2013; U.S. EPA, 1998)
- Component of various formulations, including photoresists, polyimides, anti-reflective coatings, and insulative coatings (Isaacs, 2017; Thomas, 2017; RIVM, 2013)
- Additive to coatings for magnet wires that are used in the manufacturing of motors, generators, and transformers (RIVM, 2013)
- Component of photoresist stripper formulations (Isaacs, 2017; RIVM, 2013)
- Component of solder mask remover formulations for printed circuit boards (Roberts, 2017)

NMP is used as a solvent in lithium battery manufacturing (Mitsubishi Chemical, 2017). Specifically, NMP is used as a carrier for binder resins used to adhere electrolytic cells to the battery (Roberts, 2017; Argonne National Laboratory, 2015; RIVM, 2013). In a public comment submitted to the EPA NMP risk evaluation docket, one company indicated that NMP is first mixed with powder chemicals, binders, and other substrates, then the solution is coated onto thin metal foils with a precise automated roll coating process (Roberts, 2017). EPA found information that NMP may also be used as an additive in electrolytes and in coatings used on the outside of batteries (RIVM, 2013).

NMP is used for the cleaning and stripping of silicon wafers to prepare the wafer surfaces for application of photoresist and other coating formulations (Mitsubishi Chemical, 2017; NIH, 2017; RIVM, 2013). NMP may be used to clean other electronic parts (U.S. EPA, 1998). NMP also functions as an ingredient for wafer coatings, including polyimides and anti-reflective coatings (RIVM, 2013).

NMP may be used as a thinner in photoresist formulations (Mitsubishi Chemical, 2017) and as a carrier for other coatings (U.S. EPA, 1998). A public comment to the NMP risk evaluation docket from Elantas Electrical Insulation indicates NMP is present in residual quantities in electrical insulating films (Thomas, 2017). EPA did not find additional information on the cleaning of electronic parts or the applications of the described coatings but expects that the processes occur under well-controlled conditions, as is customary for the electronics industry.

NMP is also used in coatings for magnet wires (RIVM, 2013). Specifically, NMP is an additive in polymeric coatings that are used to coat magnet wires, often to give them thermal and solvent resistance. The coating containing NMP is applied to the magnet wires by dipping, rolling, or pouring the coating onto the wires, which are then heated, thereby allowing the coating to cure onto the wire. NMP is evaporated from the coating during the curing process such that it is not likely present in the final coated magnet wires. The RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013) indicates that NMP is used particularly for magnet wires that require high quality coatings or coatings that are cured at relatively high temperatures. The magnet wires are used in the manufacturing of products such as motors, generators, and transformers.

NMP is used to strip photoresist resins from wafer surfaces (Roberts, 2017; U.S. EPA, 1998). The NMP Producers Group, Inc. provided information on the photoresist stripping process, stating that the process can be batch or continuous and is controlled within a closed system equipped with exhaust ventilation (Roberts, 2017). NMP is used at up to 100 percent concentration and is heated up to 85°F for use in the stripping process. During stripping, the NMP solution dissolves any photoresist remaining on the surfaces of the wafers after developing and etching (OECD, 2010b). Waste NMP containing the photoresist that was removed from the wafers is either treated on-site or disposed off-site as hazardous waste (Roberts, 2017).

The NMP Producers Group, Inc. also indicated that NMP is used to remove solder mask from circuit boards (Roberts, 2017). NMP is used at up to 99.9 percent purity in an open-topped tank equipped with ventilation. The NMP can either be used at ambient temperature or heated up to 180°F. Waste NMP containing the removed solder mask is either treated on-site or disposed off-site as hazardous waste.

EPA did not find exposure data to differentiate the processes described above. EPA collectively refers to these operations as electronic parts manufacturing in the remainder of this section.

2.8.2 Exposure Assessment

2.8.2.1 Worker Activities

During this scenario, workers are potentially exposed while unloading NMP from containers and charging it into equipment. If containers are not manually unloaded by workers, workers may still be potentially exposed when connecting and disconnecting transfer hoses between the containers and equipment. Workers may also be potentially exposed during dilution, mixing, or sampling of solutions containing NMP, if these processes occur (Saft, 2017b; RIVM, 2013). All these activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

As described in Section 2.8, NMP may be used at elevated temperatures, which may increase the generation of NMP vapors and potential worker inhalation exposures. However, the processes in which heated NMP is used, as well as many other processes within the electronics industries, are frequently totally or partially enclosed and equipped with ventilation that reduces the potential for worker exposures (Saft, 2017b; Isaacs, 2017; Roberts, 2017; RIVM, 2013).

A battery manufacturing company that submitted a public comment to the NMP risk evaluation docket indicated that workers use face shields, gloves, and chemical resistant clothing (Saft, 2017b). The NMP Producers Group, Inc. also indicated in a public comment that worker exposures in the electronics industries are controlled through the use of the appropriate PPE (Roberts, 2017).

The 2010 ESD on the Use of Photoresist in Semiconductor Manufacturing and a public comment from the Semiconductor Industry Association (SIA) indicate that workers in the semiconductor manufacturing industry are typically required to wear full-body chemical-resistant clothing with face shields, chemical-resistant gloves, goggles, and respirators, as needed, inside production areas, including the areas where photoresist supply containers and waste disposal lines are connected to the equipment (Isaacs, 2017; OECD, 2010b).

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.8.2.2 Number of Potentially Exposed Workers

Based on the processes described in Section 2.8, NMP is used primarily in the computer and electronic product manufacturing sector, which are included in NAICS codes starting with 334, and the electrical equipment, appliance, and component manufacturing sector, which are included in NAICS codes starting with 335. In addition to these NAICS codes, EPA expects that NMP may be used in similar capacities within other electronics manufacturing industries. A public comment submitted to the NMP risk evaluation docket from the Aerospace Industries Association (AIA) indicates NMP is used for electronics manufacturing for the aerospace industry (Riegle, 2017). EPA compiled the identified NAICS codes for these industries in Table 2-39. The number of workers associated with each industry were identified using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP and the number of employees within an establishment exposed to NMP are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP in electronics manufacturing. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP in the electronics manufacturing industries.

Table 2-39. US Number of Establishments and Employees for Electronic Parts Manufacturing

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site[a]	Number of ONUs per Site[a]
Computer and Electronic Product	3341	Computer and Peripheral Equipment Manufacturing	1,091	12 [b]	12
	3342	Communications Equipment Manufacturing	1,369	13	14
	3343	Audio and Video Equipment Manufacturing	486	6 [b]	6

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site[a]	Number of ONUs per Site[a]
Manufacturing	3344	Semiconductor and Other Electronic Component Manufacturing	3,979	30	27
	3345	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing	5,231	17	18
	3356	Manufacturing and Reproducing Magnetic and Optical Media	521	6 [b]	6
Electrical Equipment, Appliance, and Component Manufacturing	3351	Electric Lighting Equipment Manufacturing	1,104	17	5
	3352	Household Appliance Manufacturing	303	102	20
	3353	Electrical Equipment Manufacturing	2,124	28	12
	3359	Other Electrical Equipment and Component Manufacturing	2,140	23	8
Other Miscellaneous Technologies	3364	Aerospace Product and Parts Manufacturing	1,811	75	64
	3391	Medical Equipment and Supplies Manufacturing	10,767	11	4
Total number of establishments, workers, and ONUs potentially exposed [c]			***31,000***	***660,000***	***450,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest whole number.
b – No 2016 BLS data was available for this NAICS. Number of relevant workers per site and ONUs per site within this NAICS were calculated using the ratios of relevant workers and ONUs to the number of total employees at the 3-digit NAICS level.
c – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.8.2.3 Occupational Exposure Assessment Methodology

2.8.2.3.1 Inhalation

Appendix A.8 summarizes the inhalation monitoring data for use of NMP in the electronics manufacturing industry. As previously indicated, electronic parts manufacturing in this scenario covers the use of NMP for battery manufacturing, cleaning of electronic parts, coating of electronic parts, including magnet wire coatings, and photoresist and solder mask stripping.

However, EPA only found inhalation monitoring data for the use of NMP in semiconductor manufacturing. Specifically, EPA uses data received from the European Semiconductor Industry Association (SIA), which include full-shift personal breathing zone sampling results at semiconductor fabrication facilities during container handling of both small containers and drums, workers inside the fabrication rooms, maintenance workers, workers that unload trucks containing virgin NMP (100%), and workers that load trucks with waste NMP (92%) (SIA, 2019a). While operations for the various types of electronics manufacturing that are included in this scenario may vary, EPA expects these data from SIA are representative of the operating conditions expected at electronic parts manufacturing facilities, due to the use of similarly controlled operations.

The available monitoring data was summarized into the PBPK modeling full-shift input parameters in Table 2-40. The majority (96% of all samples) of samples in SIA were non-detect for NMP (SIA, 2019a). Because the geometric standard deviation of the data set is greater than three, EPA used the limit of detection (LOD) divided by two to calculate central tendency and high-end values where samples were non-detect for NMP (EPA, 1994). Due to the high amount of non-detect results, this method may result in bias. This is further described in Appendix A.8. The SIA data included samples of both 8-hour TWA and 12-hour TWA values, with the majority of the data being 12-hour TWA. EPA used the 12-hour TWA values to assess occupational exposures in this scenario, as there is more data available for this exposure duration, indicating that typical shifts in this industry are 12 hours. Note, however, that the single data points available for the last two tasks in Table 2-40 are 8-hour TWA values.

These data also include area monitoring data in the fabrication area, which are summarized in Table 2-41. EPA cannot distinguish ONU exposures from worker exposures from the data in Table 2-40 and Table 2-41. EPA used the data in Table 2-40 for inhalation exposure inputs to the PBPK model, as described in Section 2.8.3.

Table 2-40. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Electronic Parts Manufacturing

Work Activity [a]	Parameter Characterization	Full-Shift NMP Air Concentration	Duration-Based NMP Air Concentration	Source	Data Quality Rating
		(mg/m^3, 12-hour TWA)	(mg/m^3)		
Container handling, small containers	Central tendency (50th percentile)	0.507	No data	(SIA, 2019a)	High
	High-end (95th percentile)	0.608	No data		
Container handling, drums	Central tendency (50th percentile)	0.013	No data		
	High-end (95th percentile)	1.54	No data		
Fab worker	Central tendency (50th percentile)	0.138	No data		
	High-end (95th percentile)	0.405	No data		
Maintenance	Central tendency (50th percentile)	0.020	No data		
	High-end (95th percentile)	0.690	No data		
Virgin NMP truck unloading	Single value	4.78 [b]	No data		
Waste truck loading	Single value	0.709 [b]	No data		

a – Electronic parts manufacturing includes the use of NMP for battery manufacturing, cleaning of electronic parts, coating of electronic parts, including magnet wire coatings, and photoresist and solder mask stripping.
b – These are 8-hour TWA values.

Table 2-41. Summary of Area Monitoring During Electronic Parts Manufacturing

Work Activity [a]	Parameter Characterization	NMP Exposure Concentration (mg/m³, 8-hr TWA)	Duration-Based NMP Air Concentration (mg/m³)	Source	Data Quality Rating
Fab area	Central tendency	0.162	No data	(SIA, 2019a)	High
	High-end	0.284	No data		

a – Electronic parts manufacturing includes the use of NMP for battery manufacturing, cleaning of electronic parts, coating of electronic parts, including magnet wire coatings, and photoresist and solder mask stripping.

2.8.2.3.2 Dermal

Table 2-42 summarizes the parameters used to assess dermal exposure during use of NMP in the electronics industries. EPA assumed that the skin was exposed dermally to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

NMP Weight Fraction

The SIA monitoring data included some NMP concentration data for the products associated with the inhalation monitoring samples. These data have an overall confidence rating of high. Where this data was available, EPA calculated the 50th percentile and 95th percentile NMP concentration for use as the central tendency and high-end NMP concentrations, on a per task basis. Where the SIA data did not include NMP concentrations data, EPA used NMP concentrations determined from literature as described below. These concentrations are summarized in Table 2-42.

EPA identified multiple products and sources containing data on the concentration of NMP used in the electronics industry. The 2017 market profile on NMP and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document identified electronics products with NMP concentrations ranging from less than one up to 100 weight percent NMP (Abt, 2017; U.S. EPA, 2017b). The NMP Producers Group, Inc. submitted a public comment to the NMP risk evaluation docket that indicates NMP is used up to 100 percent purity in photoresist removers and up to 99.9 percent purity in a remover solution for solder mask from printed circuit boards (Roberts, 2017). These data have an overall confidence rating of high. Based on this information, EPA calculated typical (50th percentile) and worst-case (95th percentile) weight percent of NMP to be 15and 99.9, respectively. Note that, where NMP concentration was provided in a range, EPA used the midpoint of the range for the calculations of typical and worst-case NMP concentration.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. The PPE information described in Section 2.8.2.1 indicates that workers in these industries are likely to wear gloves. This information indicates workers likely wear chemical-resistant gloves (Isaacs, 2017; OECD, 2010b). In addition, due to the highly controlled nature of certain electronics manufacturing operations, EPA expects employees to have at least basic training on glove usage. Thus, EPA assesses a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3 for both the central tendency and high-end scenarios for this scenario. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA uses the maximum shift duration for the high-end and the mid-point of the shift duration for the central tendency. As described in the previous section, the container handling, fab worker, and maintenance tasks are performed by workers on a 12-hour shift. The high-end and central tendency for these tasks are 12 hours and 6 hours, respectively. The virgin NMP truck unloading and waste NMP truck loading tasks are performed by workers on a 8-hour shift. The high-end and central tendency for these tasks are 8 hours and 4 hours, respectively.

Table 2-42. Summary of Parameters for Worker Dermal Exposure During Electronic Parts Manufacturing

Work Activity [a]	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [b]	Exposure Duration	Body Weight [b]
			Unitless	cm^2	hr/day	kg
Container handling, small containers	Central Tendency	10	0.6	445 (f) 535 (m)	6	74 (f) 88 (m)
	High-End	10	0.75	890 (f) 1,070 (m)	12	
Container handling, drums	Central Tendency	10	0.5	445 (f) 535 (m)	6	74 (f) 88 (m)
	High-End	10	0.75	890 (f) 1,070 (m)	12	
Fab worker	Central Tendency	10	0.15	445 (f) 535 (m)	6	74 (f) 88 (m)
	High-End	10	0.999	890 (f) 1,070 (m)	12	
Maintenance	Central Tendency	10	0.55	445 (f) 535 (m)	6	74 (f) 88 (m)
	High-End	10	1	890 (f) 1,070 (m)	12	
Virgin NMP truck unloading	Central Tendency	10	1	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	10	1	890 (f) 1,070 (m)	8	
Waste truck loading	Central Tendency	10	0.92	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	10	0.92	890 (f) 1,070 (m)	8	

[a] Electronic parts manufacturing includes the use of NMP for battery manufacturing, cleaning of electronic parts, coating of electronic parts, including magnet wire coatings, and photoresist and solder mask stripping.
[b] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.8.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-43.

The numeric parameters corresponding to the characterizations presented in Table 2-43 are summarized in Table 2-44. These are the inputs used in the PBPK model.

Table 2-43. Characterization of PBPK Model Input Parameters for Electronic Parts Manufacturing

Scenario	Work Activity [a]	Air Concentration Data Characterization [b]	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	All activities	Central tendency (50th percentile)	Mid-point of shift duration	1-hand	Yes	Central tendency
High-end	All activities	High-end (95th percentile)	High-end of shift duration	2-hand	Yes	High-end

[a] Electronic parts manufacturing includes the use of NMP for battery manufacturing, cleaning of electronic parts, coating of electronic parts, including magnet wire coatings, and photoresist and solder mask stripping.
[b] Only a single estimate was available for virgin NMP truck unloading and waste truck loading. This single air concentration value was used with both central tendency and high-end duration and dermal parameters.

Table 2-44. PBPK Model Input Parameters for Electronic Parts Manufacturing

Activity	Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Container handling, small containers	Central tendency	N/A	6	445 (f) 535 (m)	10	0.6	74 (f) 88 (m)
	High-end	N/A	12	890 (f) 1,070 (m)	10	0.75	74 (f) 88 (m)
Container handling, drums	Central tendency	N/A	6	445 (f) 535 (m)	10	0.5	74 (f) 88 (m)
	High-end	N/A	12	890 (f) 1,070 (m)	10	0.75	74 (f) 88 (m)
Fab Worker	Central tendency	N/A	6	445 (f) 535 (m)	10	0.15	74 (f) 88 (m)
	High-end	N/A	12	890 (f) 1,070 (m)	10	0.999	74 (f) 88 (m)
Maintenance	Central tendency	N/A	6	445 (f) 535 (m)	10	0.55	74 (f) 88 (m)
	High-end	N/A	12	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)
Virgin NMP truck unloading	Inhalation - Single value; Dermal – Central tendency	N/A	4	445 (f) 535 (m)	10	1	74 (f) 88 (m)
	Inhalation - Single value; Dermal – High-end	N/A	8	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)
Waste truck loading	Inhalation - Single value; Dermal –	N/A	4	445 (f) 535 (m)	10	0.92	74 (f) 88 (m)

Activity	Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
	Central tendency						
	Inhalation - Single value; Dermal – High-end	N/A	8	890 (f) 1,070 (m)	10	0.92	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.8.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.9 Printing and Writing

2.9.1 Process Description

There are multiple types of printing technologies, including lithography, rotogravure, flexography, screen, letterpress, and digital, which encompasses electrophotography and inkjet printing. Facilities tend to employ one type of printing process exclusively, although some of the larger facilities may use two or more types. Solvents are used in inks as carriers for colorants and allow the colorants to bind to the substrate after drying (OECD, 2010c). Solvents also modify the viscosity of the inks, allowing them to be more easily applied to substrates. Hawley's Condensed Chemical Dictionary indicates that NMP specifically can be used as a pigment dispersant in printing formulations (Larranaga et al., 2016).

The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and a public comment submitted to the NMP risk evaluation docket identify three inks, ranging from one to 10 weight percent NMP, that are used in inkjet printing (Gerber, 2017; U.S. EPA, 2017b). The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and 2017 market profile for NMP identify two additional ink products that are both less than five weight percent NMP and have unspecified printing application methods (Abt, 2017; U.S. EPA, 2017b). The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document additionally states that NMP is expected to be used in lithography and screen printing but did not identify products that specify this type of printing method (U.S. EPA, 2017b).

The fundamental steps in printing are referred to as imaging/film processing, image carrier preparation, printing, and post-press operations. Printing processes also include cleanup operations, that may occur continuously during the print run or between runs. The 2010 Draft Scoping Document for an ESD on the Manufacture and Use of Printing Inks provides information on the various types of printing processes (OECD, 2010c).

During lithography, an image is transferred from a plate onto paper or another substrate. The image area on printing plates is treated to absorb an oil-based ink in the image areas and to absorb only water in the non-image areas (OECD, 2010c). At the printing facility, ink is loaded into the printing machine and transferred from the plate to the ink rollers and ultimately onto the paper. Depending on the final printed product, additional roller units may be used to add various colors and layers to the printed image.

During screen printing, an image is transferred to a substrate through a porous mesh (OECD, 2010c). The mesh is stretched over a frame and a stencil is applied to the mesh to define the image. Ink is applied to the mesh and pressure is applied to the ink to force it through the mesh and onto the substrate.

Inkjet printing is the most common method used in digital printing (OECD, 2010c). A digital image is created on a computer and then transferred onto the substrate with a digital printing press. Small drops of ink are applied to the substrate from a printing press nozzle by first passing the ink drops through an electrostatic field and then deflecting the charged drops from a oppositely charge printing plate onto the substrate. Several types of inks can be used for digital printing, including solid ink, wet/dry toner systems, and liquid ink.

The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and 2017 market profile for NMP additionally identify one commercial and consumer product in which NMP is used in the ink within a marker at 10 to 20 weight percent NMP (Abt, 2017; U.S. EPA, 2017b). The safety datasheet (SDS) for this product lists the product use as "weather-resistant marker for polyurethane tags" (http://www.markal.com/assets/1/7/aw_plastic_eartag_white_medtip.pdf).

2.9.2 Exposure Assessment

2.9.2.1 Worker Activities

Workers are potentially exposed to NMP during multiple activities involved in printing operations, including unloading volatile inks, transferring inks into printing equipment, operating the printing process, and subsequent cleaning and maintenance activities. These activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP mists and vapors.

EPA did not identify information on the use of engineering controls and worker PPE in the printing industry. NIOSH conducted a health hazard evaluation (HHE) at a newspaper printing facility and found that workers may wear hearing protection and gloves, but do not always do so (Belanger and Coye, 1983).

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the printing areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.9.2.2 Number of Potentially Exposed Workers

This section identifies worker population estimates for use of NMP-based printing inks. Application of these products are expected to fall within the NAICS group 323, Printing and Related Support Activities. EPA compiled the 6-digit NAICS codes for each industry within this group in Table 2-45. NAICS 323111, Commercial Printing (except Screen and Books), captures businesses that perform lithographic, gravure, flexographic, letterpress, engraving, and digital printing. NAICS 323113, Commercial Screen Printing, capture screen printing activities. NAICS 323117 and 323120 capture printing of books and support activities for printing, respectively. As discussed in Section 2.10, EPA identified one marker containing NMP, which is a commercial and consumer product. EPA does not know if this marker is specifically used in certain industries and does not have a way of estimating the number of commercial workers that use and are potentially exposed to these markers.

The number of workers associated with each identified industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based printing inks and the number of employees within an establishment exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based printing inks. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during printing activities.

Table 2-45. US Number of Establishments and Employees for Printing and Writing

2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers per Site [a]	Number of ONUs per Site [a]
323111	Commercial Printing (except Screen and Books)	18,687	2	1
323113	Commercial Screen Printing	4,956	1	1
323117	Books Printing	447	6	3
323120	Support Activities for Printing	1,598	2	1
Total establishments and number of potentially exposed workers and ONUs = [b]		***26,000***	***53,000***	***25,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest whole number.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.9.2.3 Occupational Exposure Assessment Methodology

2.9.2.3.1 Inhalation

Appendix A.9 summarizes methodology for determining potential worker inhalation exposure concentrations. EPA did not find personal breathing zone monitoring data for the use of NMP-based printing inks. As surrogate for personal breathing zone monitoring data for printing activities, EPA used ink mist concentration data from a NIOSH Health Hazard Evaluation at a newspaper printing shop, with assumed NMP concentrations, to assess potential inhalation exposures in this scenario (Belanger and Coye, 1983). Of the available data, this surrogate data has the highest quality; thus, EPA uses this data to assess exposure for this use.

In addition, EPA did not find inhalation monitoring data for the use of writing utensils containing NMP. EPA does not assess potential inhalation exposures during the use of NMP-based writing inks based on information indicating these exposures may be negligible from a NICNAS assessment (Australian Government Department of Health, 2016) and the likely outdoor use of the one writing product that was identified (weather-resistant marker). See Appendix A.9 for additional rationale.

The monitoring data presented in Table 2-46 are the input parameters used for the PBPK modeling. EPA compiled 4-hour exposure concentration data that can be correlated to the associated dermal exposure durations in Table 2-47.

Table 2-46. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Printing and Writing

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m³, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m³)	Source	Data Quality Rating
Printing	Central tendency (50th percentile)	0.018	0.016 (duration = 4 hr)	(Belanger and Coye, 1983)	Medium
	High-end (95th percentile)	0.172	0.042 (duration = 4 hr)		
Writing	Not assessed				

2.9.2.3.2 Dermal

Table 2-47 summarizes the parameters used to assess dermal exposure during printing and writing activities. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below.

NMP Weight Fraction

The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b), a public comment submitted to the NMP risk evaluation docket (Gerber, 2017), and the 2017 market profile on NMP (Abt, 2017) identify the following printing products:

- Two inkjet inks, each less than five weight percent NMP;
- Inkjet ink, one to five weight percent NMP;
- Inkjet ink, five to 10 weight percent NMP;
- High performance silver ink, up to five weight percent NMP; and
- Unspecified printing ink, less than five weight percent NMP.

Based on these data, for printing activities, EPA assumes a typical (50th percentile) of five weight percent NMP and a worst-case (95th percentile) weight fraction of 7 percent NMP in printing inks. For use of NMP in writing utensils, the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) and 2017 market profile on NMP (Abt, 2017) identified one marker containing NMP at 10 to 20 weight percent. No other writing products containing NMP were identified. Thus, EPA assumes a low-end composition of 10 weight percent NMP and a high-end composition of 20 weight percent NMP.

Skin Surface Area and Glove Usage

For printing, as described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. However, for writing, EPA does not expect that workers get writing inks on a significant portion of their hands. Thus, based on information from a NICNAS assessment on potential consumer exposures to writing inks, EPA assesses that 1 cm^2 of skin surface area may be exposed to writing inks (Australian Government Department of Health, 2016), for both females and males.

The PPE information described in Section 2.9.2.1 indicates that workers may or may not wear gloves during printing activities. Additionally, EPA does not expect that workers wear gloves during use of markers and other writing utensils that use inks containing NMP. Thus, EPA assesses that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the likely commercial nature of these uses, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

For printing activities, EPA identified monitoring data in Appendix A.9 that identifies worker inhalation exposure data that range in duration from 4 hr/day up to 8 hr/day. Thus, for the central tendency scenario, EPA assumes that incidental exposure can occur at such a frequency that the dermal exposure duration is 4 hours. For the high-end exposure scenario, EPA assumes that incidental exposures can occur at such a frequency that the dermal exposure duration is over an entire shift of 8 hours.

For writing, as EPA assumed one dermal contact event as low-end exposure scenario. Thus, the exposure duration is assumed to be the approximate time for evaporation of NMP from skin, or half an hour. EPA does not assess duration of exposure during writing exceeding this time.

Table 2-47. Summary of Parameters for Worker Dermal Exposure to Liquids During Printing and Writing

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Printing	Central Tendency	5	0.05	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.07	890 (f) 1,070 (m)	8	
Writing	Central Tendency	5	0.1	1 [b]	0.5	74 (f) 88 (m)
	High-End	1	0.2	1 [b]	0.5	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] This surface area was assumed based on (Australian Government Department of Health, 2016).

2.9.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-48.

The numeric parameters corresponding to the characterizations presented in Table 2-48 are summarized in Table 2-49. These are the inputs used in the PBPK model.

Table 2-48. Characterization of PBPK Model Input Parameters for Printing and Writing

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Printing	Central tendency (50th percentile)	Based on 4-hour TWA data	1-hand	Yes	Central Tendency
High-end	Printing	High-end (95th percentile)	Based on 8-hour TWA data	2-hand	No	High-end
Central Tendency	Writing	Inhalation Exposure Not Assessed	Based on one contact event	1 cm^2	Yes	Central Tendency
High-end	Writing	Inhalation Exposure Not Assessed	Based on one contact event	1 cm^2	No	High-end

Table 2-49. PBPK Model Input Parameters for Printing and Writing

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Printing	0.016	4	445 (f) 535 (m)	5	0.05	74 (f) 88 (m)
High-end	Printing	0.172	8	890 (f) 1,070 (m)	1	0.07	74 (f) 88 (m)
Central Tendency	Writing	0	0.5	1	5	0.1	74 (f) 88 (m)
High-end	Writing	0	0.5	1	1	0.2	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.9.4 Summary

In summary, dermal exposure and inhalation are expected for use of NMP in printing. Only dermal exposure is expected for use of NMP in writing activities. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.10 Soldering

2.10.1 Process Description

The 2017 market profile for NMP and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document identifies one soldering flux product with an NMP concentration ranging from 1.0 to 2.5 weight percent, used in professional applications (Abt, 2017; U.S. EPA, 2017b).

The North America's Building Trades Unions (NABTU) submitted a public comment to the NMP risk evaluation docket that indicates solder materials containing NMP may be used in the construction industry, including in plumbing work (NABTU, 2017). The RIVM *Annex XV Proposal for a Restriction - NMP* report indicates that the Finnish product registry identified around four NMP-based welding and soldering products, the composition and industries of application of which are unknown (RIVM, 2013).

Soldering is a process in which two or more substrates, or parts (usually metal), are joined together by melting a filler metal material (solder) into the joint and allowing it to cool, thereby joining the independent parts. The solder has a lower melting point than the adjoining metal substrates. Soldering differs from welding in that soldering does not involve melting the work pieces. Solder (or soldering flux) is applied to the metal substrates in a variety of methods. The manufacturer and distributor of the solder flux containing NMP that was described above indicates the soldering flux formula is designed to be used (dispensed) with a rotating disc, a doctor blade, or a drum fluxer (https://www.kester.com/products/product/tsf-6522). This product may also be dispensed with a syringe or a dot dispensing system.

2.10.2 Exposure Assessment

2.10.2.1 Worker Activities

Workers are potentially exposed to NMP in soldering formulations during the application of solder flux onto the substrate to be soldered. This activity is a potential source of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors. Workers are also potentially exposed to NMP vapors during the soldering process, which occurs at an elevated temperature, increasing the potential for NMP vapor production and associated worker inhalation exposure potential.

EPA did not find information regarding the use of engineering controls or worker PPE during the use of NMP-based soldering products. The safety datasheet (SDS) for the soldering product identified above recommends the use of nitrile or natural rubber gloves and safety glasses with side shields (http://www.kester.com/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=1169&language=en-US&PortalId=0&TabId=96). The SDS also indicates that respiratory protection is not needed if the room is well ventilated.

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.10.2.2 Number of Potentially Exposed Workers

As discussed in Section 2.10, soldering products containing NMP may be used in the construction industry, which is covered within the 2-digit NAICS group 23, construction. Within this NAICS group, EPA identified the 4-digit NAICS groups that are most likely to perform soldering activities. EPA compiled these identified NAICS codes in Table 2-50. EPA determined the number of workers associated with each industry identified using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based soldering products and the number of employees within an establishment exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based soldering products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during soldering.

Table 2-50. US Number of Establishments and Employees for Soldering

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site [a]	Number of ONUs per Site [b]
Construction	2361	Residential Building Construction	164,519	3	1
	2362	Nonresidential Building Construction	41,767	11	1
	2371	Utility System Construction	19,585	21	2
	2373	Highway, Street, and Bridge Construction	9,804	20	2
	2379	Other Heavy and Civil Engineering Construction	4,331	15	1
	2381	Foundation, Structure, and Building Exterior Contractors	87,703	7	1
	2382	Building Equipment Contractors	176,142	8	1
	2389	Other Specialty Trade Contractors	66,339	6	1
Total number of establishments, workers, and ONUs potentially exposed [c]			***570,000***	***4,000,000***	***380,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
[a] Rounded to the nearest worker. No 2016 BLS data found for this NAICS. EPA determined number of workers per site by dividing the total number of employees by the total number of establishments from the available SUSB data for the 2-digit NAICS group.
[b] Rounded to the nearest worker. No 2016 BLS data found for this NAICS. EPA determined number of ONUs per site by dividing the total number of employees by the total number of establishments from the available SUSB data for the 2-digit NAICS group.
[c] Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.10.2.3 Occupational Exposure Assessment Methodology

2.10.2.3.1 Inhalation

Appendix A.10 summarizes the inhalation monitoring data for NMP-based soldering that EPA compiled from published literature sources. While the identified monitoring data may be potentially relevant to this scenario, EPA did not find information on the specific worker activity descriptions that correlate to these exposure concentrations. Due to this lack of information, EPA excludes the data presented in Appendix A.10, as EPA cannot determine with confidence that these data relate to soldering activities.

Due to the low NMP content in the one identified soldering production containing NMP (one to 2.5 weight percent NMP), the potential for worker and ONU inhalation exposures is likely small. In addition, some of the NMP may be destroyed in the soldering process, further mitigating the potential for inhalation exposures. Thus, EPA does not assess potential inhalation exposures during soldering.

2.10.2.3.2 Dermal

Table 2-51 summarizes the parameters used to assess dermal exposure during the use of soldering products containing NMP. EPA assessed dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

NMP Weight Fraction

The 2017 market profile for NMP (Abt, 2017) and the 2017 document on the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) identified one soldering product containing NMP at a concentration of one to 2.5 weight percent. Due to lack of additional information, EPA assesses a low-end concentration of one percent and a high-end concentration of 2.5 percent.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. EPA did not find information on the use of gloves. Thus, EPA assesses that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the commercial nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-51. Summary of Parameters for Worker Dermal Exposure During Soldering

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Soldering	Central Tendency	5	0.01	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.025	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.10.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-52.

The numeric parameters corresponding to the characterizations presented in Table 2-52 are summarized in Table 2-53. These are the inputs used in the PBPK model.

Table 2-52. Characterization of PBPK Model Input Parameters for Soldering

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Soldering	Inhalation Exposure Not Assessed	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Soldering	Inhalation Exposure Not Assessed	Assumed 8 hours	2-hand	No	High-end

Table 2-53. PBPK Model Input Parameters for Soldering

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	0	4	445 (f) 535 (m)	5	0.01	74 (f) 88 (m)
High-end	0	8	890 (f) 1,070 (m)	1	0.025	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.10.4 Summary

In summary, only dermal exposure is expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.11 Commercial Automotive Servicing

2.11.1 Process Description

NMP is used in a variety of automotive service operations. The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b), 2017 market profile for NMP (Abt, 2017), and the 2017 Scope of the Risk Evaluation for NMP (U.S. EPA, 2017c) identified multiple automotive servicing products that contain NMP. These products and the associated methods of use are described further in this section.

The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and 2017 market profile for NMP identified two sealants, with concentrations of less than one weight percent and 0.1 to one weight percent, respectively (Abt, 2017; U.S. EPA, 2017b). One sealant is a paste and is thus likely to be manually applied from the package in discrete quantities or using a trowel or other tool. The other sealant is an aerosol leak sealer that could potentially be used in the automotive servicing industry. EPA does not have any additional data on these products or potential worker exposures during the use of these products. Due to a lack of specific information for this scenario, EPA does not assess potential exposures during the manual application of paste sealant. EPA assessed potential exposures during manual brush or roller application of a paste in Section 2.14.3 on Wood

Preservatives, which EPA expects to be the most representative of potential exposures during application of paste sealants based on the available information.

The "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and 2017 market profile for NMP identified multiple automotive cleaning products, including three leather cleaners that contain from 0.1 to four weight percent of NMP, one air intake cleaner that contains 15 to 40 weight percent NMP, and one automotive headlight cleaner that contains 0.2 weight percent NMP (Abt, 2017; U.S. EPA, 2017b). The product details do not specify the methods of application. EPA expects the most applicable methods of application for these products to be spray then wiping or polishing and aerosol cleaning. EPA assessed potential exposures during spray / wipe cleaning in Section 2.10, thus does not reassess these exposures in this scenario because EPA did not find additional monitoring data specific to automotive cleaning.

In addition to the products listed above, the Scope of Risk Evaluation of NMP, which refers to 2016 CDR results as well as public comments on the NMP docket, indicates that NMP is used in the following automotive products: paints / coatings / adhesives, strippers, anti-freeze and de-icing products, and lubricants (MacRoy, 2017; U.S. EPA, 2017c). EPA assessed application of paints, coating, and adhesives in Section 2.5 and paint stripping in Section 2.6; EPA did not assess these exposures in this scenario because no new information was found that would result in differing exposure estimates from those already assessed.

EPA expects that some of the above products may be used as aerosols. Additionally, the California Air Resources Board (CARB) surveyed automotive brake cleaner manufacturers and automotive repairs shops as part of a rulemaking to mitigate air releases of certain chlorinated solvents used in aerosol cleaning products by automotive maintenance and repair shops (CARB, 2000). CARB's survey of automotive maintenance and repair shops included a compilation of safety data sheets of brake cleaners, carburetor and air intake cleaners, engine degreasers, and general purpose degreasers used in California at the time of the survey. NMP was identified as a component of unspecified formulations in this survey. Thus, it is feasible that NMP is used in aerosol applications during automotive servicing.

Aerosol activities typically involve the application of a solution from pressurized cans or bottles that use propellant to aerosolize the solution, allowing it to be sprayed onto substrates. Based on identified safety data sheets (SDS) for cleaning products, NMP-based formulations typically use liquified petroleum gas (LPG) (i.e., propane and butane) as the propellant (Abt, 2017; U.S. EPA, 2017b).

EPA did not assess aerosol exposures in other conditions of use; thus, EPA presents potential exposures for the use of aerosols in this scenario.

2.11.2 Exposure Assessment

2.11.2.1 Worker Activities

Workers may be potentially exposed to NMP during multiple activities involved in automotive servicing, including the application of cleaning, lubricant, and other servicing formulations onto car parts, as well as any subsequent wiping, polishing, or maintenance activities that occur once the formulation has been applied to the car parts. These activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP mists and vapors.

EPA identified limited information on the use of PPE and engineering controls at automotive service sites. The Draft ESD on Chemical Additives used in Automotive Lubricants indicates that workers in automotive servicing shops are likely to wear disposable gloves and protective footwear (OECD, 2017). Workers may also use protective headwear when working in pits, under lifts, or hoisting machinery. The ESD did not identify typical PPE used but indicates that breathing protection may include dust masks or respirators, if workers are handling highly volatile substances.

ONUs include employees that work at the automotive servicing shops where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other mechanics that may be in the automotive servicing areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.11.2.2 Number of Potentially Exposed Workers

This section identifies worker population estimates for use of NMP-based automotive servicing formulations. Application of these products are expected to occur at automotive servicing shops, which fall within the NAICS group 8111, Automotive Repair and Maintenance. The 6-digit NAICS codes within this group include both automotive servicing and automotive body work. While EPA expects that the use of aerosols is largely within the automotive servicing sector, workers at automotive body shops may still be exposed to NMP in paints and sealants. Thus, EPA includes these NAICS in the worker estimates provided in this section.

Additionally, because EPA is including aerosol cleaning / degreasing within this scenario, EPA included industries beyond the automotive servicing sector that are expected to perform aerosol degreasing activities. Specifically, EPA identified additional industries in which aerosol degreasing may occur from the 2016 Risk Assessment on Spray Adhesives, Dry Cleaning, and Degreasing Uses of 1-BP (U.S. EPA, 2016c).

EPA compiled the associated NAICS codes for the identified industries in Table 2-54. The number of workers associated with each industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based aerosol products and the number of employees within an establishment exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based aerosol products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during use of aerosol products.

Table 2-54. US Number of Establishments and Employees for Commercial Automotive Servicing

Industry	2016 NAICS [a]	2016 NAICS Title	Number of Establishments	Number of Workers per Site [b]	Number of ONUs per Site [b]
Automotive Servicing	441110	Automobile Dealers	46,531	6	1
	811111	General Automotive Repair	80,243	2	0
	811112	Automotive Exhaust System Repair	1,907	2	0
	811113	Automotive Transmission Repair	4,684	2	0

Industry	2016 NAICS [a]	2016 NAICS Title	Number of Establishments	Number of Workers per Site [b]	Number of ONUs per Site [b]
	811118	Other Automotive Mechanical and Electrical Repair and Maintenance	3,839	2	0
	811121	Automotive Body, Paint, and Interior Repair and Maintenance	33,648	3	0
	811122	Automotive Glass Replacement Shops	6,106	2	0
	811191	Automotive Oil Change and Lubrication Shops	8,380	4	0
	811192	Car Washes	15,902	5	0
	811198	All Other Automotive Repair and Maintenance	4,140	2	0
Other Industries Conducting Aerosol Degreasing	811211	Consumer Electronics Repair and Maintenance	1,814	3	0
	811212	Computer and Office Machine Repair and Maintenance	5,195	4	0
	811213	Communication Equipment Repair and Maintenance	1,604	5	1
	811219	Other Electronic and Precision Equipment Repair and Maintenance	3,470	6	1
	811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance	21,721	5	1
	811411	Home and Garden Equipment Repair and Maintenance	1,735	1	1
	811490	Other Personal and Household Goods Repair and Maintenance	9,943	1	1
	451110	Sporting Goods Stores	21,890	1	0
Total establishments and number of potentially exposed workers and ONUs = [c]			**270,000**	**910,000**	**110,000**

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Source: (U.S. EPA, 2016c)
b – Rounded to the nearest whole number.
c – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.11.2.3 Occupational Exposure Assessment Methodology

2.11.2.3.1 Inhalation

EPA did not find monitoring data for the use of NMP products during automotive servicing. Because EPA did not find relevant monitoring data monitoring data for this use in the published literature, EPA used modeling estimates with the highest data quality to assess exposure for this use, as described below.

In lieu of monitoring data, EPA modeled potential occupational inhalation exposures for workers and ONUs using EPA's model for *Occupational Exposures during Aerosol Degreasing of Automotive Brakes*. This model uses a near-field/far-field approach, where an aerosol application located inside the near-field generates a mist of droplets, and indoor air movements lead to the convection of the droplets between the near-field and far-field. Workers are assumed to be exposed to NMP droplet concentrations in the near-field, while ONUs are exposed at concentrations in the far-field. This model involves probabilistic modeling. Appendix A.11 includes some background information on this model, EPA's rationale for using this model, and the model results.

The results of this modeling are summarized for workers in Table 2-55 and for ONUs in Table 2-56. This model calculates both 8-hour TWA and 1-hour TWA exposure concentrations. For workers, EPA uses the 50th and 95th percentile model results in Table 2-55 to represent central tendency and worst-case inhalation exposures, respectively. Consistent with the approach for other OESs, EPA uses the central tendency worker air concentration to evaluate ONU exposure and further refines this estimate using far-field modeling or applicable area monitoring data if needed due to risk. Refinement was not necessary for this OES.

Table 2-55. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Commercial Automotive Servicing

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m³, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m³)	Source	Data Quality Rating
Aerosol Degreasing	Central tendency (50th percentile)	6.39	19.96 (duration = 1 hr)	*Occupational Exposures during Aerosol Degreasing of Automotive Brakes Model*	Not applicable[a]
	High-end (95th percentile)	43.4	128.8 (duration = 1 hr)		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

Table 2-56. Summary of Occupational Non-User Inhalation Exposure During Commercial Automotive Servicing

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m³, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m³)	Source	Data Quality Rating
Aerosol Degreasing	Central Tendency	0.13	0.40 (duration = 1 hr)	*Occupational Exposures during Aerosol Degreasing of Automotive Brakes Model*	Not applicable[a]
	High-end	1.57	4.71 (duration = 1 hr)		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

2.11.2.3.2 Dermal

Table 2-57 summarizes the parameters used to assess dermal exposure during cleaning activities. EPA assumed that the skin was exposed dermally to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

<u>NMP Weight Fraction</u>

As discussed in Section 2.13.1.1, EPA identified two aerosol cleaning products containing NMP at concentrations of 4.5 weight percent and between 35 and 40 weight percent. EPA identified multiple additional automotive care products ranging in NMP concentration from 0.1 to 40 weight percent. Based on this information, EPA calculated typical (50th percentile) and worst-case (95th percentile) weight percent of NMP to be 2.5 and 33, respectively. Note that, where NMP concentration was provided in a range, EPA used the midpoint of the range for the calculations of typical and worst-case NMP concentration. The underlying data used for these estimates have an overall confidence rating of high.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. As described in Section 2.11.2.1, EPA did not find information on the typical usage of gloves in the automotive servicing industry. Due to the wide-spread use of NMP-based products in this scenario, EPA assumes that no gloves are used for the worst-case exposure scenario. Thus, EPA assesses that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the wide-spread nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

Based on EPA's model for *Occupational Exposures during Aerosol Degreasing of Automotive Brakes* described in Appendix A.11, EPA modeled worker inhalation exposure over 8 hr/day (based on a full shift) and 1 hr/day (based on the length of time for aerosol degreasing of one job).

Table 2-57. Summary of Parameters for Worker Dermal Exposure to Liquids During Commercial Automotive Servicing

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Commercial Automotive Servicing	Central Tendency	5	0.025	445 (f) 535 (m)	1	74 (f) 88 (m)
	High-End	1	0.33	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.11.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-58.

The numeric parameters corresponding to the characterizations presented in Table 2-58 are summarized in Table 2-59. These are the inputs used in the PBPK model.

Table 2-58. Characterization of PBPK Model Input Parameters for Commercial Automotive Servicing

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Aerosol degreasing	Central tendency (50th percentile)	Based on time for one job	1-hand	Yes	Central Tendency
High-end	Aerosol degreasing	High-end (95th percentile)	Assumed 8 hours	2-hand	No	High-end

Table 2-59. PBPK Model Input Parameters for Commercial Automotive Servicing

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Aerosol degreasing	19.96	1	445 (f) 535 (m)	5	0.025	74 (f) 88 (m)
High-end	Aerosol degreasing	43.4	8	890 (f) 1,070 (m)	1	0.33	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.11.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.12 Laboratory Use

2.12.1 Process Description

The 2017 Scope Document for the Risk Evaluation for NMP (U.S. EPA, 2017c) and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) both indicate that NMP is used in laboratories, but do not identify any specific products that are marketed for laboratory use. Additionally, no NMP-based laboratory chemicals were identified in the 2017 market profile on NMP (Abt, 2017).

EPA found limited information on the function of NMP in laboratory chemicals. The Scope Document (U.S. EPA, 2017c) identifies one public comment to the NMP risk evaluation from the Motor & Equipment Manufacturers Association (MEMA), which states that NMP is used as a carrier in chemical analyses for research and development within the automotive industry (Holmes, 2017). A health study published in the Journal of Occupational Medicine indicates NMP was used to dissolve solid samples, which were analyzed in atomic absorption spectrophotometers, and subsequently discarded as hazardous waste (Solomon et al., 1996). In this application, NMP was poured by the laboratory technician from 5-gallon containers through an ion exchange column for filtering before use.

Based on the information found, NMP is likely used in laboratories largely as a carrier chemical, which is a media in which samples are prepared for analysis. EPA did not find information indicating that NMP is used as a reagent, which is consumed to some extent in laboratory research activities.

2.12.2 Exposure Assessment

2.12.2.1 Worker Activities

Workers may be potentially exposed to NMP in laboratories during multiple activities, including unloading of NMP from the containers in which they were received, transferring NMP into laboratory equipment (i.e., beakers, flasks, other intermediate storage containers), dissolving substances into NMP or otherwise preparing samples that contain NMP, analyzing these samples, and discarding the samples. In addition, NMP may be used to clean glassware, which is likely done manually by workers. These activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

The RIVM *Annex XV Proposal for a Restriction - NMP* report assessed potential worker exposures to NMP during use in laboratories (RIVM, 2013). While this report does not have information from industries on the type of engineering controls and worker PPE employed, RIVM does consider the use of LEV in its assessment of potential worker exposures in laboratories. EPA expects that some laboratories may use fume hoods.

The health study report at a laboratory that uses NMP to dissolve solid photoresist for quality testing indicates that the lab uses LEV in some, but not all, areas within the lab (Solomon et al., 1996). The report also indicates that workers in the lab typically wear a lab coat, safety goggles, and latex gloves, and occasionally use a half-face air-purifying respirator.

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the laboratory but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.12.2.2 Number of Potentially Exposed Workers

EPA found limited information on the industries that use of NMP-based products in laboratories. The public comment to the NMP risk evaluation docket from the Motor & Equipment Manufacturers Association (MEMA) indicates that NMP is used for research and development within the automotive industry (Holmes, 2017).

Based on this information, EPA expects the NMP is used in professional laboratories and within the automotive manufacturing industry. The use of NMP for research and development in other industries is unknown. EPA compiled the associated NAICS codes for the identified industries in Table 2-60. The number of workers associated with each industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP and the number of employees within an establishment exposed to NMP are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP in a laboratory setting. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP in laboratories.

Table 2-60. US Number of Establishments and Employees for Laboratory Use

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site [a]	Number of ONUs per Site [a]
Automotive Research & Development	336100	Motor Vehicle Manufacturing	340	235	99
	336200	Motor Vehicle Body and Trailer Manufacturing	1,917	41	7
	336300	Motor Vehicle Parts Manufacturing	5,088	51	15
Professional Laboratories	541380	Testing Laboratories	6844	1	9
Total number of establishments, workers, and ONUs potentially exposed [b]			***14,000***	***420,000***	***180,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest worker. No 2016 BLS data found for this NAICS. EPA determined number of workers per site by dividing the total number of employees by the total number of establishments from SUSB data.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.12.2.3 Occupational Exposure Assessment Methodology

2.12.2.3.1 Inhalation

Appendix A.12 summarizes EPA's methodology for determining potential worker inhalation exposure concentrations during this scenario. EPA only found one data source that had inhalation monitoring data, representing the preparation of NMP for use in samples, sample preparation involving the dissolving of solids in NMP, and sample analysis. This sample result is used as input into the PBPK model for 2-hour exposure duration. EPA did not find additional monitoring data, thus used a modeled exposure for the use of NMP in a laboratory setting from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013) to represent 8-hour NMP exposure concentration. As the quality of both the monitoring and modeled data is acceptable, EPA used all available data to assess this scenario.

The monitoring data and modeled exposure summarized in Table 2-61 are the input parameters used for the PBPK modeling. Note that EPA assesses full-shift exposure duration and a 2-hour exposure duration based on the available monitoring data (Solomon et al., 1996) (two hours is the duration of the sampled task - sample preparation and analysis).

Table 2-61. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Laboratory Use

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Laboratory Use	Central tendency (unknown statistical characterization)	2.07	0.200 (duration = 2 hr)	(Solomon et al., 1996)	Medium

	High-end (unknown statistical characterization)	4.13	No data	(RIVM, 2013)	High

2.12.2.3.2 Dermal

Table 2-62 summarizes the parameters used to assess dermal exposure during use of NMP in laboratories. EPA assumed that the skin was exposed dermally to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

NMP Weight Fraction

EPA found limited information on the concentration of NMP carrier and reagent solutions used in laboratories. Neither the 2017 market profile on NMP (Abt, 2017) nor the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) any NMP products that are marketed for laboratory use. Because NMP is used as a carrier chemical, EPA expects that NMP may be used in pure form (i.e., 100 percent NMP). This assumption was also used by RIVM in the Proposal for Restriction of NMP report (RIVM, 2013). While NMP may be used in concentrations below 100 weight percent, EPA did not find additional information on these potential concentrations.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Because laboratories have procedures and trainings to ensure accuracy and quality of the performed analyses, EPA expects workers are likely to wear protective gloves and have basic training on the proper usage of these gloves, corresponding to a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3. Thus, EPA assesses a protection factor 10 for both the central tendency and high-end scenarios for this scenario. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA found one task-based inhalation monitoring data point (for the preparation and analysis of a sample containing NMP) indicating an exposure duration of two hours. EPA uses this exposure duration for the central tendency scenario. For the high-end scenario, EPA assumes eight hours, as described in Section 1.4.3.2.4.

Table 2-62. Summary of Parameters for Worker Dermal Exposure During Laboratory Use

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Laboratory Use	Central tendency	10	1	445 (f) 535 (m)	2	74 (f) 88 (m)
	High-end	10	1	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.12.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-63.

The numeric parameters corresponding to the characterizations presented in Table 2-63 are summarized in Table 2-64. These are the inputs used in the PBPK model.

Table 2-63. Characterization of PBPK Model Input Parameters by Laboratory Use

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Laboratory activities	Central tendency (unknown statistical characterization)	Based on 2-hour TWA data	1-hand	Yes	N/A - 100% is assumed for both exposure scenarios
High-end	Laboratory activities	High-end (unknown statistical characterization)	Assumed 8 hours	2-hand	Yes	N/A - 100% is assumed for both exposure scenarios

Table 2-64. PBPK Model Input Parameters for Laboratory Use

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	0.200	2	445 (f) 535 (m)	10	1	74 (f) 88 (m)
High-end	4.13	8	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.12.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.13 Cleaning

2.13.1 Process Description

NMP may be used in a variety of cleaning products that can be used in multiple occupational applications, including industrial facilities and commercial shops. EPA identified the following distinct NMP-containing cleaning products with expected occupational applications:

- Aerosol degreasing
- Dip degreasing and cleaning products
- Wipe cleaning, including use of spray-applied cleaning products

2.13.1.1 Aerosol Degreasing

EPA's 2017 market profile for NMP (Abt, 2017) and "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) identified three aerosol cleaning products containing NMP. One product is listed as a bore cleaning foam with 4.5 weight percent NMP (Abt, 2017; U.S. EPA, 2017b). Another product is listed as an aerosol stainless polish with an unknown concentration of NMP (U.S. EPA, 2017b). The final product is listed as a resin remover used as an aerosol with a concentration of 35 to 40 weight percent NMP (Abt, 2017; U.S. EPA, 2017b). A public comment on the NMP risk evaluation docket from CRC Industries, Inc. indicates that NMP is present at less than 20 weight percent in their gasket removal products (Rudnick, 2017).

EPA did not find monitoring data for the use of the above-listed aerosol cleaners and did not identify information that clearly defines scenarios in which these aerosol cleaners are used. However, EPA has identified NMP as a potential ingredient in aerosol brake cleaners (see Section 2.11). Therefore, EPA assesses potential inhalation exposures during the aerosol cleaning of automotive brakes and assesses these potential exposures as surrogate for miscellaneous aerosol cleaning. Section 2.11 presents the assessment of aerosol brake cleaning.

2.13.1.2 Dip Degreasing and Cleaning

NMP has historically been used for the degreasing of optical lenses and metal parts by dipping into a tank containing NMP (Xiaofei et al., 2000; BASF, 1993). A public comment to the NMP risk evaluation docket indicates that NMP is used in the immersive cleaning of wire coating equipment at facilities that also used NMP-based wire coatings (National Electrical Manufacturers Association, 2017).

In dip cleaning processes, the parts to be cleaned are first placed in a basket. Workers will then open the lid of a tank containing NMP and submerge the basket into the tank (National Electrical Manufacturers Association, 2017; Xiaofei et al., 2000). The cleaning solution in the tank can range from 90 percent up to 100 percent NMP and may optionally be heated (RIVM, 2013; BASF, 1993). Once the basket of parts is submerged in the tank, the lid of the tank is closed and the parts soak in the NMP cleaning solution. Sonication or some other form of agitation of the parts may be used to aid in the cleaning process. The basket containing the parts is then lifted from the tank and the parts may be air dried or may be transferred to a tank containing water to rinse the parts of any residual NMP or NMP-solubilized oil remaining on the surfaces of the parts.

EPA's "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) identified one cleaning product with an NMP concentration of 60 to 80 weight percent. EPA's 2017 market profile identified two additional products that can be used for immersion cleaning of items such as spray gun heads (Abt, 2017). These products contain 40 to 60 weight percent NMP and >99 weight percent NMP, respectively. Additionally, literature indicates that some dip cleaning processes use pure NMP (i.e., 100 percent NMP) (BASF, 1993).

2.13.1.3 Wipe Cleaning, Including Use of Spray-Applied Cleaning Products

Wipe cleaning involves first wetting towels or rags with cleaning solution or spraying, pouring, or brushing the cleaning solution onto the surfaces to be cleaned. Spray products are deployed from non-pressurized containers, such as bottles, and use a spray nozzle to discharge the liquid at a high velocity to atomize the liquid into fine droplets. Some spray applications use an atomizing gas, such as air, to aid in the atomization of the liquid (U.S. EPA, 2016c). Workers then manually wipe surfaces clean with towels and rags (Bader et al., 2006). Any residual cleaning solution on the wiped surfaces is expected to volatilize. The dirty towels and rags may be disposed of entirely or laundered so they may be reused.

EPA found limited information regarding products that are used for wipe cleaning. The 2017 market profile for NMP (Abt, 2017) identified numerous cleaning products of unknown application type (i.e., aerosol, dip, wipe), ranging in NMP concentration of <1 to 100 weight percent. Based on the SDSs for these products, EPA believes that it is feasible that these products may be spray applied or otherwise poured onto surfaces or rags and then wiped off.

2.13.2 Exposure Assessment

2.13.2.1 Worker Activities

Worker are potentially exposed to NMP when unloading cleaning solutions from containers, mixing and/or diluting the solutions before use, performing cleaning activities (i.e., spraying, dipping, wiping), and associated equipment cleaning and maintenance (RIVM, 2013). These worker activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

EPA did not find information on the customary engineering controls and worker PPE used in the many industries that conduct cleaning activities. However, a public comment on the NMP risk evaluation docket from the National Electrical Manufacturers Association (NEMA) indicates that, at facilities that use NMP for wire coating and associated equipment cleaning, the cleaning tanks containing NMP are enclosed and equipped with ventilation (National Electrical Manufacturers Association, 2017). This comment also indicates that workers utilize PPE such as gloves, aprons and goggles.

ONUs include employees that work at the sites where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include supervisors, managers, and other employees that may be in the production areas but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of NMP.

2.13.2.2 Number of Potentially Exposed Workers

This section identifies relevant industries and worker population estimates for NMP-based cleaners. Cleaning activities are widespread, occurring in many industries. EPA determined the industries likely to use NMP for cleaning activities from the following sources: the non-CBI 2016 CDR results for NMP (U.S. EPA, 2016a), the 2017 market profile for NMP (Abt, 2017), process descriptions for the use of NMP for cleaning purposes (Xiaofei et al., 2000; BASF, 1993), and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b). EPA estimates the number of potentially exposed workers for aerosol cleaning activities in Section 2.11.

In some cases, the industries that distinctly perform dip cleaning and/or spray/wipe cleaning are unknown. For these cases, EPA conservatively assumes that cleaning within these industries may involve all cleaning scenarios. EPA compiled the associated NAICS codes for the identified industries in Table 2-65. EPA determined the number of workers associated with each industry from using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based cleaning products and the number of employees within an establishment exposed to NMP-based cleaning products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and employees potentially exposed to NMP-based cleaning products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during cleaning activities.

Table 2-65. US Number of Establishments and Employees for Cleaning

Occupational Exposure Scenario	Occupational Exposure Scenario Source	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers per Site [a]	Number of ONUs per Site [a]
Dip Cleaning (Machinery, Optical Lenses)	(RIVM, 2013; IFA, 2010; Xiaofei et al., 2000)	333300	Commercial and Service Industry Machinery Manufacturing	2,014	14	6
Unknown - assumes all cleaning scenarios may occur in these industries	(U.S. EPA, 2016a)	335100	Electric Lighting Equipment Manufacturing	1,104	17	5
	(U.S. EPA, 2016a)	335200	Household Appliance Manufacturing	303	102	20
	(U.S. EPA, 2016a)	335300	Electrical Equipment Manufacturing	2,124	28	12
	(U.S. EPA, 2016a)	335900	Other Electrical Equipment and Component Manufacturing	2,140	23	8
	(U.S. EPA, 2016c)	811420	Reupholstery and furniture repair	3,720	1	1
Total establishments and number of potentially exposed workers and ONUs = [b]				***11,000***	***190,000***	***71,000***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest whole number.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.13.2.3 Occupational Exposure Assessment Methodology

2.13.2.3.1 Inhalation

Appendix A.13 summarizes the inhalation monitoring data for NMP-based cleaning activities that EPA compiled from published literature sources, including full-shift, short-term, and partial shift sampling results. This appendix also includes EPA's rationale for inclusion or exclusion of these data in the risk evaluation. EPA used the available monitoring data for use of NMP in cleaning that had the highest quality rating to assess exposure for this use.

EPA used the available full-shift monitoring data and the modeled exposures for cleaning activities to calculate central tendency (based on 50th percentile) and worst-case (based on 95th percentile) inhalation exposure concentrations. These values are summarized in Table 2-66. EPA did not find short-term exposure concentration data. Again, note that EPA did not assess aerosol exposures in this section, but considers the modeled exposures in Section 2.11 to be the closest representation of these exposures based on the available information.

Table 2-66. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Cleaning

Work	Parameter	Full-Shift NMP	Duration-Based	Source	Data

Activity	Characterization	Air Concentration (mg/m^3, 8-hour TWA)	NMP Air Concentration (mg/m^3)		Quality Rating
Dip Cleaning / Degreasing	Central tendency (50th percentile)	0.99	No data	(RIVM, 2013; IFA, 2010; Nishimura et al., 2009; Bader et al., 2006; Xiaofei et al., 2000)	Medium to high
	High-end (95th percentile)	2.75	No data		
Spray / Wipe Cleaning	Central tendency (50th percentile)	1.01	No data	(RIVM, 2013; IFA, 2010; Nishimura et al., 2009; Bader et al., 2006)	Medium to high
	High-end (95th percentile)	3.38	No data		

2.13.2.3.2 Dermal

Table 2-67 summarizes the parameters used to assess dermal exposure during cleaning activities. EPA assumed that the skin was exposed dermally to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

NMP Weight Fraction

As discussed in Section 2.13.1, EPA identified three immersion cleaning formulations that range concentrations of 40 to >99 weight percent NMP. Additionally, literature indicates that some dip cleaning processes use pure NMP (i.e., 100 percent NMP) (BASF, 1993). Based on this information, EPA calculated typical (50th percentile) and worst-case (95th percentile) weight percent of NMP to be 84.5 and 99.9, respectively. Note that, where NMP concentration was provided in a range, EPA used the midpoint of the range for the calculations of typical and worst-case NMP concentration. The underlying data used for these estimates have overall confidence ratings that range from medium to high.

As discussed in Section 2.13.1, EPA found limited information regarding products that are used for spray and wipe cleaning. The 2017 market profile for NMP (Abt, 2017) identified numerous cleaning products of unknown application type (i.e., aerosol, dip, wipe), ranging in NMP concentration of 0.1 to 100 weight percent. Based on the SDSs for these products, EPA believes that it is feasible that these products may be spray applied or otherwise poured onto surfaces or rags and then wiped off. Based on these data, EPA calculated typical (50th percentile) and worst-case (95th percentile) weight percent of NMP to be 31.3 and 98.9, respectively. Note that, where NMP concentration was provided in a range, EPA used the midpoint of the range for the calculations of typical and worst-case NMP concentration. The underlying data used for these estimates have overall confidence ratings that range from medium to high.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. Due to the wide-spread commercial and industrial use of NMP-based cleaners, EPA assumes that no gloves are used for the worst-case exposure scenario. Thus, EPA assesses that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. The PPE information described in Section 2.7.2.1 indicates that workers who perform dip degreasing wear gloves (National Electrical Manufacturers Association, 2017). EPA does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the widespread nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-67. Summary of Parameters for Worker Dermal Exposure to Liquids During Cleaning

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Dip Degreasing and Cleaning	Central Tendency	5	0.845	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.999	890 (f) 1,070 (m)	8	
Spray/Wipe Cleaning	Central Tendency	5	0.313	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.989	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.13.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-68.

The numeric parameters corresponding to the characterizations presented in Table 2-68 are summarized in Table 2-69. These are the inputs used in the PBPK model.

Table 2-68. Characterization of PBPK Model Input Parameters for Cleaning

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Dip cleaning	Central tendency (50^{th} percentile)	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Dip cleaning	High-end (95^{th} percentile)	Assumed 8 hours	2-hand	No	High-end
Central Tendency	Spray / wipe cleaning	Central tendency (50^{th} percentile)	Assumed 4 hours	1-hand	Yes	Central Tendency
High-end	Spray / wipe cleaning	High-end (95^{th} percentile)	Assumed 8 hours	2-hand	No	High-end

Table 2-69. PBPK Model Input Parameters for Cleaning

Scenario	Activity	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	Dip cleaning	1.98	4	445 (f) 535 (m)	5	0.845	74 (f) 88 (m)
High-end	Dip cleaning	2.75	8	890 (f) 1,070 (m)	1	0.999	74 (f) 88 (m)
Central Tendency	Spray / wipe cleaning	2.02	4	445 (f) 535 (m)	5	0.313	74 (f) 88 (m)
High-end	Spray / wipe cleaning	3.38	8	890 (f) 1,070 (m)	1	0.989	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.13.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.14 Fertilizer Application

2.14.1 Process Description

Based on information identified in the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document, NMP is used as a component in a variety of granular or liquid pesticides, as well as in herbicides, fungicides, and dog flea treatments (U.S. EPA, 2017b). The 2017 Scope Document for the Risk Assessment of NMP and 2016 CDR results indicate that NMP may also be used in fertilizers (U.S. EPA, 2017c, 2016a). The use of pesticides, including herbicides and fungicides, is regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and is not assessed in this risk evaluation. The use of flea treatments is regulated by the Food and Drug Administration (FDA). However, the use of fertilizers is under the purview of TSCA and is assessed in this risk evaluation.

NMP is used both in the synthesis of and as a co-solvent in the formulation of agricultural chemicals (U.S. EPA, 2017c; RIVM, 2013). When used for synthesis, NMP may only be present in the final formulation in residual quantities. When used as a co-solvent, NMP remains in the final formulation, usually in concentrations ranging from one to 20 weight percent (U.S. EPA, 2017b; RIVM, 2013). The NMP Producers Group, Inc. submitted a comment to the NMP risk evaluation docket indicating that NMP is used in a fertilizer additive that prevents the volatilization of urea (Roberts, 2017). The NMP Producers Group, Inc. states that NMP comprises 15 to 45 weight percent of the fertilizer additive, which is blended into a final fertilizer formulation at a recommended rate such that the final fertilizer contains less than 0.1 weight percent NMP. Per the NMP Producers Group, Inc., the final fertilizer formulations can be liquid or granular.

Fertilizer application is based on the physical form of the fertilizer, which is typically a liquid solution/suspension or solid (MRI, 1998). Liquid solutions are often applied from a vehicle that houses a tank containing the fertilizer. The fertilizer is metered from the vehicle and onto fields through a manifold of spray nozzles. Applicators may adjust these spray nozzles to manipulate the flow of fertilizer solution. Solid fertilizers are similarly applied from vehicles containing hoppers through which the solid fertilizers are metered. The metered fertilizer drops onto a belt that feeds into spreading equipment. The spreaders are usually either fans through which fertilizer is propelled or long booms that extend from the back of the vehicle that drop fertilizer onto the field.

This information relates to the automated application of fertilizers from vehicles. Fertilizers may also be applied manually by workers using handheld spray application systems or other types of application equipment. EPA did not find additional information regarding the extent of automated versus manual application of NMP-containing fertilizers or other agricultural products.

2.14.2 Exposure Assessment

2.14.2.1 Worker Activities

Workers are potentially exposed to NMP in fertilizers during multiple activities. These activities include transfers of fertilizers from storage containers into application equipment, any additional mixing activities that may occur prior to application, application of the fertilizers, and cleaning of application equipment that may occur after application (NIOSH, 2014; RIVM, 2013). These activities are potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors. In addition, if the fertilizers are granular, workers may have potential inhalation exposures to dusts that contain NMP during the application of these fertilizers.

The 1993 Generic Scenario (GS) on the Application of Agricultural Pesticides indicates that workers will typically wear boots, gloves, and masks during the application of pesticides on fields (U.S. EPA, 1993). A NIOSH Health Hazard Evaluation (HHE) on the application of sea lamprey pesticides found that workers wore eye protection (safety glasses, goggles, or face shield) and chemical resistant gloves when mixing and applying pesticides (NIOSH, 2014). The investigation also included the application of granular pesticides, for which workers were observed wearing NIOSH-approved full facepiece dual cartridge (particulate and organic vapor) respirators. EPA expects that similar PPE may be employed for workers who apply fertilizers.

The RIVM *Annex XV Proposal for a Restriction - NMP* report recommends that workers who manually apply agrochemicals by spraying and fogging wear protective coveralls and a respirator (RIVM, 2013). For workers that apply agrochemicals from an automated vehicle, the report recommends that workers do so from a vented cab supplied with filtered air. Additionally, the report indicates that workers should wear gloves for all work where dermal contact is possible.

EPA did not find information on the extent of use of the above engineering controls and PPE within the fertilizer application industry.

ONUs include farmers that work at the farms where NMP is used, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for this scenario include farm managers and other farmers that may be near the fields that are receiving fertilizer application, but do not perform tasks that result in the same level of exposures as those workers that apply fertilizer containing NMP.

2.14.2.2 Number of Potentially Exposed Workers

Fertilizer products containing NMP are used in the agricultural industry on crop farms (as opposed to cattle farms). These farms are covered within the 3-digit NAICS group 111, Crop Production.

EPA compiled these identified NAICS codes in Table 2-70. EPA determined the number of workers associated with each industry from U.S. Department of Agriculture (USDA) Census of Agriculture Data (USDA, 2014). The USDA conducts a census of agriculture instead of the US Census Bureau. Census of agriculture data were available for 2012 and the number of farms and workers is summarized in Table 2-70. EPA did not find data on the number of workers and occupational non-users on a NAICS level. Information on the total number of workers is available, but no information on the number of occupational non-users was found in the census of agriculture.

The number of farms within each industry that use NMP-based fertilizers and the number of employees at a farm exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based fertilizers. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during fertilizer application.

Table 2-70. U.S. Number of Establishments and Employees for Fertilizer Application

2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site [a]	Number of ONUs per Site [a]
1111	Oilseed and Grain Farming	369,332	NAICS specific data not found	
1112	Vegetable and Melon Farming	43,021		
1113	Fruit and Tree Nut Farming	93,020		
1114	Greenhouse, Nursery, and Floriculture Production	52,777		
1119	Other Crop Farming	496,837		
Total number of establishments, workers, and ONUs potentially exposed [b]		***1,100,000***	***1,300,000***	***Unknown***

Sources: Number of establishments, workers per site, ONUs per site – (USDA, 2014)
a – EPA did not find data on the number of workers and occupational non-users on a NAICS level. EPA determined the number of total workers for these NAICS codes by multiplying the total number of workers for all farms on the 2012 NAICS by the fraction of farms that fall within the listed NAICS codes.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.14.2.3 Occupational Exposure Assessment Methodology

2.14.2.3.1 Inhalation

EPA did not find inhalation monitoring data for the application of fertilizers containing NMP. The RIVM *Annex XV Proposal for a Restriction - NMP* report presented the modeled potential inhalation exposures during spray and fog application of agrochemicals (RIVM, 2013). EPA summarized these modeled exposures in Appendix A.14. Due to lack of additional information or modeling approaches, EPA uses the modeled exposures from the RIVM *Annex XV Proposal for a Restriction - NMP* report to represent potential inhalation exposures during this scenario. These data are of acceptable quality.

The input parameters used for the PBPK modeling based on the modeled exposures are summarized in Table 2-71. The RIVM *Annex XV Proposal for a Restriction - NMP* report recommends that manual application activities should be limited to four hours per shift or less (RIVM, 2013). Application with more automated equipment and separation of the worker from the sources of exposure can exceed this recommendation. EPA thus assesses both full-shift 8-hour TWA and short-term 4-hour TWA inhalation exposures. EPA did not find data on short-term exposures.

Table 2-71. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Fertilizer Application

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Manual spray or boom application of fertilizers [a]	Low-end (of range)	2.97	No data	(RIVM, 2013)	High
	High-end (of range)	5.27	No data		

a – These data are from (RIVM, 2013) and are modeled exposures during the manual spray or boom application of agrochemicals. No data on other forms of application were identified.

2.14.2.3.2 Dermal

Table 2-72 summarizes the parameters used to assess dermal exposure during the use of agricultural products containing NMP. EPA assessed dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

<u>NMP Weight Fraction</u>

As described in Section 2.14.1, the NMP Producers Group, Inc. indicated that NMP is present in fertilizers in very small quantities, less than 0.1 weigh percent (Roberts, 2017). EPA identified multiple other agricultural products from the 2017 market profile on NMP and the “Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP” document; however, these products are all pesticides and other products that are not regulated under TSCA (Abt, 2017; U.S. EPA, 2017b). EPA excludes those products from this risk evaluation. The RIVM *Annex XV Proposal for a Restriction - NMP* report indicates that NMP is typically less than seven weight percent in agrochemical formulations (RIVM, 2013). Due to lack of additional information, EPA assesses a low-end concentration of 0.1 percent and a high-end concentration of seven percent. The underlying data used for these estimates have overall confidence ratings of high.

<u>Skin Surface Area and Glove Usage</u>

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. The PPE information described in Section 2.14.2.1 indicates that workers are likely to wear gloves. EPA does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the commercial nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA also assesses that no gloves are used for a high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-72. Summary of Parameters for Worker Dermal Exposure During Fertilizer Application

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [b]	Exposure Duration	Body Weight [b]
			Unitless	cm^2	hr/day	kg
Manual spray or boom application of fertilizers [a]	Central Tendency	5	0.001	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.07	890 (f) 1,070 (m)	8	

[a] These data are from (RIVM, 2013) and are modeled exposures during the manual spray or boom application of agrochemicals. No data on other forms of application were identified.
[b] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.14.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-73.

The numeric parameters corresponding to the characterizations presented in Table 2-73 are summarized in Table 2-74. These are the inputs used in the PBPK model.

Table 2-73. Characterization of PBPK Model Input Parameters for Fertilizer Application

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Manual spray or boom application of fertilizers	Low-end (of range)	Calculated 4-hour TWA from the 8-hour TWA data	1-hand	Yes	Central Tendency
High-end	Manual spray or boom application of fertilizers	High-end (of range)	Based on 8-hour TWA data	2-hand	No	High-end

Table 2-74. PBPK Model Input Parameters for Fertilizer Application

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	5.94	4	445 (f) 535 (m)	5	0.001	74 (f) 88 (m)
High-end	5.27	8	890 (f) 1,070 (m)	1	0.07	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.14.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.15 Wood Preservatives

2.15.1 Process Description

The 2017 NMP market profile and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document identify one product containing NMP that is used as a wood preservative for in-service utility poles (Abt, 2017; U.S. EPA, 2017b). The physical state of this product is a paste. Per the supplier, this product protects against decay and deterioration of wood (https://www.osmose.com/documents/MP400-EXT%20product%20information%20bulletin.pdf).

Additionally, based on the physical form of the product and the description provided in the supplier's information bulletin, EPA assesses application of this product as manual brushing or plastering onto utility poles.

Because only one wood preservative product containing NMP was identified, this is likely a niche use of NMP.

2.15.2 Exposure Assessment

2.15.2.1 Worker Activities

Workers are potentially exposed to NMP in wood preservative formulations during transferring of formulations into smaller portable containers that can be taken out into the field to service utility poles. During application of wood preservative pastes, EPA believes that workers are likely to manually apply the wood preservatives using a large brush or trowel. These activities are both potential sources of worker exposure through dermal contact, vapor-through-skin, and inhalation of NMP vapors.

EPA did not find information regarding the use of engineering controls or worker PPE during the use of wood preservatives containing NMP. Because utility poles are located outdoors, EPA does not expect the use of engineering controls during servicing of the utility poles. Utility workers generally wear hard hats, safety vests, and may wear work gloves. The use of respiratory protection is unknown but considered unlikely.

Because the servicing of in-use utility poles typically occurs outdoors, along the sides of roads and other outdoor areas that aren't typically occupied, EPA does not expect there to be ONUs nearby during the use of wood preservatives for the servicing of existing utility poles. Thus, EPA does not assess potential ONU exposure to NMP.

2.15.2.2 Number of Potentially Exposed Workers

Because the use of NMP in wood preservatives is a niche use, the only affected workers are likely to be municipal utility workers. The utility industries are covered within the 3-digit NAICS code 221. Within this NAICS group, EPA expects that the only NAICS codes that are likely to cover industries that service utility poles are those within NAICS group 221120, Electric Power Transmission, Control, and Distribution.

EPA compiled the associated NAICS codes for the identified industries in Table 2-75. EPA determined the number of workers associated with each industry using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The number of establishments within each industry that use NMP-based wood preservative products and the number of employees within an establishment exposed to these NMP-based products are unknown. Therefore, EPA provides the total number of establishments and employees in these industries as bounding estimates of the number of establishments that use and the number of employees that are potentially exposed to NMP-based wood preservative products. These bounding estimates are likely overestimates of the actual number of establishments and employees potentially exposed to NMP during use of wood preservatives.

Table 2-75. US Number of Establishments and Employees for Industries Using Wood Preservatives

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments	Number of Workers Site [a]	Number of ONUs per Site [b]
Utilities	221121	Electric Bulk Power Transmission and Control	268	49	0
	221122	Electric Power Distribution	7487	48	0
Total number of establishments, workers, and ONUs potentially exposed [c]			***7,800***	***380,000***	***0***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest worker. No 2016 BLS data found for this NAICS. EPA determined number of workers per site by dividing the total number of employees by the total number of establishments from SUSB data.
b – No 2016 BLS data found for this NAICS. EPA does not expect ONUs to be affected during outdoor utility pole servicing.
c – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.15.2.3 Occupational Exposure Assessment Methodology

2.15.2.3.1 Inhalation

Appendix A.15 summarizes the inhalation monitoring data and modeled exposure data for NMP-based wood preservative application. Due to limited relevance and quality of monitoring data and modeling estimates for application of wood preservatives found in the published literature, EPA used modeling estimates with the highest data quality for this use, as described further below.

The summarized monitoring data does not include worker activities which EPA expects to occur within this scenario. Thus, EPA uses a modeled exposure for the brush application of a substance containing NMP that was presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report. Additional details on EPA's rationale for inclusion or exclusion of these data in the risk evaluation are included in Appendix A.15.

The modeled exposure from brush application is summarized into the input parameters used for the PBPK modeling in Table 2-76. EPA did not find data on short-term exposures for this scenario.

Note that EPA does not expect there to be ONUs nearby during the use of wood preservatives for the servicing of existing utility poles. Thus, EPA does not assess potential ONU exposure to NMP.

Table 2-76. Summary of Parameters for Wood Preservatives

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m^3, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m^3)	Source	Data Quality Rating
Brush Application	Single estimate	4.13	No data	(RIVM, 2013)	High

2.15.2.3.2 Dermal

Table 2-77 summarizes the parameters used to assess dermal exposure during the use of wood preservatives containing NMP. EPA assessed dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration.

<u>NMP Weight Fraction</u>

The 2017 market profile for NMP (Abt, 2017) and the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document (U.S. EPA, 2017b) identified one wood preservative product containing NMP. The SDS for this product indicates NMP is present in the formulation at less than one percent. Due to lack of additional information, EPA assesses a weight fraction of one percent.

<u>Skin Surface Area and Glove Usage</u>

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. EPA did not find information on the use of gloves. Thus, EPA assesses that no gloves are used for the high-end exposure scenario, corresponding to a protection factor of 1 from Table 1-2 of Section 1.4.3.2.3. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found, but due to the commercial nature of this use, EPA expects minimal to no employee training. Based on this information EPA assesses a central tendency protection factor of 5 from Table 1-2 of Section 1.4.3.2.3. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-77. Summary of Parameters for Worker Dermal Exposure to Wood Preservatives

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Brush Application	Central Tendency	5	0.01	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	1	0.01	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.15.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-78.

The numeric parameters corresponding to the characterizations presented in Table 2-78 are summarized in Table 2-79. These are the inputs used in the PBPK model.

Table 2-78. Characterization of PBPK Model Input Parameters for Wood Preservatives

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Brush application	Single estimate	Assumed 4 hours	1-hand	Yes	Single data point available and used for both exposure scenarios
High-end	Brush application	Single estimate	Assumed 8 hours	2-hand	No	Single data point available and used for both exposure scenarios

Table 2-79. PBPK Model Input Parameters for Wood Preservatives

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [b]
Central Tendency	8.26	4	445 (f) 535 (m)	5	0.01	74 (f) 88 (m)
High-end	4.13	8	890 (f) 1,070 (m)	1	0.01	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.15.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

2.16 Recycling and Disposal

2.16.1 Process Description

Each of the conditions of use of NMP may generate waste streams of the chemical that are collected and transported to third-party sites for disposal, treatment, or recycling. Industrial sites that treat or dispose onsite wastes that they themselves generate are likely for chemical processing sites (excluding formulation) and are assessed in Section 2.3. Wastes of NMP that are generated during a scenario and sent to a third-party site for treatment, disposal, or recycling may include the following:

- Wastewater: NMP may be contained in wastewater discharged to POTW or other, non-public treatment works for treatment. Industrial wastewater containing NMP discharged to a POTW may be subject to EPA or authorized NPDES state pretreatment programs.

- Solid Wastes: Solid wastes are defined under RCRA as any material that is discarded by being: abandoned; inherently waste-like; a discarded military munition; or recycled in certain ways (certain instances of the generation and legitimate reclamation of secondary materials are exempted as solid wastes under RCRA). Solid wastes may subsequently meet RCRA's definition of hazardous waste by either being listed as a waste at 40 CFR §§ 261.30 to 261.35 or by meeting waste-like characteristics as defined at 40 CFR §§ 261.20 to 261.24. Solid wastes that are hazardous wastes are regulated under the more stringent requirements of Subtitle C of RCRA, whereas non-hazardous solid wastes are regulated under the less stringent requirements of Subtitle D of RCRA.
    - NMP is not designated as a hazardous substance under federal regulations. However, three states, Massachusetts, New Jersey and Pennsylvania have designated NMP as a hazardous substance, thereby regulating NMP disposal (U.S. EPA, 2018c). The 2016 TRI results indicate multiple sites reported releases to RCRA Subtitle C Landfills (U.S. EPA, 2016b).

- Wastes Exempted as Solid Wastes under RCRA: Certain conditions of use of NMP may generate wastes of NMP that are exempted as solid wastes under 40 CFR § 261.4(a). For example, the generation and legitimate reclamation of hazardous secondary materials of NMP may be exempt as a solid waste.

2016 TRI data lists off-site transfers of NMP to land disposal, wastewater treatment, incineration, recycling facilities, and other off-site transfers. About 51% of off-site transfers were recycled off-site, 26% were incinerated, 12% were sent to land disposal, 7% were sent to wastewater treatment, and 5% were disposed of via other off-site transfers (U.S. EPA, 2016b). See Figure 2-4 for a diagram of a typical waste disposal process.

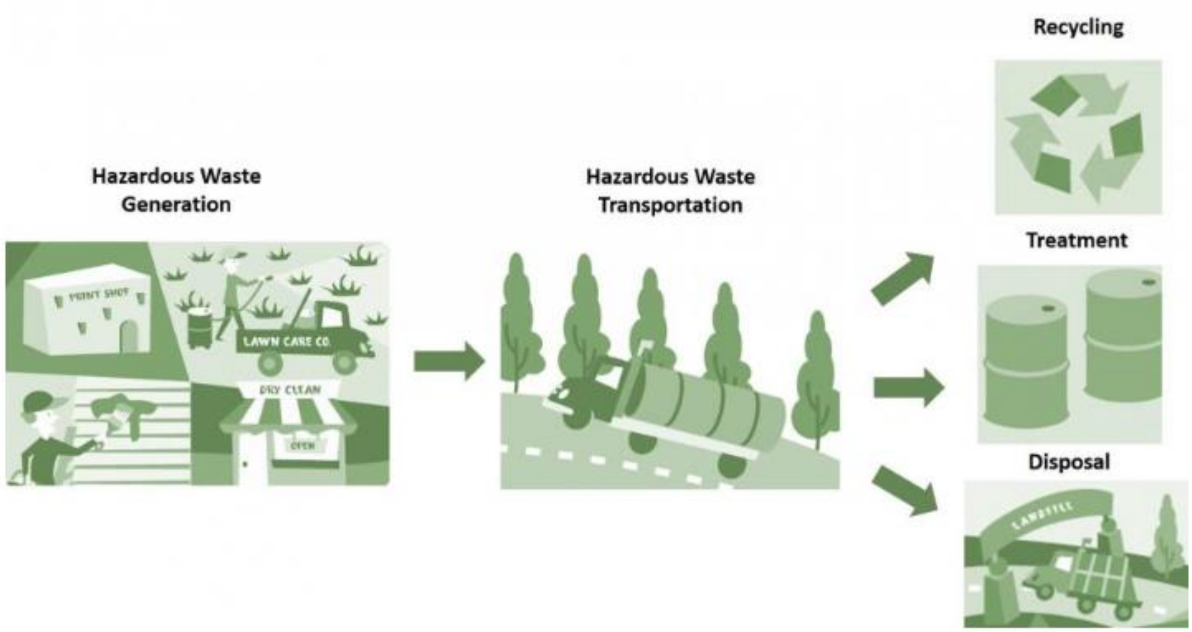

Figure 2-4. Typical Waste Disposal Process ([U.S. EPA, 2017a](#))

Municipal Waste Incineration

Municipal waste combustors (MWCs) that recover energy are generally located at large facilities comprising an enclosed tipping floor and a deep waste storage pit. Typical large MWCs may range in capacity from 250 to over 1,000 tons per day. At facilities of this scale, waste materials are not generally handled directly by workers. Trucks may dump the waste directly into the pit, or waste may be tipped to the floor and later pushed into the pit by a worker operating a front-end loader. A large grapple from an overhead crane is used to grab waste from the pit and drop it into a hopper, where hydraulic rams feed the material continuously into the combustion unit at a controlled rate. The crane operator also uses the grapple to mix the waste within the pit, in order to provide a fuel consistent in composition and heating value, and to pick out hazardous or problematic waste.

Facilities burning refuse-derived fuel (RDF) conduct on-site sorting, shredding, and inspection of the waste prior to incineration to recover recyclables and remove hazardous waste or other unwanted materials. Sorting is usually an automated process that uses mechanical separation methods, such as trommel screens, disk screens, and magnetic separators. Once processed, the waste material may be transferred to a storage pit, or it may be conveyed directly to the hopper for combustion.

Tipping floor operations may generate dust. Air from the enclosed tipping floor, however, is continuously drawn into the combustion unit via one or more forced air fans to serve as the primary combustion air and minimize odors. Dust and lint present in the air is typically captured in filters or other cleaning devices in order to prevent the clogging of steam coils, which are used to heat the combustion air and help dry higher-moisture inputs (Kitto, 1992).

Hazardous Waste Incineration

Commercial scale hazardous waste incinerators are generally two-chamber units, a rotary kiln followed by an afterburner, that accept both solid and liquid waste. Liquid wastes are pumped through pipes and are fed to the unit through nozzles that atomize the liquid for optimal combustion. Solids may be fed to the kiln as loose solids gravity fed to a hopper, or in drums or containers using a conveyor (ETC, 2018;

Heritage, 2018).

Incoming hazardous waste is usually received by truck or rail, and an inspection is required for all waste received. Receiving areas for liquid waste generally consist of a docking area, pumphouse, and some kind of storage facilities. For solids, conveyor devices are typically used to transport incoming waste (ETC, 2018; Heritage, 2018).

Smaller scale units that burn municipal solid waste or hazardous waste (such as infectious and hazardous waste incinerators at hospitals) may require more direct handling of the materials by facility personnel. Units that are batch-loaded require the waste to be placed on the grate prior to operation and may involve manually dumping waste from a container or shoveling waste from a container onto the grate.

A typical industrial incineration process is depicted in Figure 2-5 below.

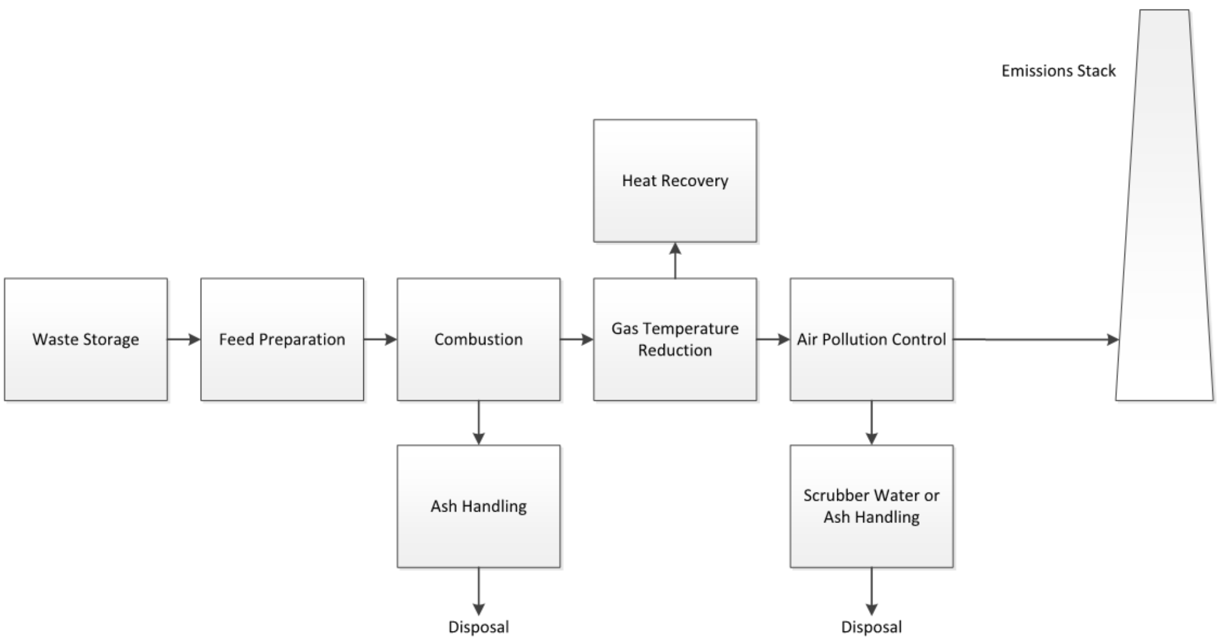

Figure 2-5. Typical Industrial Incineration Process

Municipal Waste Landfill

Municipal solid waste landfills are discrete areas of land or excavated sites that receive household wastes and other types of non-hazardous wastes (e.g. industrial and commercial solid wastes). Standards and requirements for municipal waste landfills include location restrictions, composite liner requirements, leachate collection and removal system, operating practices, groundwater monitoring requirements, closure-and post-closure care requirements, corrective action provisions, and financial assurance. Non-hazardous solid wastes are regulated under RCRA Subtitle D, but states may impose more stringent requirements.

Municipal solid wastes may be first unloaded at waste transfer stations for temporary storage, prior to being transported to the landfill or other treatment or disposal facilities.

Hazardous Waste Landfill

Hazardous waste landfills are excavated or engineered sites specifically designed for the final disposal of non-liquid hazardous wastes. Design standards for these landfills require double liner, double leachate collection and removal systems, leak detection system, run on, runoff and wind dispersal controls, and construction quality assurance program (U.S. EPA, 2018b). There are also requirements for closure and post-closure, such as the addition of a final cover over the landfill and continued monitoring and maintenance. These standards and requirements prevent potential contamination of groundwater and nearby surface water resources. Hazardous waste landfills are regulated under Part 264/265, Subpart N.

According to 2016 TRI data, a large portion of land releases are to landfills other than RCRA Subtitle C hazardous waste landfills. Approximately 150,000 pounds of NMP were reportedly released RCRA Subtitle C hazardous waste landfills, while 2.4 million pounds of NMP were reported to other landfills (U.S. EPA, 2016b). EPA expects that NMP wastes sent to municipal landfills are likely to be consumer and commercial wastes with low potential for NMP to be available for exposure. For example, NMP in used aerosol cans, paint and coating containers, and other containers that held NMP formulations.

Recycling

Waste NMP solvent is generated when it becomes contaminated with suspended and dissolved solids, organics, water, or other substances (U.S. EPA, 1980). Waste solvents can be restored to a condition that permits reuse via solvent reclamation/recycling (U.S. EPA, 1985, 1980). Waste NMP is shipped to a solvent recovery site where it is piped or manually loaded into process equipment (U.S. EPA, 1985). The waste solvent then undergoes a vapor recovery (e.g., condensation, adsorption and absorption) or mechanical separation (e.g., decanting, filtering, draining, setline and centrifuging) step followed by distillation, purification and final packaging (U.S. EPA, 1985, 1980).

2.16.2 Exposure Assessment

2.16.2.1 Worker Activities

EPA assumes that any exposures related to on-site waste treatment and disposal are addressed in the assessments for those uses in this report; therefore, this section assesses exposures to workers for wastes transferred from the use site to an off-site waste treatment and disposal facility. At waste disposal sites, workers are potentially exposed via dermal contact with waste containing NMP or via inhalation of NMP vapor. Depending on the concentration of NMP in the waste stream, the route and level of exposure may be similar to that associated with container unloading activities.

ONUs include employees that work disposal and recycling sites, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and vapor-through-skin uptake and are not expected to have dermal exposures by contact with liquids. ONUs for disposal and recycling sites include supervisors, managers, and tradesmen that may be in the processing and disposal area but do not perform tasks that result in the same level of exposures as workers that directly handle NMP wastes.

Municipal Waste Incineration

At municipal waste incineration facilities, there may be one or more technicians present on the tipping floor to oversee operations, direct trucks, inspect incoming waste, or perform other tasks as warranted by individual facility practices. These workers may wear protective gear such as gloves, safety glasses, or dust masks. Specific worker protocols are largely up to individual companies, although state or local regulations may require certain worker safety standards be met. Federal operator training requirements pertain more to the operation of the regulated combustion unit rather than operator health and safety.

Workers are potentially exposed via inhalation to vapors while working on the tipping floor. Potentially-exposed workers include workers stationed on the tipping floor, including front-end loader and crane operators, as well as truck drivers. The potential for dermal exposures is minimized by the use of trucks and cranes to handle the wastes.

Hazardous Waste Incineration

More information is needed to determine the potential for worker exposures during hazardous waste incineration and any requirements for personal protective equipment. There is likely a greater potential for worker exposures for smaller scale incinerators that involve more direct handling of the wastes.

Municipal and Hazardous Waste Landfill

At landfills, typical worker activities may include operating refuse vehicles to weigh and unload the waste materials, operating bulldozers to spread and compact wastes, and monitoring, inspecting, and surveying and landfill site (CalRecycle, 2018).

2.16.2.2 Number of Potentially Exposed Workers

As discussed in Section 2.16.1, NMP may be disposed of as hazardous waste at TSDFs, recycled, or disposed of as municipal waste in used commercial and consumer articles. These operations are covered by the NAICS codes EPA compiled in Table 2-80. EPA determined the number of workers associated with each industry identified using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). EPA also searched available 2016 TRI NMP data for the each NAICS code. The 2016 TRI results indicate that there are 22 sites with operations covered by NAICS 562211 and two sites with operations covered by NAICS 562920 reporting NMP releases.

The total number of sites that treat and dispose wastes containing NMP is not known. It is possible that additional hazardous waste treatment facilities treat and dispose NMP but do not meet the TRI reporting threshold for reporting year 2016. In addition, it is possible that some consumer products containing NMP may be improperly disposed as municipal solid wastes, and that some amount of NMP is present in non-hazardous waste streams. Therefore, the total number of workers and ONUs potentially exposed to NMP may exceed those estimates presented in Table 2-80.

Table 2-80. US Number of Establishments and Employees for Recycling and Disposal

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments per 2016 TRI	Number of Workers per Site per BLS Data [a]	Number of ONUs per Site per BLS Data [a]
Hazardous waste disposal and recycling	562211	Hazardous Waste Treatment and Disposal	22	9	5
Non-hazardous waste disposal	562212	Solid Waste Landfill	0	3	2
	562213	Solid Waste Combustors and Incinerators	0	13	8
	562219	Other Nonhazardous Waste Treatment and Disposal	0	3	2
Other materials recovery	562920	Materials Recovery Facilities	2	2	2

Industry	2016 NAICS	2016 NAICS Title	Number of Establishments per 2016 TRI	Number of Workers per Site per BLS Data [a]	Number of ONUs per Site per BLS Data [a]
Total number of establishments, workers, and ONUs potentially exposed [c]			***24***	***200***	***120***

Sources: Number of establishments, workers per site, ONUs per site - (U.S. BLS, 2016; U.S. Census Bureau, 2015)
a – Rounded to the nearest worker.
b – Unrounded figures were used for total worker and ONU calculations. Totals may not add exactly due to rounding to two significant figures.

2.16.2.3 Occupational Exposure Assessment Methodology

2.16.2.3.1 Inhalation

EPA did not find monitoring data on the handling of NMP wastes at disposal and recycling sites. EPA therefore compiled the same monitoring and modeled exposure concentration data for this scenario as that for manufacturing. These data are summarized in Appendix A.1. As described for Manufacturing in Section 2.1.2.3.1, due to limited relevance and quality of monitoring data and modeling estimates found in the published literature, EPA used modeling estimates with the highest data quality for this use, as further described below.

EPA only found one source with monitoring data on the storing and conveying of NMP, which did not include details on worker activities, sample locations, or sampling times. EPA also summarized in Appendix A.16 the modeled inhalation exposure concentrations during the manufacturing of NMP, for closed- and open-system transfers of NMP, that were presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013).

Consistent with the approach EPA took in Section 2.1.2.3.1 for the manufacture of NMP, EPA modeled potential worker inhalation exposures during the unloading of bulk storage containers and drums using EPA models. EPA's modeled exposure concentrations represent a larger range of potential inhalation exposure concentrations than those presented by RIVM; thus, EPA uses these modeled exposures in lieu of using the monitoring data or modeled exposure in the RIVM *Annex XV Proposal for a Restriction - NMP* report. The inhalation monitoring data as well as the RIVM and EPA's modeled exposure concentrations are summarized and further explained in Appendix A.16.

The inhalation exposure concentrations modeled by EPA for unloading of 100% NMP are summarized into the input parameters used for the PBPK modeling in Table 2-81. The container unloading models used by EPA calculate short-term exposure concentrations, with the exposure duration equal to the duration of the unloading event (for bulk containers, typical case is 0.5 hours for unloading tank trucks and worst-case is 1 hour for unloading rail cars; for drums, 20 containers are unloaded per hour and the duration was determined based on the throughput of NMP at a site [refer to Appendix A.16 for further explanation]) and number of unloading events per day. EPA calculated the 8-hour TWA exposures to as the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift.

The *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* involves deterministic modeling and the *Drum Loading and Unloading Release and Inhalation Exposure Model* involves probabilistic modeling. See Appendix B.2 and B.3 for additional details on the bulk container loading modeling and the drum loading modeling, respectively.

Table 2-81. Summary of Parameters for PBPK Modeling of Worker Inhalation Exposure During Recycling and Disposal

Work Activity	Parameter Characterization	Full-Shift NMP Air Concentration (mg/m³, 8-hour TWA)	Duration-Based NMP Air Concentration (mg/m³)	Source	Data Quality Rating
Unloading bulk containers	Central tendency (50th percentile)	0.048	0.760 (duration = 0.5 hr)	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* (U.S. EPA, 2013a)	Not applicable[a]
	High-end (95th percentile)	0.190	1.52 (duration = 1 hr)		
Unloading drums	Central tendency (50th percentile)	0.125	1.65 (duration = 0.603 hr)	*Drum Loading and Unloading Release and Inhalation Exposure Model* (U.S. EPA, 2013a)	Not applicable[a]
	High-end (95th percentile)	0.441	5.85 (duration = 0.603 hr)		

a - EPA models are standard sources used by RAD for engineering assessments. EPA did not systematically review models that were developed by EPA.

2.16.2.3.2 Dermal

Table 2-82 summarizes the parameters used to assess dermal exposure during worker handling of wastes containing NMP. EPA assesses dermal exposure to NMP at the specified liquid weight fraction, skin surface area, and exposure duration, based on the methodology described below. During this scenario, workers are potentially exposed during unloading and loading activities, waste sorting activities, and equipment maintenance. For this scenario, EPA assessed dermal exposures during the unloading of pure NMP from bulk containers and drums. See below for additional information.

NMP Weight Fraction

EPA found limited information on the concentration of NMP in waste solvents to be recycled and industrial and commercial wastes containing NMP. The data submitted by SIA for the use of NMP in the production of semiconductors (discussed in Section 2.8.2) include one inhalation monitoring data point for the loading of trucks with waste NMP. This data point indicates that NMP is 92% in the handled waste material (SIA, 2019b). EPA uses this concentration for the central tendency NMP weight fraction. Due to lack of information on the concentration of NMP in waste solvents, for the high-end NMP concentration value, EPA expects that waste NMP may contain very little impurities and be up to 100 weight percent NMP.

Skin Surface Area and Glove Usage

As described in Section 1.4.3.2.2, EPA assessed high-end skin surface areas of 890 cm^2 for females and 1,070 cm^2 for males and central tendency skin surface areas of 445 cm^2 for females and 535 cm^2 for males. As discussed in Section 2.16.2.1, EPA did not find information regarding the use of PPE for this scenario. EPA expects that workers may potentially wear gloves but does not know the likelihood that workers wear gloves of the proper material and have training on the proper usage of gloves. No information on employee training was found. Because solvent recycling activities likely occur at industrial sites, but are not highly controlled in nature, EPA expects that employees may have basic training, corresponding to a protection factor of 10 from Table 1-2 of Section 1.4.3.2.3. As EPA expects this is the most likely scenario, EPA uses a glove protection factor of 10 for both the central tendency and high-end scenarios. EPA did not find data on the use of gloves for this occupational exposure scenario and the glove protection factor assumptions are based on professional judgment. The assumed glove protection factor values are highly uncertain.

Exposure Duration

EPA did not find data on exposure duration. As described in Section 1.4.3.2.4, EPA assumes a high-end exposure duration of eight hours and a central tendency exposure duration of four hours.

Table 2-82. Summary of Parameters for Worker Dermal Exposure During Recycling and Disposal

Work Activity	Parameter Characterization	Glove Protection Factor(s)	NMP Weight Fraction	Skin Surface Area Exposed [a]	Exposure Duration	Body Weight [a]
			Unitless	cm^2	hr/day	kg
Unloading bulk containers; Unloading drums	Central Tendency	10	0.92	445 (f) 535 (m)	4	74 (f) 88 (m)
	High-End	10	1	890 (f) 1,070 (m)	8	

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).

2.16.3 PBPK Inputs

Based on the methodology described in the previous sections, EPA assessed PBPK parameters for central tendency and high-end exposure scenarios based on the characterizations listed in Table 2-83.

The numeric parameters corresponding to the characterizations presented in Table 2-83 are summarized in Table 2-84. These are the inputs used in the PBPK model.

Table 2-83. Characterization of PBPK Model Input Parameters for Recycle and Disposal

Scenario	Work Activity	Air Concentration Data Characterization	Exposure Duration	Skin Surface Area Exposed	Gloves	NMP Weight Fraction Characterization
Central Tendency	Unloading bulk containers	Central tendency (50^{th} percentile)	Duration calculated by model	1-hand	Yes	Central tendency
High-end	Unloading drums	High-end (95^{th} percentile)	Duration calculated by model	2-hand	Yes	High-end

Table 2-84. PBPK Model Input Parameters for Recycle and Disposal

Scenario	Duration-Based NMP Air Concentration (mg/m^3)	Exposure Duration (hr)	Skin Surface Area Exposed (cm^2) [a,b]	Gloves Protection Factor	NMP Weight Fraction	Body Weight (kg) [a]
Central Tendency	0.760	0.5	445 (f) 535 (m)	10	0.92	74 (f) 88 (m)
High-end	5.85	0.603	890 (f) 1,070 (m)	10	1	74 (f) 88 (m)

[a] EPA assessed these exposure factors for both females and males. Values associated with females are denoted with (f) and values associated with males are denoted with (m).
[b] EPA assessed a skin surface area exposed of 0.1 cm^2 for ONUs for each scenario. However, EPA did not assess glove usage (protection factor = 1) for ONUs.

2.16.4 Summary

In summary, dermal exposure and inhalation are expected for this use. EPA has not identified additional uncertainties for this use beyond those included in Section 3.

3 Discussion of Results

3.1 Variability

EPA addressed variability in models by identifying key model parameters to apply a statistical distribution that mathematically defines the parameter's variability. EPA defined statistical distributions for parameters using documented statistical variations where available.

3.2 Uncertainties and Limitations

Uncertainty is "the lack of knowledge about specific variables, parameters, models, or other factors" and can be described qualitatively or quantitatively (U.S. EPA, 2001). The following sections discuss uncertainties in each of the assessed NMP use scenarios.

3.2.1 Number of Workers

There are a number of uncertainties surrounding the estimated number of workers potentially exposed to NMP, as outlined below.

First, BLS' OES employment data for each industry/occupation combination are only available at the 3-, 4-, or 5-digit NAICS level, rather than the full 6-digit NAICS level. This lack of granularity could result in an overestimate of the number of exposed workers if some 6-digit NAICS are included in the less granular BLS estimates but are not, in reality, likely to use NMP for the assessed applications. EPA addressed this issue by refining the OES estimates using total employment data from the U.S. Census' SUSB. However, this approach assumes that the distribution of occupation types (SOC codes) in each 6-digit NAICS is equal to the distribution of occupation types at the parent 5-digit NAICS level. If the distribution of workers in occupations with NMP exposure differs from the overall distribution of workers in each NAICS, then this approach will result in inaccuracy. The effects of this uncertainty on the number of worker estimates are unknown, as the uncertainties may result in either over or underestimation of the estimates depending on the actual distribution.

Second, EPA's judgments about which industries (represented by NAICS codes) and occupations (represented by SOC codes) are associated with the uses assessed in this report are based on EPA's understanding of how NMP is used in each industry. Designations of which industries and occupations have potential exposures is nevertheless subjective, and some industries/occupations with few exposures might erroneously be included, or some industries/occupations with exposures might erroneously be excluded. This would result in inaccuracy but would be unlikely to systematically either overestimate or underestimate the count of exposed workers.

3.2.2 PBPK Input Parameters

Key uncertainties in the occupational exposure parameters are summarized below. Most parameters are related specifically to the route of dermal contact with liquids by workers, while air concentrations are related to the routes of inhalation and vapor-through-skin exposure. The body weight parameter is related to all of these routes. The assumed values for human body weight have relatively lower uncertainties, and the median values used may underestimate exposures at the high-end of PBPK exposure results.

The dermal exposure parameters used in this assessment have uncertainties because many parameters lack data and were therefore based on assumptions. The assumed parameter values with the greatest uncertainties are glove use and effectiveness (using protection factors based on the ECETOC TRA model that are what-if type values as described in Section 1.4.3.2.3), durations of contact with liquid, and skin surface areas for contact with liquids. The assumed values for effectiveness, durations of contact, and surface areas for contact may or may not be representative of actual values. The assumed values for NMP concentrations in formulations have relatively lower uncertainties. The midpoints of some ranges serve as substitutes for 50th percentiles of the actual distributions and high ends of ranges serve as substitutes for 95th percentiles of the actual distributions. However, these substitutes are uncertain and are weak substitutes for the ideal percentile values. Generally, EPA cannot determine whether most of these assumptions may overestimate or underestimate exposures. However, high-end duration of dermal contact estimates of 8 hours may be more likely to overestimate exposure potential to some extent, and some activity-based durations may be more likely to underestimate exposure potential to some extent. For many OESs, the high-end surface area assumption of contact over the full area of two hands likely overestimates exposures. Occupational non-users (ONUs) may have direct contact with NMP-based liquid products due to incidental exposure at shared work areas with workers who directly work with NMP, and the estimate of zero surface area contact may underestimate their exposure. The parameter values NMP concentrations are from available data and are likely to have a relatively low impact on the magnitude (less than an order of magnitude, or factor of 10) of overestimation or underestimation of exposure. The impact of vapors being trapped next to the skin during glove use is also uncertain.

Where monitoring data are available, limitations of the data also introduce uncertainties into the exposures. The principal limitation of the air concentration data is the uncertainty in the representativeness of the data. EPA identified a limited number of exposure studies and data sets that provided data for facilities or job sites where NMP was used. Some of these studies primarily focused on single sites. This small sample pool introduces uncertainty as it is unclear how representative the data for a specific end use are for all sites and all workers across the US. Differences in work practices and engineering controls across sites can introduce variability and limit the representativeness of any one site relative to all sites. Age of the monitoring data can also introduce uncertainty due to differences in work practices and equipment used at the time the monitoring data were taken and those used currently, so the use of older data may over- or underestimate exposures. Additionally, some data sources may be inherently biased. For example, bias may be present if exposure monitoring was conducted to address concerns regarding adverse human health effects reported following exposures during use. The effects of these uncertainties on the occupational exposure assessment are unknown, as the uncertainties may result in either over or underestimation of exposures depending on the actual distribution of inhalation exposure concentrations and the variability of work practices among different sites.

The impact of these uncertainties precluded EPA from describing actual parameter distributions. In most scenarios where data were available, EPA did not find enough data to determine complete statistical distributions. Ideally, EPA would like to know 50th and 95th percentiles for each exposed population. In the absence of percentile data for monitoring, the means or midpoint of the range serve as substitutes for 50th percentiles of the actual distributions and high ends of ranges serve as substitutes for 95th percentiles of the actual distributions. However, these substitutes are uncertain and are weak substitutes for the ideal percentile values. The effects of these substitutes on the occupational exposure assessment are unknown, as the substitutes may result in either over or underestimation of exposures depending on the actual distribution.

Where data were not available, the modeling approaches used to estimate air concentrations also have uncertainties. Parameter values used in models did not all have distributions known to represent the modeled scenario. It is also uncertain whether the model equations generate results that represent actual workplace air concentrations. Some activity-based modeling does not account for exposures from other activities. Additional model-specific uncertainties are included below. In general, unless specified otherwise, the effects of the below model-specific uncertainties on the exposure estimates are unknown, as the uncertainties may result in either over or underestimation on exposures depending on the actual distributions of each of the model input parameters.

3.2.2.1 Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model

For manufacturing; repackaging; and recycling and disposal, the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* was used to estimate the airborne concentration associated with generic chemical loading scenarios at industrial facilities. Specific uncertainties associated with this model are described below:

- After each loading event, the model assumes saturated air containing NMP that remains in the transfer hose and/or loading arm is released to air. The model calculates the quantity of saturated air using design dimensions of loading systems published in the OPW Engineered Systems catalog and engineering judgment. These dimensions may not be representative of the whole range of loading equipment used at industrial facilities handling NMP.
- The model estimates fugitive emissions from equipment leaks using total organic compound emission factors from EPA's *Protocol for Equipment Leak Emission Estimates* (U.S. EPA, 1995), and engineering judgement on the likely equipment type used for transfer (e.g. number of valves, seals, lines, and connections). The applicability of these emission factors to NMP, and the accuracy of EPA's assumption on equipment type are not known.

3.2.2.2 Drum Loading and Unloading Release and Inhalation Exposure Model

For chemical processing, excluding formulation and incorporation into formulation, mixture, or reaction product, the *Drum Loading and Unloading Release and Inhalation Exposure Model* was used to estimate the airborne concentration associated with generic chemical loading scenarios at industrial facilities. Specific uncertainties associated with this model are described below:

- The model estimates fugitive emissions using the *EPA/OAQPS AP-42 Loading Model.* The applicability of the emission factors used in this model to NMP is not known.
- EPA assigned statistical distributions based on available literature data or engineering judgment to address the variability in Ventilation Rate (Q), Mixing Factor (k), Vapor Saturation Factor (f), and Exposed Working Years per Lifetime (WY). The selected distributions may vary from the actual distributions.

3.2.2.3 Model for Occupational Exposures during Aerosol Degreasing of Automotive Brakes

The aerosol degreasing assessment uses a near-field/far-field approach (uncertainties on this approach are presented below) to model worker exposure. Specific uncertainties associated with the aerosol degreasing scenario are presented below:

- The model references a CARB study (CARB, 2000) on brake servicing to estimate use rate and application frequency of the degreasing product. The brake servicing scenario may not be representative of the use rates for other aerosol degreasing applications involving NMP;

- Aerosol formulations were taken from available safety data sheets, and some were provided as ranges. For each Monte Carlo iteration the model selects an NMP concentration within the range of concentrations using a uniform distribution. In reality, the NMP concentration in the formulation may be more consistent than the range provided.

3.2.2.4 Near-Field/Far-Field Model Framework

The near-field/far-field approach is used as a framework to model inhalation exposure for aerosol degreasing. The following describe uncertainties and simplifying assumptions generally associated with this modeling approach:

- There is some degree of uncertainty associated with each model input parameter. In general, the model inputs were determined based on review of available literature. Where the distribution of the input parameter is known, a distribution is assigned to capture uncertainty in the Monte Carlo analysis. Where the distribution is unknown, a uniform distribution is often used. The use of a uniform distribution will capture the low-end and high-end values but may not accurately reflect actual distribution of the input parameters.
- The model assumes the near-field and far-field are well mixed, such that each zone can be approximated by a single, average concentration.
- All emissions from the facility are assumed to enter the near-field. This assumption will overestimate exposures and risks in facilities where some emissions do not enter the airspaces relevant to worker exposure modeling.
- The exposure models estimate airborne concentrations. Exposures are calculated by assuming workers spend the entire activity duration in their respective exposure zones (i.e., the worker in the near-field and the occupational non-user in the far-field). A worker may actually walk away from the near-field during part of the process. As such, assuming the worker is exposed at the near-field concentration for the entire activity duration may overestimate exposure.
- The exposure models represent model workplace settings for NMP used in aerosol degreasing of automotive brakes. The model has not been regressed or fitted with monitoring data.

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APPENDICES

Appendix A Inhalation Data for Each Occupational Scenario

This appendix summarizes the personal monitoring data EPA found for each scenario, as well as EPA's rationale for inclusion or exclusion in the risk evaluation.

A.1 Manufacturing

Limited monitoring data for the manufacture of NMP are available based on the information searched at the time of preparation of this report. Two data points for the storing and conveying of NMP were included in a compilation of NMP monitoring data prepared by the German Institute for Occupational Safety and Health (IFA) (IFA, 2010). These data are summarized in Rows 1 and 2 of Table_Apx A-1. However, the associated worker activities, sampling areas, sampling times, and type of storing and conveying systems associated with these data are unknown. EPA therefore excluded these data points from this analysis.

In addition to this monitoring data, EPA identified modeled potential inhalation exposures during manufacturing of NMP that were included in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These modeled exposures are presented in Rows 3 through 12. Rows 3 through 5 are for closed-system transfers of NMP, with various degrees of control of the system (i.e., the system in Row 3 is the most well-controlled, while the system in Row 5 is the least controlled closed system). RIVM modeled and assessed potential inhalation exposures during manufacturing for each of these three modeled scenarios of system control levels. The report indicated closed-system transfers are likely for manufacturing of NMP.

In addition to these closed systems, RIVM included modeled exposures for the transfer of NMP in open systems, which the report assesses for conditions of use other than manufacturing (as closed systems are assumed for manufacturing). These modeled exposures are presented in Rows 6 through 12 of Table_Apx A-1. EPA excludes those points that describe commercial operations, as manufacturing of NMP is expected to be an industrial process.

EPA modeled potential worker inhalation exposures during the loading of bulk storage containers (i.e., tank trucks and rail cars) and drums with pure NMP using common loading models developed by EPA, to compare to the RIVM modeled exposures. The loading activity during manufacture is expected to present the highest potential for worker exposure during a shift. EPA assumes NMP is loaded into transport containers and distributed in bulk as a pure substance (100 percent concentration).

For the loading of bulk containers with NMP, EPA developed the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*, which calculates potential exposure concentrations based on the loading of one tank truck (typical case) and one rail car (worst-case) assuming a closed transfer system and accounting for displacement of vapors from the transfer line and from leaks in equipment such as transfer line seals and valves. The exposure duration is the time required to load one container, which is half an hour for tank trucks and one hour for rail cars. For the loading of drums with NMP, EPA used the *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model* to determine NMP volatilization to air and associated potential worker inhalation exposures, respectively. These models use default parameter values and standard assumptions to provide screening level assessments of inhalation and dermal exposures for container loading operations.

Note that, to determine an exposure duration for the loading of drums during the manufacturing scenario, EPA first determined annual throughput of NMP at manufacturing sites. To do so, EPA divided the total NMP production volume of 161 million pounds (determined from 2016 CDR results; (U.S. EPA, 2016a) by the 33 sites that reported to 2016 CDR (see Section 2.1.2.2). EPA assumes that each of the 33 sites have the same annual throughput, regardless of whether the site manufactures or imports NMP. Thus, the site throughput for manufacturing and importation sites is the same. To determine the daily throughput of NMP at these sites, EPA assumed that sites operate 250 days per year. Based on this throughput information and the model's assumed loading rate of 20 drums/hour, the model determined an exposure duration of 2.06 hr/day for the loading of drums with NMP at manufacturing sites (assuming the site only fills drums and no other container sizes, as a worst-case exposure scenario).

For both loading of bulk containers and drums, EPA calculated short-term and 8-hour TWA exposures to workers during loading activities. The short-term TWA exposure is the weighted average exposure during the entire exposure duration per shift, accounting for the number of loading events per shift. The 8-hour TWA exposure is the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. Table_Apx A-1 presents a summary of the exposure modeling results in Rows 13 through 16.

EPA's modeled exposure concentrations for loading NMP into bulk containers are similar in value and the same order of magnitude as those modeled by RIVM for closed-system NMP transfers. EPA's modeled exposure concentrations for loading NMP into drums are the same magnitude but higher in value than those modeled by RIVM for open-system NMP transfers. EPA's modeled exposure concentrations represent a larger range of potential inhalation exposure concentrations than those presented by RIVM; thus, EPA uses these modeled exposures in lieu of using the monitoring data or modeled exposure in the RIVM *Annex XV Proposal for a Restriction - NMP* report. EPA uses the modeled exposures in these Rows 13 through 16 as inputs for the PBPK model for worker inhalation exposure over 8-hours and short-term.

Table_Apx A-1. Summary of Inhalation Monitoring Data for Manufacturing

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Storing, conveying	Area	Listed as "storing, conveying." No specific industries are listed.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 0.64 95th percentile: 1.155	13	Unknown	Unknown - Per source, the sampling time is greater than or equal to 1 hour and exposure duration is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 129	Medium	Excluded - unknown sample times, worker activities, and sampling areas
2	Storing, conveying	Unknown	Listed as "storing, conveying." No specific industries are listed. Samples taken in the presence of LEV.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 0.7 95th percentile: 1.35	10	Unknown	Unknown - Per source, the sampling time is greater than or equal to 1 hour and exposure duration is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 145	Medium	Excluded - unknown sample times, worker activities, and sampling areas
3	Closed system transfers	Modeled using EasyTRA model	Transfer using closed systems - varying levels of openness. Most closed system.	0.04	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 106	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
4	Closed system transfers	Modeled using EasyTRA model	Transfer using closed systems - varying levels of openness. Medium closed system.	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 106	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
5	Closed system transfers	Modeled using EasyTRA model	Transfer using closed systems - varying levels of openness. Least closed system.	12.39	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 106	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
6	Open system transfers - industrial setting without LEV	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. No ventilation. Industrial setting.	17.35	Not applicable - this is a modeled exposure	Partial shift	4 hours	(RIVM, 2013)	3809440 - 108	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
7	Open system transfers - industrial setting without LEV	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. No ventilation. Industrial setting.	14.46	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 108	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
8	Open system transfers - commercial setting without LEV	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. No ventilation. Commercial setting.	14.46	Not applicable - this is a modeled exposure	Partial shift	1 hours	(RIVM, 2013)	3809440 - 108	High	Excluded - commercial settings are not expected for NMP manufacturing
9	Open system transfers - commercial setting without LEV	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. No ventilation. Commercial setting.	17.35	Not applicable - this is a modeled exposure	Partial shift	4 hours	(RIVM, 2013)	3809440 - 108	High	Excluded - commercial settings are not expected for NMP manufacturing
10	Open system transfers - high temperature NMP - industrial setting with LEV (95%)	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. NMP handled at elevated temperatures. Local exhaust ventilation (95% efficiency). Industrial setting.	3.1	Not applicable - this is a modeled exposure	Partial shift	4 hours	(RIVM, 2013)	3809440 - 108	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
11	Open system transfers - high temperature NMP - industrial setting with LEV (90%)	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. NMP handled at elevated temperatures. Local exhaust ventilation (90% efficiency). Industrial setting.	12.39	Not applicable - this is a modeled exposure	Partial shift	4 hours	(RIVM, 2013)	3809440 - 108	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
12	Open system transfers - high temperature NMP - industrial setting without LEV	Modeled using EasyTRA model	Loading and unloading from containers using transfer lines or a dedicated fill point. NMP handled at elevated temperatures. No ventilation. Industrial setting.	12.91	Not applicable - this is a modeled exposure	Partial shift	1 hour	(RIVM, 2013)	3809440 - 108	High	Excluded - EPA modeled exposures, as shown in Rows 13 through 16
13	Transferring NMP to / from bulk containers (tank trucks and rail cars)	Modeled with *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Manually transferring 100% NMP to / from tank trucks (typical) and rail cars (worst-case), including equipment leaks	Typical = 0.76 Worst-case = 1.52	Not applicable - this is a modeled exposure	TWA (averaged over exposure duration)	transfer activity is 0.5 hours (typical) and 1 hour (worst-case)	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Not applicable	Not applicable	Included as short-term inhalation exposure concentration for PBPK model
14	Transferring NMP to / from bulk containers (tank trucks and rail cars)	Modeled with *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Manually transferring 100% NMP to / from tank trucks (typical) and rail cars (worst-case), including equipment leaks	Typical = 0.047 Worst-case = 0.19	Not applicable - this is a modeled exposure	8-hour TWA	8 hours - transfer activity is 0.5 hours (typical) and 1 hour (worst-case), with zero exposure the remainder of the shift	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Not applicable	Not applicable	Included as 8-hour worker inhalation exposure concentration for PBPK model

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
15	Transferring NMP to / from drums	Modeled with *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model*	Manually transferring 100% NMP to / from drums	Typical = 1.65 Worst-case = 5.85	Not applicable - this is a modeled exposure	TWA (averaged over exposure duration)	Manufacturing & Repackaging: 2.06 hours Disposal: 0.603 hours	(U.S. EPA, 2013a)	Not applicable	Not applicable	Included as short-term inhalation exposure concentration for PBPK model
16	Transferring NMP to / from drums	Modeled with *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model*	Manually transferring 100% NMP to / from drums	Manufacturing & Repackaging: Typical = 0.427 Worst-case = 1.51 Disposal: Typical = 0.125 Worst-case = 0.441	Not applicable - this is a modelled exposure	TWA (averaged over exposure duration)	8 hours - transfer activity duration from the above cell, with zero exposure the remainder of the shift	(U.S. EPA, 2013a)	Not applicable	Not applicable	Included as 8-hour worker inhalation exposure concentration for PBPK model

N/A - Not Applicable.

A.2 Repackaging

EPA did not find inhalation monitoring data related to the repackaging of NMP. The same monitoring data and modeled data presented in Appendix A.1 for the manufacturing of NMP are also applicable to repackaging of NMP, as these data apply to the transfers (i.e., loading and unloading) of NMP, which occurs at both manufacturing and repackaging sites.

EPA uses the calculated PBPK input parameters for full-shift (8-hour TWA) and short-term (acute) worker inhalation exposures presented in Rows 13 through 16 of Table_Apx A-1 in Appendix A.1. See Appendix A.1 for additional information on the calculation of these exposure concentrations.

A.3 Chemical Processing, Excluding Formulation

Table_Apx A-2 summarizes the inhalation monitoring data that are available in published literature for the use of NMP in non-incorporative processing activities. Rows 1 through 10 include air monitoring data for NMP from a compilation of NMP monitoring data prepared by the German Institute for Occupational Safety and Health (IFA) (IFA, 2010). These data are for processing activities related to the production of polymer activities, as well as for the storing and conveying of NMP. However, these data do not include information on the associated worker activities, sampling areas, sampling times, and type of storing and conveying systems associated with these data are unknown. EPA, therefore, cannot determine the function of NMP at the sites conducting polymer processing activities or the type of measurement taken. Thus, EPA excluded these data points from this analysis.

Rows 11 through 28 include air monitoring data that was submitted to EPA from E.I. DuPont De Nemours & Company in response to a proposed TSCA Section 4 test rule on NMP. These data were submitted in 1990 and were taken from 1983 to 1989, during polymer production using NMP. Some of these data lack information on sample durations and explanation on what the associated worker activities involve. Due to the age and lack of sample context, these data were rated of Medium quality. EPA found data that was rated High quality, presented in Rows 29 through 38 and discussed further below, which EPA used to estimate exposures for this scenario.

EPA summarized modeled inhalation exposure concentrations from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These modeled inhalation exposure concentrations are for the use of NMP as a process solvent or reagent in an industrial setting and include scenarios for closed processing systems with various levels of enclosure as well as the handling of NMP at both ambient and elevated temperatures. These data are all 8-hour TWA values and are presented in Rows 29 to 34 of Table_Apx A-2.

In addition to the modeled exposures compiled from the RIVM *Annex XV Proposal for a Restriction - NMP* report, EPA modeled potential worker inhalation exposures during the unloading of pure NMP. The unloading activity during this scenario is expected to present a high potential for worker exposure and is not already covered in the RIVM modeled exposures presented for this scenario. EPA modeled these exposure concentrations consistent with the methodology presented in Appendix A.1 for the manufacturing of NMP. Refer to Appendix A.1 for additional details on this modeling.

For the unloading of bulk containers containing pure NMP, EPA developed the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*, which calculates potential exposure concentrations based on the unloading of one tank truck (typical case) and one rail car (worst-case). The exposure duration is the time required to unload one container, which is half an hour for tank trucks and one hour for rail cars. For the unloading of drums containing NMP, EPA used the *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model* to determine NMP volatilization to air and associated potential worker inhalation exposures, respectively.

Note that, to determine an exposure duration for the unloading of drums at processing sites, EPA first determined throughput of NMP at these sites. NMP processing is assessed in both this scenario and in Section 2.4, Incorporation into Formulation, Mixture, or Reaction Product. EPA does not expect that NMP is processed in both conditions of use, but that the production volume of NMP is split between these conditions of use. EPA assumes that the entire production volume of NMP (161 million pounds per 2016 CDR; (U.S. EPA, 2016a) is processed and determined the throughput at processing sites by dividing the production volume by the total number of sites assessed between the two processing conditions of use (94 sites each per Sections 2.3.2.2 and 2.4.2.2) and by 250 days of operation per site per year. Based on this daily site throughput, the capacity of drums, and an assumed unloading rate of 20 drums/hour, the model determined an exposure duration of 0.362 hours for processing sites (assuming the site only unloads drums and no other container sizes).

For both unloading of bulk containers and drums, EPA calculated short-term and 8-hour TWA exposures to workers during unloading activities. The short-term TWA exposure is the weighted average exposure during the entire exposure duration per shift, accounting for the number of unloading events per shift. The 8-hour TWA exposure is the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. Table_Apx A-2 presents a summary of the exposure modeling results in Rows 35 through 38. EPA used the short-term modeled exposure concentrations for unloading drums (Row 37) as a conservative exposure scenario as input for the PBPK model for worker short-term exposures.

To determine potential full-shift inhalation exposure concentration, EPA calculated the central tendency (50^{th} percentile) and worst-case (95^{th} percentile) 8-hour TWA exposure concentrations from the data in Rows 29 through 35, and 38.

Table_Apx A-2. Summary of Inhalation Monitoring Data for Chemical Processing, Excluding Formulation

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Processing - polymer	Area	Listed as "plastics and plastic foam, processing and manufacture; manufacture and processing of rubber products." Worker activities and sampling areas are unknown.	50th percentile: 0.3 (below analytical quantification limit of 0.42) 90th percentile: 3 95th percentile: 3.5	40	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 102	Medium	Excluded - unknown worker activities and sampling areas
2	Processing - polymer	Personal	Listed as "plastics and plastic foam, processing and manufacture; manufacture and processing of rubber products." Worker activities and sampling areas are unknown.	50th percentile: 0.35 (below analytical quantification limit of 0.42) 90th percentile: 2.93 95th percentile: 4.985	61	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 110	Medium	Excluded - unknown worker activities and sampling areas
3	Processing - polymer	Unknown	Listed as "plastics and plastic foam, processing and manufacture; manufacture and processing of rubber products." Worker activities and sampling areas are unknown. Samples taken in the presence of LEV.	50th percentile: 0.5 90th percentile: 3.45 95th percentile: 4.775	65	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 117	Medium	Excluded - unknown worker activities and sampling areas
4	Processing - polymer	Unknown	Listed as "plastics and plastic foam, processing and manufacture; manufacture and processing of rubber products." Worker activities and sampling areas are unknown. Samples taken in the absence of LEV.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 1.92 95th percentile: 2.9	22	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 124	Medium	Excluded - unknown worker activities and sampling areas
5	Processing - polymer	Unknown	Listed as "plastics and plastic foam, processing and manufacture; manufacture and processing of rubber products." Work area group listed as "Foaming." These data are likely a subset of the above data.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 0.84 95th percentile: 1.72	14	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 160	Medium	Excluded - unknown worker activities and sampling areas
6	Processing - polymer	Unknown	Listed as "plastics and plastic foam, processing and manufacture; manufacture and processing of rubber products." Work area group listed as "Surface coating, painting, coating." These data are likely a subset of the above data.	50th percentile: 0.3 (below analytical quantification limit of 0.42) 90th percentile: 2 95th percentile: 2.6	28	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 161	Medium	Excluded - unknown worker activities and sampling areas

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
7	Processing - polymer	Personal	Work group area is listed as "foaming." No additional details are provided.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 0.38 (below analytical quantification limit of 0.42) 95th percentile: 0.49	11	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 136	Medium	Excluded - unknown worker activities and sampling areas
8	Processing - polymer	Unknown	Work group area is listed as "foaming." Samples taken in the presence of LEV. No additional details are provided.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 0.88 95th percentile: 1.84	13	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 147	Medium	Excluded - unknown worker activities and sampling areas
9	Storing, conveying	Area	Listed as "storing, conveying." No specific industries are listed.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 0.64 95th percentile: 1.155	13	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 129	Medium	Excluded - unknown worker activities and sampling areas
10	Storing, conveying	Unknown	Listed as "storing, conveying." No specific industries are listed. Samples taken in the presence of LEV.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 0.7 95th percentile: 1.35	10	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 145	Medium	Excluded - unknown worker activities and sampling areas
11	Processing - polymer	Personal	Organic polymer prep and solvent recovery	Mean: 0.02 Maximum: 0.81	21	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100-101	Medium	Excluded - data is from the 1980s and sample duration is unknown
12	Processing - polymer	Personal	Manufacture of composite prepreg	0.81	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 102	Medium	Excluded - data is from the 1980s and sample duration is unknown
13	Processing - polymer	Personal	Manufacture of composite prepreg	4.05	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 102	Medium	Excluded - data is from the 1980s and sample duration is unknown
14	Processing - polymer	Area	Resin heating mill hood	24.33	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 103	Medium	Excluded - data is from the 1980s and sample duration is unknown
15	Processing - polymer	Area	Resin heating mill hood	4.05	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 103	Medium	Excluded - data is from the 1980s and sample duration is unknown
16	Processing - polymer	Personal	Curing composite article at 800 F	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 106	Medium	Excluded - data is from the 1980s and sample duration is unknown
17	Processing - polymer	Area	Curing composite article at 800 F	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 107	Medium	Excluded - data is from the 1980s and sample duration is unknown
18	Processing - polymer	Personal	Devolatilizing composite article in laboratory hood	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 108	Medium	Excluded - data is from the 1980s and sample duration is unknown
19	Processing - polymer	Personal	Devolatilizing composite article in ventilated press	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 109	Medium	Excluded - data is from the 1980s and sample duration is unknown
20	Processing - polymer	Area	Devolatilizing composite article in ventilated press	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 110	Medium	Excluded - data is from the 1980s and sample duration is unknown

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
21	Processing - polymer	Personal	Impregnating fibers with resin in laboratory hood	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 111	Medium	Excluded - data is from the 1980s and sample duration is unknown
22	Processing - polymer	Personal	Cut patterns from prepreg and devolatilized for 2 hours	<0.41	1	Unknown	2 hours	(DuPont, 1990)	4214100 - 112	Medium	Excluded - data is from the 1980s
23	Processing - polymer	Area	Cut patterns from prepreg and devolatilized for 2 hours	<0.41	2	Unknown	2 hours	(DuPont, 1990)	4214100 - 113	Medium	Excluded - data is from the 1980s
24	Processing - polymer	Personal	Operator cut patterns from prepreg wearing skin protective equipment	<0.41	1	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100 - 114	Medium	Excluded - data is from the 1980s and sample duration is unknown
25	Processing - polymer	Personal	Clean up of 310 F heater plates	21.08	1	Unknown	9 minutes	(DuPont, 1990)	4214100 - 115	Medium	Excluded - data is from the 1980s
26	Processing - polymer	Personal	Clean up of 310 F heater plates	15.00	1	Unknown	13 minutes	(DuPont, 1990)	4214100 - 116	Medium	Excluded - data is from the 1980s
27	Processing - polymer	Personal	Clean up of 310 F heater plates	40.55	1	Unknown	17 minutes	(DuPont, 1990)	4214100 - 116	Medium	Excluded - data is from the 1980s
28	Processing - polymer	Personal	Clean up of 310 F heater plates	48.65	1	Unknown	13 minutes	(DuPont, 1990)	4214100 - 117	Medium	Excluded - data is from the 1980s
29	Processing - NMP used as a process solvent or reagent - closed system	Modeled using EasyTRA model	Manufacture of chemicals (NMP used as a process solvent or reagent) in a closed system at ambient temperatures. Most enclosed system. Industrial setting. No local exhaust ventilation.	0.04	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20
30	Processing - NMP used as a process solvent or reagent - closed system	Modeled using EasyTRA model	Manufacture of chemicals (NMP used as a process solvent or reagent) in a closed system at ambient temperatures. Medium level of enclosed system. Industrial setting. No local exhaust ventilation.	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20
31	Processing - NMP used as a process solvent or reagent - closed system	Modeled using EasyTRA model	Manufacture of chemicals (NMP used as a process solvent or reagent) in a closed system at ambient temperatures. Least enclosed system. Industrial setting. No local exhaust ventilation.	12.39	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20
32	Processing - NMP used as a process solvent or reagent - closed system - elevated temperature	Modeled using EasyTRA model	Manufacture of chemicals (NMP used as a process solvent or reagent) in a closed system at an elevated temperature up to 180C. Medium level of enclosed system. Industrial setting. Local exhaust ventilation with 90% capture efficiency.	0.04	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
33	Processing - NMP used as a process solvent or reagent - closed system - elevated temperature	Modeled using EasyTRA model	Manufacture of chemicals (NMP used as a process solvent or reagent) in a closed system at an elevated temperature up to 180C. Least enclosed system. Industrial setting. Local exhaust ventilation with 90% capture efficiency.	10.33	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20
34	Processing - NMP used as a process solvent or reagent - closed system - elevated temperature	Modeled using EasyTRA model	Manufacture of chemicals (NMP used as a process solvent or reagent) in a closed system at an elevated temperature up to 180C. Least enclosed system. Industrial setting. No local exhaust ventilation.	20.65	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20
35	Transferring NMP to / from bulk containers (tank trucks and rail cars)	Modeled with *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Manually transferring 100% NMP to / from tank trucks (typical) and rail cars (worst-case), including equipment leaks	Typical = 0.047 Worst-case = 0.95	Not applicable - this is a modeled exposure	8-hour TWA	8 hours - transfer activity is 0.5 hours (typical) and 1 hour (worst-case), with zero exposure the remainder of the shift	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Not applicable	Not applicable	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20
36	Transferring NMP to / from bulk containers (tank trucks and rail cars)	Modeled with *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Transferring 100% NMP to / from tank trucks (typical) and rail cars (worst-case), including equipment leaks	Typical = 0.76 Worst-case = 7.62	Not applicable - this is a modeled exposure	TWA (averaged over exposure duration)	transfer activity is 0.5 hours (typical) and 1 hour (worst-case)	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Not applicable	Not applicable	Excluded - EPA used the modeled short-term exposure from loading drums (Row 19) as a more conservative exposure scenario
37	Transferring NMP to / from drums	Modeled with *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model*	Manually transferring 100% NMP to / from drums	Typical = 1.65 Worst-case = 5.85	Not applicable - this is a modelled exposure	TWA (averaged over exposure duration)	Transfer activity is 0.362 hours, based on assumed throughput	(U.S. EPA, 2013a)	Not applicable	Not applicable	Included as short-term inhalation exposure concentration for PBPK model

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
38	Transferring NMP to / from drums	Modeled with *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model*	Manually transferring 100% NMP to / from drums	Typical = 0.075 Worst-case = 0.265	Not applicable - this is a modelled exposure	TWA (averaged over exposure duration)	8 hours - transfer activity is 0.362 hours, with zero exposure the remainder of the shift	(U.S. EPA, 2013a)	Not applicable	Not applicable	Included - EPA calculated the central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 11 through 17, and 20

A.4 Incorporation into Formulation, Mixture, or Reaction Product

Table_Apx A-3 shows inhalation monitoring data that are available in published literature for incorporation of NMP into a formulation, mixture, or reaction product. Rows 1 through 14 include air monitoring data for NMP at a site that formulate adhesives. These data include both 8-hour TWA exposure concentrations, as well as short-term exposure concentrations. EPA used the 8-hour TWA data in Rows 1 through 7 to calculate central tendency (50th percentile) and worst-case (95th percentile) potential full-shift worker inhalation exposure concentrations. EPA calculated a 50th percentile of 2.8 mg/m^3 and a 95th percentile of 12.8 mg/m^3 from these data. EPA used the 95th percentile 8-hour TWA value of 12.8 mg/m^3 as input for the PBPK model for this scenario.

EPA excluded the monitoring data in Row 8 through 14, as indicated in Table_Apx A-3. The monitoring data in Row 15 is for the formulation of printing inks and is not NMP-specific; thus, EPA excluded these data in favor of the NMP monitoring data as described above. The monitoring data in Rows 16 through 27 are from a compilation of NMP monitoring data prepared by the German Institute for Occupational Safety and Health (IFA) (IFA, 2010). However, the associated worker activities, sampling areas, sampling times, and type of storing and conveying systems associated with these data are unknown. EPA therefore excluded these data points from this analysis.

In addition to personal monitoring data, EPA summarized modeled inhalation exposure concentrations from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These exposure concentrations were modeled using the EasyTRA model, which is based on the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC) Targeted Risk Assessment (TRA) tool. These modeled inhalation exposure concentrations include all formulation activities and include scenarios for open and closed processing systems as well as for formulation at both ambient and elevated temperatures. These data are presented in Rows 28 to 38 of Table_Apx A-3. However, EPA uses NMP monitoring data as described above in lieu of modeled data.

In addition to the monitoring data, EPA modeled potential worker inhalation exposures unloading of pure NMP at formulation sites. The unloading activity during this scenario is expected to present a high potential for worker exposure and is not already covered in the RIVM modeled exposures presented for this scenario. EPA modeled these exposure concentrations consistent with the methodology presented in Appendix A.1 for the manufacturing of NMP. Refer to Appendix A.1 for additional details on this modeling.

For the unloading of bulk containers containing pure NMP, EPA developed the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*, which calculates potential exposure concentrations based on the loading of one tank truck (typical case) and one rail car (worst-case). The exposure duration is the time required to load one container, which is half an hour for tank trucks and one hour for rail cars. For the unloading of drums containing pure NMP, EPA used the *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model* to determine NMP volatilizations to air and associated potential worker inhalation exposures, respectively.

Note that, to determine an exposure duration for the unloading of drums at processing sites, EPA first determined throughput of NMP at these sites. NMP processing is assessed in both this scenario and in Section 2.3, Chemical Processing, Excluding Formulation. EPA does not expect that NMP is processed in both conditions of use, but that the production volume of NMP is split between these conditions of use. EPA assumes that the entire production volume of NMP (161 million pounds per the (U.S. EPA, 2016a) is processed and determined the throughput at processing sites by dividing the production volume by the total number of sites assessed between the two processing conditions of use (94 sites each per Sections 2.3.2.2 and 2.4.2.2) and by 250 days of operation per site per year. Based on this daily site throughput, the capacity of drums, and an assumed unloading rate of 20 drums/hour, the model determined an exposure duration of 0.362 hours for processing sites (assuming the site only unloads drums and no other container sizes).

For both unloading of bulk containers and drums, EPA calculated short-term and 8-hour TWA exposures to workers during unloading activities. The short-term TWA exposure is the weighted average exposure during the entire exposure duration per shift, accounting for the number of unloading events per shift. The 8-hour TWA exposure is the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. Table_Apx A-3 presents a summary of the exposure modeling results in Rows 39 through 42. EPA used the central tendency (50th percentile) short-term and 8-hour TWA modeled exposure concentrations for unloading drums (Row 19 and Row 20) as the central tendency input for the PBPK model, in addition to the monitoring data described above.

In addition to the formulation of liquid products, EPA identified formulation activities that may result in potential worker exposures to particulates containing NMP. Specifically, these include plastics compounding and blending of granular fertilizers, as described in Section 2.4.1. Due to the lower volatility of NMP, workers may be potentially exposed to NMP in inhaled dusts. EPA did not find monitoring data for NMP at sites that compound plastic or blend granular fertilizers.

The Draft 2014 ESD on Use of Additives in Plastics Compounding summarized OSHA monitoring data for total dust at compounding sites that was compiled in (U.S. EPA, 2014). These OSHA data are personal monitoring samples taken between 2006 and 2010 for particulates not otherwise regulated (PNOR) at facilities whose operations fall within the NAICS code 325991, Custom Compounding of Purchased Resins. However, these data are not activity-specific and have varying sample times ranging from about one to four hours. Thus, consistent with the methodology presented in the Draft 2014 ESD on Use of Additives in Plastics Compounding, EPA uses the OSHA PEL for Total Dust of 15 mg/m^3 to assess potential worker inhalation exposures to solids in this scenario. EPA identified five solid polymer resins with residual NMP ranging from 0.0017 to seven weight percent NMP and two granular agricultural chemicals with NMP content of less than 0.1 and less than five weight percent NMP. EPA multiplied the OSHA PEL by each of the identified NMP weight fractions to determine the potential NMP inhalation exposure concentrations, then calculated the central tendency (50th percentile) and worst-case (95th percentile) to be 0.75 and 0.96 mg/m^3, respectively, from these seven exposure concentrations. EPA did not use these values as input to the PBPK model because the model does not account for solid NMP.

Table_Apx A-3. Summary of Inhalation Monitoring Data for Incorporation into Formulation, Mixture, or Reaction Product

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Formulation of adhesives	Personal	Maintenance, foreman	1	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 106	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
2	Formulation of adhesives	Personal	Maintenance	2.8	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 106	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
3	Formulation of adhesives	Personal	Bottling, shipping	0.9	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 106	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
4	Formulation of adhesives	Personal	Maintenance, cleaning	2.3	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 107	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
5	Formulation of adhesives	Personal	Mixing, stirrer cleaning	3.4	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 109	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
6	Formulation of adhesives	Personal	Mixing, stirrer cleaning	6.6	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 109	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
7	Formulation of adhesives	Personal	Vessel cleaning	15.5	1	8-hour TWA	8 hours	(Bader et al., 2006)	3539720 - 111	High	Included - EPA calculated central tendency and worst-case 8-hour TWA exposure concentrations from the data in Rows 1 through 7
8	Formulation of adhesives	Personal	Maintenance, cleaning	5.9	1	Peak	42 min	(Bader et al., 2006)	3539720 - 108	High	Excluded - these data are short-term
9	Formulation of adhesives	Personal	Mixing, stirrer cleaning	18.7	1	Peak	19 min	(Bader et al., 2006)	3539720 - 110	High	Excluded - these data are short-term
10	Formulation of adhesives	Personal	Vessel cleaning	18	1	Peak	102 min	(Bader et al., 2006)	3539720 - 104	High	Excluded - these data are short-term
11	Formulation of adhesives	Personal	Vessel cleaning	85	1	Peak	5 min	(Bader et al., 2006)	3539720 - 112	High	Excluded - these data are short-term
12	Formulation of adhesives	Personal	manual vessel and fittings cleaning	Mean: 10.7 to 18.0	Unknown	Short term	NR	(Bader et al., 2006)	3539720 - 104	High	Excluded - these data are short-term

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
13	Formulation of adhesives	Area	Production area	Mean: 3.0	Unknown	NR	NR	(Bader et al., 2006)	3539720 - 103	High	Excluded – type of measurement is unknown
14	Formulation of adhesives	Area	Bottling and shipping department	Mean: 0.2	Unknown	NR	NR	(Bader et al., 2006)	3539720 - 105	High	Excluded – type of measurement is unknown
15	formulation of paste and liquid printing inks	Unknown	Average sample concentration at a printing inks manufacturing site that produces paste (75%) and liquid (assumed 25%) inks	2 (concentration of particulates, not NMP-specific)	Unknown	8-hour TWA	8 hours	(U.S. EPA, 2001)	Not applicable	Not applicable	Excluded - This sample result is not for NMP, but for particulates in general
16	Storing, conveying	Area	Listed as "storing, conveying." No specific industries are listed.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 0.64 95th percentile: 1.155	13	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 129	Medium	Excluded - unknown worker activities and sampling areas
17	Storing, conveying	Unknown	Listed as "storing, conveying." No specific industries are listed. Samples taken in the presence of LEV.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 0.7 95th percentile: 1.35	10	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 145	Medium	Excluded - unknown worker activities and sampling areas
18	Manufacture / processing of coatings, glue, adhesives	Area	Listed as "chemical industry and mineral processing," including manufacture / processing of coatings, glue, adhesives. Worker activities and sampling areas are unknown.	50th percentile: 0.175 (below analytical quantification limit of 0.42) 90th percentile: 13.41 95th percentile: 16.93	11	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 101	Medium	Excluded - unknown worker activities and sampling areas
19	Manufacture / processing of coatings, glue, adhesives	Personal	Listed as "chemical industry and mineral processing," including manufacture / processing of coatings, glue, adhesives. Worker activities and sampling areas are unknown.	50th percentile: 0.45 90th percentile: 6 95th percentile: 9.75	30	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 109	Medium	Excluded - unknown worker activities and sampling areas
20	Manufacture / processing of coatings, glue, adhesives	Unknown	Listed as "chemical industry and mineral processing," including manufacture / processing of coatings, glue, adhesives. Worker activities and sampling areas are unknown. Samples taken in the presence of LEV.	50th percentile: 0.45 90th percentile: 12.5 95th percentile: 16.8	30	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 116	Medium	Excluded - unknown worker activities and sampling areas

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
21	Manufacture / processing of coatings, glue, adhesives	Unknown	Listed as "chemical industry and mineral processing," including manufacture / processing of coatings, glue, adhesives. Work area group listed as "mixing, pressing." These data are likely a subset of the above data.	50th percentile: 0.4 (below analytical quantification limit of 0.42) 90th percentile: 4.5 95th percentile: 6.2	14	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 159	Medium	Excluded - unknown worker activities and sampling areas
22	Formulation - Mixing, pressing	Personal	Listed as work group area "mixing, pressing (compacting)." No additional details provided.	50th percentile: 0.35 (below analytical quantification limit of 0.42) 90th percentile: 3.45 95th percentile: 5.875	21	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 135	Medium	Excluded - unknown worker activities and sampling areas
23	Formulation - Mixing, pressing	Unknown	Listed as work group area "mixing, pressing (compacting)." Samples taken in the presence of LEV. No additional details provided.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 3.45 95th percentile: 5.875	21	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 146	Medium	Excluded - unknown worker activities and sampling areas
24	Processing of liquid coating materials	Unknown	Mfg. and processing of metals - processing of liquid coating materials	50th percentile: 0.2 below analytical quantification limit of 0.42 90th percentile: 13.45 95th percentile: 86.9	19	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 125	Medium	Excluded - unknown worker activities and sampling areas
25	Processing of liquid coating materials	Unknown	Mfg. and processing of metals - processing of liquid coating materials	50th percentile: 0.55 90th percentile: 4 95th percentile: 6.5	55	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 119	Medium	Excluded - unknown worker activities and sampling areas
26	Processing of liquid coating materials	Personal	Mfg. and processing of metals - processing of liquid coating materials	50th percentile: 0.5 90th percentile: 2.72 95th percentile: 3	44	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 111	Medium	Excluded - unknown worker activities and sampling areas

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
27	Processing of liquid coating materials	Area	Mfg. and processing of metals - processing of liquid coating materials	50th percentile: 0.2 below analytical quantification limit of 0.42 90th percentile: 13.41 95th percentile: 24.65	43	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 104	Medium	Excluded - unknown worker activities and sampling areas
28	Formulation - Closed system - Including all formulation activities	Modeled using EasyTRA model	Formulation of products at ambient temperature in a closed system. Most enclosed system. Industrial setting. No local exhaust ventilation.	0.04	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
29	Formulation - Closed system - Including all formulation activities	Modeled using EasyTRA model	Formulation of products at ambient temperature in a closed system. Medium level of enclosed system. Industrial setting. No local exhaust ventilation.	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
30	Formulation - Closed system - Including all formulation activities	Modeled using EasyTRA model	Formulation of products at ambient temperature in a closed system. Least enclosed system. Commercial and industrial settings. No local exhaust ventilation.	12.39	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
31	Formulation - Closed system - Elevated temperature - Including all formulation activities	Modeled using EasyTRA model	Formulation of products at an elevated temperature up to 120C in a closed system. Most enclosed system. Industrial setting. No local exhaust ventilation.	0.04	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
32	Formulation - Closed system - Elevated temperature - Including all formulation activities	Modeled using EasyTRA model	Formulation of products at an elevated temperature up to 120C in a closed system. Medium level of enclosed system. Industrial setting. No local exhaust ventilation.	20.65	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
33	Formulation - Closed system - Elevated temperature - Including all formulation activities	Modeled using EasyTRA model	Formulation of products at an elevated temperature up to 120C in a closed system. Least enclosed system. Industrial setting. Local exhaust ventilation with 90% capture efficiency.	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
34	Formulation - Open system - Elevated temperature - Including all formulation activities	Modeled using EasyTRA model	Mixing and blending products at an elevated temperature up to 60C. Industrial setting. No local exhaust ventilation.	20.65	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
35	Formulation - Open system - Elevated temperature - Including all formulation activities	Modeled using EasyTRA model	Mixing and blending products at an elevated temperature up to 120C. Industrial setting. Local exhaust ventilation with 90% capture efficiency.	20.65	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
36	Formulation - Open system - Elevated temperature - Including all formulation activities	Modeled using EasyTRA model	Mixing and blending products at an elevated temperature up to 60C. Commercial setting. No local exhaust ventilation.	17.35	Not applicable - this is a modeled exposure	Partial shift	4 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
37	Formulation - Loading	Modeled using EasyTRA model	Filling containers with final product (assumed) at ambient temperatures. Industrial setting. No local exhaust ventilation.	14.46	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
38	Formulation - Loading - Elevated temperature	Modeled using EasyTRA model	Filling containers with final product (assumed) at an elevated temperature up to 120C. Industrial setting. Local exhaust ventilation with 90% capture efficiency.	20.65	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 110	High	Excluded - EPA uses monitoring data over modeled data
39	Transferring NMP to / from bulk containers (tank trucks and rail cars)	Modeled with *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Transferring 100% NMP to / from tank trucks (typical) and rail cars (worst-case), including equipment leaks	Typical = 0.047 Worst-case = 0.95	Not applicable - this is a modeled exposure	8-hour TWA	8 hours - transfer activity is 0.5 hours (typical) and 1 hour (worst-case), with zero exposure the remainder of the shift	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Not applicable	Not applicable	Excluded - EPA uses monitoring data over modeled data
40	Transferring NMP to / from bulk containers (tank trucks and rail cars)	Modeled with *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Transferring 100% NMP to / from tank trucks (typical) and rail cars (worst-case), including equipment leaks	Typical = 0.76 Worst-case = 7.62	Not applicable - this is a modeled exposure	TWA (averaged over exposure duration)	transfer activity is 0.5 hours (typical) and 1 hour (worst-case)	*Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*	Not applicable	Not applicable	Excluded - EPA uses monitoring data over modeled data
41	Transferring NMP to / from drums	Modeled with *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model*	Manually transferring 100% NMP to / from drums	Typical = 1.65 Worst-case = 5.85	Not applicable - this is a modelled exposure	TWA (averaged over exposure duration)	Transfer activity is 0.362 hours, based on assumed throughput	(U.S. EPA, 2013a)	Not applicable	Not applicable	Included as short-term inhalation exposure concentration for PBPK model
42	Transferring NMP to / from drums	Modeled with *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model*	Manually transferring 100% NMP to / from drums	Typical = 0.075 Worst-case = 0.265	Not applicable - this is a modelled exposure	TWA (averaged over exposure duration)	8 hours - transfer activity is 0.362 hours, with zero exposure the remainder of the shift	(U.S. EPA, 2013a)	Not applicable	Not applicable	Excluded - EPA uses monitoring data over modeled data

A.5 Metal Finishing

Table_Apx A-4 shows inhalation monitoring data that are available in published literature for use of NMP-based metal finishing products. In addition to personal monitoring data, EPA summarized modeled inhalation exposure concentrations from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These exposure concentrations were modeled using the EasyTRA model, which is based on the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC) Targeted Risk Assessment (TRA) tool, and the Stoffenmanager risk assessment software. The ECHA report modeled potential inhalation exposures during generic application scenarios, specifically the dip, roll/brush, and spray application of formulations containing NMP. These modeled inhalation exposure concentrations are presented in Rows 3 to 7 of Table_Apx A-4.

The data in Rows 1 through 4 are from a compilation of monitoring data by the German Institute for Occupational Safety and Health (IFA). These data are listed as "foundries" and "manufacture and processing of metals" (IFA, 2010). EPA is unsure how NMP is used at the companies that fall within these industry categories. It is uncertain if the exposure monitoring data are 8-hour TWA values, but IFA indicates that they are representative of shift measurements (IFA, 2010). However, these data do not include any information regarding worker activities or sampling areas that can be used to determine the appropriate occupational exposure scenario.

While there are no personal monitoring data for spray application of metal formulations, there are data for the spray application of paints and coatings. EPA summarized and used these data in Section 2.5. Due to lack of data for this scenario, EPA used the same low-end, mean, and high-end values for spray application of paints and coatings in Section 2.7 as surrogate (surrogate work activities using NMP) for this scenario.

EPA also did not find any personal monitoring data for dip application of metal finishing fluids. While EPA did not find monitoring data for dip application of metal finishing fluids containing NMP, EPA did find monitoring data for the dip application of cleaning products containing NMP. EPA summarized and used these data in Section 2.13. Due to lack of data for this scenario, EPA used the same central tendency and worst-case values calculated for dip application of cleaning products in Section 2.13 as surrogate (surrogate work activities using NMP) for this scenario.

Finally, EPA did not find personal monitoring data on the brush application of metal finishing formulations. Thus, EPA assesses potential inhalation exposures for this scenario consistent with the approach used for brush application of paints, coatings, adhesives, and sealants used in Section 2.7. Specifically, EPA assesses the concentration of the modeled value shown in Row 7 of Table_Apx A-4.

Table_Apx A-4. Summary of Parameters for Worker Inhalation Exposure Concentrations During Metal Finishing

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Unknown application type	Area	Unknown application type. Unknown area of sampling.	50th percentile: below analytical quantification limit [b] 90th percentile: 15.8 95th percentile: 21.1	11	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 134	Unacceptable	Excluded – This sample does not indicate the type of application or sample time
2	Unknown application type	Personal	Unknown application type. Unknown area of sampling. Samples were taken in the presence of LEV.	50th percentile: below analytical quantification [b] 90th percentile: 0.6 95th percentile: 0.75	10	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 152	Unacceptable	Excluded – This sample does not indicate the type of application or sample time
3	Unknown application type	Unknown	Industry listed as "manufacture and processing of metals." Work group area listed as "surface coating, painting." Unknown application type. Unknown area of sampling. No additional details are provided.	50th percentile: 0.7 90th percentile: 3.86 95th percentile: 5.415	37	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 153	Medium	Excluded – This sample does not indicate the type of application nor sample time
4	Unknown application type	Unknown	Industry listed as "manufacture and processing of metals." Work group area listed as "cleaning." Unknown application type. Unknown area of sampling. No additional details are provided.	50th percentile: 1.5 90th percentile: 57 95th percentile: 96.4	14	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 154	Medium	Excluded – This sample does not indicate the type of application nor sample time
5	Dip application	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 117	High	Excluded - dip cleaning data for NMP is used as surrogate for this scenario
6	Dip application	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	12.4	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 117	High	Excluded - dip cleaning data for NMP is used as surrogate for this scenario
7	Brush / Roller Application	Modeled using EasyTRA model	Roll/brush application of NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 115	High	Included as PBPK input for roller / brush application

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
8	Spray application	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. With spray booth.	7.96	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded – NMP monitoring data for application of coatings is used as surrogate for this scenario
9	Spray application	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. Without spray booth.	18.7	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded – NMP monitoring data for application of coatings is used as surrogate for this scenario

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.
b – This analytical quantification limit is 0.42 mg/m^3 (IFA, 2010)

A.6 Removal of Paints, Coatings, Adhesives, and Sealants

Table_Apx A-5 shows all inhalation monitoring data for NMP-based paint and coating removal that EPA compiled from published literature sources, including 8-hour TWA, short-term, and partial shift sampling results. In addition to personal monitoring data, EPA summarized modeled inhalation exposure concentrations from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These exposure concentrations were modeled using the EasyTRA model, which is based on the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC) Targeted Risk Assessment (TRA) tool, and the Stoffenmanager risk assessment software. The ECHA report modeled potential inhalation exposures during generic application scenarios, specifically the dip, roll/brush, and spray application of formulations containing NMP. These modeled inhalation exposure concentrations are presented in Rows 22 to 26 of Table_Apx A-5.

The available data does not always distinguish the specific circumstances and industries in which paint and coating removal occurs; however, these data customarily identify graffiti removal separately from other paint and coating removal activities. Note that, where the literature source did not specify the industry or location of the removal activities, EPA includes these data in the miscellaneous paint, coating, adhesive, and sealant removal category.

Rows 1 – 8 were translated into 1-hour TWA values, from which low, mean, and high-end values were calculated for inputs into the PBPK model. Rows 9 and 10 were used for 8-hour TWA inputs into the PBPK model for paint stripping. Rows 11 – 15 were not considered in the risk evaluation because the sample times are unknown or are not representative of the assessed exposure durations.

For graffiti removal, the data in Row 19 were used as 8-hour TWA inputs into the PBPK model. The data in Rows 17 and 18 were not used because the results fall within the range in Row 19. Row 16, 21, and 22 were not used because the sample time is not representative of the assessed exposure durations.

Rows 22 – 26 were not used because actual data are favorable to modeled data.

The Department of Defense (DoD) provided monitoring data from its Defense Occupational and Environmental Health Readiness System – Industrial Hygiene (DOEHRS-IH), which collects occupational and environmental health risk data from each service branch (DOEHRS-IH, 2018). These data are included in Rows 27 and 28. These measurements all appear to be task-based samples; however, the work shift duration for workers performing the monitored activities is reported to be eight hours. The DOD NMP samples were taken during the removal of coatings and adhesives, which occur at a weekly or occasional frequency. Information on whether an activity is repeated during a work shift is not provided. One data point was provided as a less than value and no metadata were provided with which to interpret the data point (i.e., less than values are provided for measurements below the limit of detection). The overall confidence rating of the DOD data is High; however, the numeric confidence score is higher than the data from (U.S. EPA, 2015b), indicating lower quality. Therefore, EPA did not use these data in this risk evaluation.

Table_Apx A-5. Summary of Inhalation Monitoring Data for Removal of Paints, Coatings, Adhesives, and Sealants

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source [b]	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rational for Inclusion / Exclusion
1	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Application of floor stripping solution	17.4	1	Short-term	93 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
2	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Floor stripping	9.3	1	Short-term	48 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
3	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Floor stripping with window open	5.7	1	Short-term	64 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
4	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Application of floor stripping solution	21.1	1	Short-term	46 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
5	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Application of floor stripping solution. Windows and doors closed.	12.6	1	Short-term	47 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
6	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Application of floor stripping solution. Windows and doors closed.	21.1	1	Short-term	52 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
7	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Application of floor stripping solution. Windows and doors closed.	14.2	1	Short-term	43 minutes	(U.S. EPA, 2015b; NIOSH, 1998)	3827504 - 104	High	Included in 1-hour PBPK input summary
8	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Non-Specific Paint stripping	280	Unknown	Peak	1 hour	(U.S. EPA, 2015b; RIVM, 2013; EC, 2007; WHO, 2001)	3827504 - 104	High	Included in 1-hour PBPK input summary
9	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Furniture paint stripping	1.0 to 3.8	Unknown	TWA	125 to 167 minutes	(U.S. EPA, 2015b; Group, 2012)	3827504 - 104	High	Included as the minimum for 8-hour TWA input summary to PBPK model
10	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Non-Specific Paint stripping	64	Unknown	Maximum 8-hour TWA	8 hours	(U.S. EPA, 2015b; RIVM, 2013; EC, 2007; WHO, 2001)	3827504 - 105	High	Included in 8-hour TWA input summary to PBPK model
11	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Brush application of paint stripper	39	1	Consumer measurement [c]	129 minutes	(U.S. EPA, 2015b, 1994)	3827504 - 104	High	Excluded – This short-term sample is not representative of the assessed exposure durations
12	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Brush application of paint stripper	37	1	Consumer measurement [c]	130 minutes	(U.S. EPA, 2015b, 1994)	3827504 - 104	High	Excluded – This short-term sample is not representative of the assessed exposure durations
13	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Brush application of paint stripper	37	1	Consumer measurement [c]	143 minutes	(U.S. EPA, 2015b, 1994)	3827504 - 104	High	Excluded – This short-term sample is not representative of the assessed exposure durations
14	Miscellaneous paint coating, adhesive, and sealant removal	Unknown	Non-Specific Paint stripping with dip application	0.01 to 6	Unknown	Unknown	Unknown	(U.S. EPA, 2015b; Group, 2012)	3827504 - 104	High	Excluded – This short-term sample is not representative of the assessed exposure durations
15	Miscellaneous paint coating, adhesive, and sealant removal	Unknown	Non-Specific Paint stripping	0.82 to 4.1	Unknown	Unknown	Unknown	(RIVM, 2013; Will et al., 2004)	3827504 - 104	High	Excluded – This short-term sample is not representative of the assessed exposure durations

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source [b]	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rational for Inclusion / Exclusion
16	Graffiti removal	Unknown	Graffiti removal - Unknown worker activities or conditions	0.01 to 30	Unknown	Unknown	Unknown	(U.S. EPA, 2015b; Group, 2012)	3827504 - 104	High	Excluded – This short-term sample is not representative of the assessed exposure durations
17	Graffiti removal	Personal	Graffiti removal in poorly ventilated, partially enclosed spaces	Range: 0 to 1.68 Geometric mean: 0.4 Mean: 0.56	Unknown (data for 6 workers)	8-hour TWA	8 hours	(U.S. EPA, 2015b; Anundi et al., 2000)	3827504 - 106	High	Excluded – this sample set falls within the range used from Row 19
18	Graffiti removal	Personal	Graffiti removal in poorly ventilated, partially enclosed spaces	Range: 0.61 to 2.56 Geometric mean: 1.5 Mean: 1.78	Unknown (data for 3 workers)	8-hour TWA	8 hours	(U.S. EPA, 2015b; Anundi et al., 2000)	3827504 - 106	High	Excluded – this sample set falls within the range used from Row 19
19	Graffiti removal	Personal	Graffiti removal in poorly ventilated, partially enclosed spaces	Range: 0.03 to 4.52 Geometric mean: 0.67 Mean: 1	Unknown (data for 25 workers)	8-hour TWA	8 hours	(U.S. EPA, 2015b; Anundi et al., 2000)	3827504 - 103	High	Included – this sample set has the highest range for graffiti removal thus is used for 8-hour TWA PBPK inputs
20	Graffiti removal	Personal	Graffiti removal in poorly ventilated, partially enclosed spaces	Range: 0.01 to 24.61 Geometric mean: 1.97 Mean: 4.71 Standard deviation: 6.17	Unknown (data for 40 workers)	Short-term	15 minutes	(U.S. EPA, 2015b; Anundi et al., 2000)	3827504 - 107	High	Excluded – This short-term sample is not representative of the assessed time frames
21	Graffiti removal	Personal	Graffiti removal in partially enclosed spaces	9.9	1	Short-term	15 minutes	(U.S. EPA, 2015b; Anundi et al., 1993)	3827504 - 107	High	Excluded – This short-term sample is not representative of the assessed time frames
22	Miscellaneous paint coating, adhesive, and sealant removal	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 117	High	Excluded – Monitoring data is used over modeled data
23	Miscellaneous paint coating, adhesive, and sealant removal	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	12.4	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 117	High	Excluded – Monitoring data is used over modeled data
24	Miscellaneous paint coating, adhesive, and sealant removal	Modeled using EasyTRA model	Roll/brush application of NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 115	High	Excluded – Monitoring data is used over modeled data
25	Miscellaneous paint coating, adhesive, and sealant removal	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. With spray booth.	7.96	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded – Monitoring data is used over modeled data
26	Miscellaneous paint coating, adhesive, and sealant removal	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. Without spray booth.	18.7	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded – Monitoring data is used over modeled data
27	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Using Safe Strip to Remove Plastic Covering	<15.2	1	Short-term	17 minutes	(DOEHRS-IH, 2018)	5178607 - 103	High	Excluded – Air concentration is a less than value and no metadata were provided to interpret this value

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source [b]	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rational for Inclusion / Exclusion
28	Miscellaneous paint coating, adhesive, and sealant removal	Personal	Glue removal	11	1	Short-term	78 minutes	(DOEHRS-IH, 2018)	5178607 - 104	High	Excluded – These data have a lower confidence score than the data from (U.S. EPA, 2015b)

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.
b – Where information is presented in multiple sources all sources are listed. Information was not combined from these sources but was presented in all sources independently.
c – Consumer measurements may be used as surrogate for occupational exposures.

A.7 Application of Paints, Coatings, Adhesives, and Sealants

Table_Apx A-6 shows inhalation monitoring data that are available in published literature for NMP-based paints, coatings, adhesives and sealants. In addition to personal monitoring data, EPA summarized modeled inhalation exposure concentrations from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These exposure concentrations were modeled using the EasyTRA model, which is based on the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC) Targeted Risk Assessment (TRA) tool, and the Stoffenmanager risk assessment software. The RIVM *Annex XV Proposal for a Restriction - NMP* report modeled potential inhalation exposures during generic application scenarios, specifically the dip, roll/brush, and spray application of formulations containing NMP. These modeled inhalation exposure concentrations are presented in Rows 19 to 23 of Table_Apx A-6.

In the study by NIOSH, presented in Rows 1 – 9, samples were taken over two 3.5-hour periods (7 am to 10:30 am and 10:30 am to 2 pm) (totaling 7 hours per day for each monitored worker) (NIOSH, 1998). Since the NIOSH study authors did not assemble the two 3.5-hour samples for each worker together into a single 7-hour TWA exposure, nor provide the 3.5-hour TWA exposures for each unique worker, EPA assumed the distribution of exposures for a given worker in the first half of their shift is equal to the distribution of exposures in the second-half of their shift. Therefore, the 3.5-hour TWA exposure in the first-half of the shift equals the 3.5-hour TWA exposure in the second-half of the shift, which is also equal to the 7-hour TWA exposure.

Further, for spray application, EPA uses the data in Row 1 to represent potential inhalation exposure to workers. EPA translated these data into 4-hour TWA values by assuming no exposure during the remaining half hour in the 4 hour exposure duration. EPA translated these data into 8-hour TWA values by assuming workers are exposed to the concentrations in Row 1 for 7 hours, as described above, and have no exposure for the remaining 1 hour.

EPA did not use the data in Rows 3 to 5 because of the smaller sample size and the potential for the same workers to be captured in the sample results presented in Row 1. EPA did not use the data in Rows 6 to 11 because these are area samples, which are expected to be less representative of worker and ONU exposures than personal breathing zone samples.

The DoD provided NMP monitoring data taken during spray painting processes that occur at a weekly frequency (DOEHRS-IH, 2018). These data are included in Rows 24 and 25. Information on whether an activity is repeated during a work shift is not provided. Additionally, these data were provided as less than values and no metadata were provided with which to interpret these data (i.e., less than values are provided for measurements below the limit of detection). Therefore, EPA did not use these data in this risk evaluation.

Due to lack of personal monitoring data or modeled exposure data for roll coating, EPA assessed exposures using the *EPA/OPPT UV Roll Coating Inhalation Model*, which assumes a low-end particulate concentration in air of 0.04 mg/m^3 and a high-end particulate concentration of 0.26 mg/m^3 (OECD, 2011). To determine the potential worker exposure concentration of NMP, EPA multiplied these particulate air concentrations by the low, mid-range, and high-end mass fractions of NMP discussed in Section 2.7.2.3.2. Then, from these six calculated NMP exposure concentrations, EPA calculated a central tendency (50th percentile) and worst-case (95th percentile) exposure concentration to be 0.03 and 0.19, respectively. Note that the *EPA/OPPT UV Roll Coating Inhalation Model* is intended for assessing potential exposure concentrations to non-volatile portions of mists. Therefore, these exposure estimates may underestimate exposure as they do not account for the portion of NMP that volatilizes. However, NMP's low volatility should mitigate this underestimation.

EPA did not find any personal monitoring data for dip application of paints, coatings, adhesives, and sealants. The RIVM *Annex XV Proposal for a Restriction - NMP* report modeled a typical 8-hour TWA NMP exposure concentration of 4.13 mg/m^3 for a generic dip application scenario (see Row 19 of Table_Apx A-6) (RIVM, 2013). While EPA did not find monitoring data for dip application of paints, coatings, adhesives, and sealants containing NMP, EPA did find monitoring data for the dip application of cleaning products containing NMP. EPA summarized and used these data in Section 2.13. Due to lack of data for this scenario, EPA used the same central tendency and worst-case values calculated for dip application of cleaning products in Section 2.13 as surrogate (surrogate work activities using NMP) for this scenario.

EPA did not find any personal monitoring data for manual brush / roller or syringe / bead application of paints, coatings, adhesives, and sealants. The RIVM *Annex XV Proposal for a Restriction - NMP* report modeled a typical NMP exposure concentration of 4.13 mg/m^3 for a generic roller / brush application scenario (see Row 21 of Table_Apx A-6) (RIVM, 2013). EPA expects that these two application types result in similar exposure potential, as neither are expected to produce mists or aerosols, thus the main inhalation exposure point is the potential worker inhalation exposure to NMP vapors during the application and drying of paints, coatings, adhesives and sealants. Due to lack of any additional information, EPA utilizes this value to assess a typical potential worker exposure scenario.

Table_Apx A-6. Summary of Inhalation Monitoring Data for Application of Paints, Coatings, Adhesives, and Sealants

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Spray application	Personal	Workers who entered the paint booths to adjust the spray guns and/or to change the air filters.	Range: 0.04 to 5.15 Mean: 0.61 [b]	26	Short-term	3.5 hours	(NIOSH, 1998)	4287129 - 101	High	Included - used to represent 8-hour TWA input summary to PBPK model for spray application for workers
2	Spray application	Personal	Workers who did not work with paint or paint booths.	Range: 0.04 to 0.61 Mean: 0.16 [b]	19	Short-term	3.5 hours	(NIOSH, 1998)	4287129 - 102	High	Excluded – EPA used the range of exposures from Row 1, which is inclusive of these data
3	Spray application	Personal	Spray equipment operators (application done in a spray booth by worker from outside of booth).	Range: 0.04 to 0.12 Mean: 0.08 [b]	3	Short-term	3.5 hours	(NIOSH, 1998)	4287129 - 102	High	Excluded - these workers are expected to be included in those samples for the data set in Row 1
4	Spray application	Personal	Changing air filters inside a paint booth.	0.77 [b]	1	Short-term, for duration of task	5 minutes	(NIOSH, 1998)	4287129 - 101	High	Excluded – This sample is not representative of the assessed exposure durations
5	Spray application	Personal	Mixing the paint and filling the paint booth canister.	0.024 [b]	1	Short-term, for duration of task	12 minutes	(NIOSH, 1998)	4287129 - 102	High	Excluded – This sample is not representative of the assessed exposure durations
6	Spray application	Area	Inside paint booth.	Range: 18 to 101 Mean: 49 [b]	6	Short-term	90 minutes	(NIOSH, 1998)	4287129 - 103	High	Excluded – Personal samples are used over area samples
7	Spray application	Area	Area outside paint booth.	Range: 0.04 to 0.47 Mean: 0.20 [b]	8	Short-term	90 minutes	(NIOSH, 1998)	4287129 - 104	High	Excluded – Personal samples are used over area samples
8	Spray application	Area	Paint mix area.	Range: 0.16 to 0.81 Mean: 0.41 [b]	3	Short-term	90 minutes	(NIOSH, 1998)	4287129 - 104	High	Excluded – Personal samples are used over area samples
9	Spray application	Area	Lunch area.	Range: 0.04 to 0.12 Mean: 0.08 [b]	3	Short-term	90 minutes	(NIOSH, 1998)	4287129 - 104	High	Excluded – Personal samples are used over area samples
10	Spray application	Area	Air concentration of particulates while using a conventional air-atomized spray gun	Particulate concentration: 2.3 (downdraft) and 15 (cross-draft)	Unknown	Unknown	Unknown	(OECD, 2011)	Not applicable	Not applicable	Excluded – This sample is not representative of the assessed exposure durations
11	Spray application	Area	Air concentration of particulates while high volume-low pressure (HVLP) spray gun	Particulate concentration: 1.9 (downdraft) and 15 (cross-draft)	Unknown	Unknown	Unknown	(OECD, 2011)	Not applicable	Not applicable	Excluded – This sample is not representative of the assessed exposure durations
12	Unknown application type	Area	Unknown paint application type. Unknown area of sampling.	50th percentile: 0.2 90th percentile: 0.5 95th percentile: 2.5	12	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 108	Medium	Excluded – This sample does not indicate the type of application nor sample time

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
13	unknown application type	Area	Work group area listed as "surface coating, painting." No additional details are provided.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 3 95th percentile: 5.35	55	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 131	Medium	Excluded – This sample does not indicate the type of application nor sample time
14	unknown application type	Personal	Work group area listed as "surface coating, painting." No additional details are provided.	50th percentile: 0.65 90th percentile: 3 95th percentile: 4.865	39	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 138	Medium	Excluded – This sample does not indicate the type of application nor sample time
15	unknown application type	Unknown	Work group area listed as "surface coating, painting." Samples taken in the absence of LEV. No additional details are provided.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 3.24 95th percentile: 4.055	11	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 142	Medium	Excluded – This sample does not indicate the type of application nor sample time
16	unknown application type	Unknown	Work group area listed as "surface coating, painting." Samples taken in the presence of LEV. No additional details are provided.	50th percentile: 0.3 (below analytical quantification limit of 0.42) 90th percentile: 3.76 95th percentile: 5.46	68	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 149	Medium	Excluded – This sample does not indicate the type of application nor sample time
17	unknown application type	Personal	Equipment clean up in paint shop	Mean: 0.53 Maximum: 0.81	3	Unknown	unknown - greater than 5.5 hours	(DuPont, 1990)	4214100-104	Medium	Excluded - data is from the 1980s and sample duration is unknown
18	unknown application type	Personal	Solvent for spray application of roll coating	Mean: 8.11 Maximum: 12.16	2	Unknown	25 mins	(DuPont, 1990)	4214100-105	Medium	Excluded - data is from the 1980s
19	Dip application	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 117	High	Excluded - dip cleaning data for NMP is used as surrogate for this scenario
20	Dip application	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	12.4	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 117	High	Excluded - dip cleaning data for NMP is used as surrogate for this scenario
21	Brush / Roller Application	Modeled using EasyTRA model	Roll/brush application of NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 115	High	Included as PBPK input for roller / brush application
22	Spray application	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. With spray booth.	7.96	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded – Monitoring data is used over modeled data

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
23	Spray application	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. Without spray booth.	18.7	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded – Monitoring data is used over modeled data
24	Spray application	Personal	Spray paint tending	<5.08	1	Short-term	50 minutes	(DOEHRS-IH, 2018)	5178607 – 101	High	Excluded – Air concentration is a less than value and no metadata were provided to interpret this value
25	Spray application	Personal	Spray paint tending	<5.64	1	Short-term	45 minutes	(DOEHRS-IH, 2018)	5178607 – 102	High	Excluded – Air concentration is a less than value and no metadata were provided to interpret this value

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.
b – Converted from ppm to mg/m3 by multiplying the measurement in ppm by the molecular weight of NMP (99.133 g/mol) and dividing by molar volume (24.45 L).

A.8 Electronic Parts Manufacturing

EPA reviewed the assessment of exposures for workers in the electronics manufacturing industry that was presented in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). This report does not assess the use of NMP for cleaning in the electronics industries separately from other cleaning occupational exposure scenarios. The report additionally does not assess battery manufacturing separately from other coatings occupational exposure scenarios. EPA assessed exposures to NMP in the electronics manufacturing industry distinctly, due to the potential differences in processes and engineering controls at electronics manufacturing sites over other sites that perform cleaning and coating activities using NMP-based products.

Table_Apx A-8 shows inhalation monitoring data that are available in published literature for the use of NMP in the electronics manufacturing industries. Rows 1 through 5 present data compiled by the German Institute for Occupational Safety and Health (IFA, 2010). These data are categorized as being within the industry categories of electrical engineering, fine mechanics, and optics, which are classified as conducting surface coating and cleaning activities. The specific worker activities associated with the presented data are unknown. EPA therefore does not use these data.

The data presented in Rows 6 and 7 are from a study conducted by Beaulieu and Schmerber (1991) on the use of NMP in the microelectronics fabrication industry. The data in Row 7 represents the area air concentration of NMP when NMP is used at elevated temperatures (80°C). This sample is not expected to be representative of worker exposures because it is not a personal breathing zone sample and because current industry information indicates that processes are frequently totally or partially enclosed and equipped with ventilation that reduces the potential for worker exposures (Saft, 2017b; Roberts, 2017; RIVM, 2013).

The data provided in Rows 8 through 11 were provided in a public comment by the Semiconductor Industry Association (SIA) (SIA, 2017). These data were originally provided by the European Semiconductor Industry Association to the EU commission and ECHA for consideration in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013) and were collected at various semiconductor fabrication facilities between 2003 and 2012. These samples were taken in worker personal breathing zones.

SIA provided an additional data submission to EPA in 2019 (SIA, 2019a). These data are presented in Rows 12 through 22. These data are 8-hour and 12-hour TWA values for personal breathing zone samples of workers involved in handing and changeout of containers, photolithography operations, maintenance activities, virgin (100%) NMP unloading, and waste NMP (92%) loading. In addition, the SIA data contains 8-hour and 12-hour TWA area samples taken in the fabrication area. EPA calculated central tendency and high-end values for this dataset, for each task and 8-hour and 12-hour TWA values. The majority (i.e., 96% of all sample results) of samples were non-detect for NMP. Where non-detect values were included in the dataset, EPA calculated the limit of detection (LOD) divided by two. EPA used this method for approximating a concentration for non-detect samples because the geometric standard deviation of the dataset is greater than three (EPA, 1994). Because greater than 50% of the monitoring data results are non-detect for NMP, the use of the LOD/2 for the calculation of statistics will results in potentially biased estimates. However, no other methods to address the reporting limit of detection exist (EPA, 1994).

EPA calculated the central tendency and high-end values listed in Table_Apx A-7, using the LOD/2 for sample results that were non-detect for NMP. EPA used the SIA (SIA, 2019a) data to evaluate inhalation exposures for this scenario. EPA used these data in place of the 2017 data submitted by SIA (SIA, 2017). The SIA (SIA, 2019a) data was rated as High overall confidence compared to the previous SIA data, which was rated Medium. Additionally, the SIA (SIA, 2019a) data represents the same worker activities as those in the previous SIA submission, as well as a few additional worker activities.

Specifically, using the SIA (SIA, 2019a) data, EPA used the calculated 12-hour TWA central tendency (50^{th} percentile) and high-end (95^{th} percentile) values as inputs in the PBPK modeling. EPA used the 12-hour TWA data because there are more sample results for 12-hour shifts, indicating this is the more frequent shift length for this industry. EPA used these 12-hour TWA values in conjunction with dermal parameters for the PBK modeling. Note that EPA used updated NMP concentration values provided in the SIA (SIA, 2019a) dataset to calculate the central tendency and high-end NMP concentration that workers may be dermally exposed to.

Table_Apx A-7. Summary of SIA Data SIA (SIA, 2019a)

Task	Number of samples	Non-detects	8-hour TWA			12-hour TWA			notes
			Count	Central Tendency (mg/m3)	High-End (mg/m3)	Count	Central Tendency (mg/m3)	High-End (mg/m3)	
Container handling, small containers	19	19	5	0.026	0.243	14	0.507	0.608	8-hr: 50th percentile presented as central tendency and maximum value presented as high end 12-hr: 50th percentile presented as central tendency and 95th percentile presented as high end
Container handling, drums	15	15	5	0.026	0.026	10	0.013	1.544	8-hr: 50th percentile presented as central tendency and maximum value presented as high end 12-hr: 50th percentile presented as central tendency and 95th percentile presented as high end
Fab worker	28	28	0	N/A		28	0.138	0.405	12-hr: 50th percentile presented as central tendency and 95th percentile presented as high end
Maintenance	45	41	9	0.026	0.726	36	0.020	0.690	8-hr and 12-hr: 50th percentile presented as central tendency and 95th percentile presented as high end
Fab area samples	9	9	2	0.026	0.026	7	0.162	0.284	8-hr: Central tendency is the midpoint value between the two data points; high end is the higher of the two values 12-hr: 50th percentile presented as central tendency and 95th percentile presented as high end
Virgin NMP truck unloading	1	0	1	4.78		0	N/A		Single 8-hr TWA value available
Waste truck loading	1	1	1	0.709		0	N/A		Single 8-hr TWA value available

Table_Apx A-8. Summary of Worker Inhalation Exposure Concentrations During Electronics Manufacturing

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m³) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Electrical engineering, fine mechanics, optics	Area	Unknown activities within electrical engineering, fine mechanics, and optics manufacturing. Likely includes both cleaning and surface coatings activities.	50th percentile: 0.3 (below analytical quantification limit of 0.42) 90th percentile: 3.54 95th percentile: 6.2	44	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 106	Medium	Excluded - conditions of use and sample time are unknown
2	Electrical engineering, fine mechanics, optics	Personal	Unknown activities within electrical engineering, fine mechanics, and optics manufacturing. Likely includes both cleaning and surface coatings activities.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 9.6 95th percentile: 11.9	21	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 113	Medium	Excluded - conditions of use and sample time are unknown
3	Electrical engineering, fine mechanics, optics	Unknown	Unknown activities within electrical engineering, fine mechanics, and optics manufacturing. Likely includes both cleaning and surface coatings activities. Samples taken at facilities with LEV.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 3 95th percentile: 3.9	40	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 121	Medium	Excluded - conditions of use and sample time are unknown
4	Electrical engineering, fine mechanics, optics	Unknown	Listed as "surface coating, painting" within electrical engineering, fine mechanics, and optics manufacturing. Additional details are not provided.	50th percentile: 0.2 (below analytical quantification limit of 0.42) 90th percentile: 1.22 95th percentile: 1.965	21	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 157	Medium	Excluded - conditions of use and sample time are unknown
5	Electrical engineering, fine mechanics, optics	Unknown	Listed as "cleaning" within electrical engineering, fine mechanics, and optics manufacturing. Additional details are not provided.	50th percentile: 0.95 90th percentile: 11.9 95th percentile: 12	21	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 158	Medium	Excluded - conditions of use and sample time are unknown
6	Microelectronics fabrication	Personal	Unknown - workers in the microelectronics fabrication industry	Up to 6 mg/m3	Unknown	8-hour TWA	8 hours	(EC, 2007; WHO, 2001)	3809476 - 102	Low	Excluded - this sample is from a 1991 study and may not be representative of current industry conditions
7	Microelectronics fabrication	Area	Unknown - workers in the microelectronics fabrication industry when warm NMP (80°C) was being handled	Up to 280 mg/m3 (NMP at a temperature of 80°C)	Unknown	Full-shift	Unknown	(EC, 2007; WHO, 2001)	3809476 - 103	Low	Excluded - this sample is from a 1991 study and may not be representative of current industry conditions
8	Wafer stripping and removing processes	Personal	Wafer stripping ('cleaning') removing photoresist. Wafer cleaning for organics removal. Operations are in a closed processing system.	Range: less than the detection limit to 0.202	Unknown	Unknown - likely full-shift	Unknown	(SIA, 2017)	5176409 - 101	Medium	Excluded – EPA used updated data from SIA (SIA, 2019a) included below
9	Deposition processes	Personal	Photolithography layer spin-on. Polyimide deposition. Operations are in a closed processing system.	Range: 0.0247 to 0.857	Unknown	Unknown - likely full-shift	Unknown	(SIA, 2017)	5176409 - 102	Medium	Excluded – EPA used updated data from SIA (SIA, 2019a) included below
10	Maintenance	Personal	Preventive maintenance at process equipment tools in the cleanroom. Invasive maintenance.	Range: less than the detection limit to 0.770	Unknown	Unknown - likely full-shift	Unknown	(SIA, 2017)	5176409 - 103	Medium	Excluded – EPA used updated data from SIA (SIA, 2019a) included below

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
11	Chemical storage and handling	Personal	Chemicals storage and delivery areas open to ambient air. Canister, bottle and container change at tools and chemfill stations not in the cleanroom.	Range: less than the detection limit to 4.054	Unknown	Unknown - likely full-shift	Unknown	(SIA, 2017)	5176409 - 104	Medium	Excluded – EPA used updated data from SIA (SIA, 2019a) included below
12	Container handling	Personal	Container handling, small containers: 5-gallon to 20L	0.0263 - 0.243 (all samples are non-detect; values presented are LOD/2)	5	8-hr TWA	8-hour TWA	(SIA, 2019a)	5161295 - 101 to 105	High	Included – EPA used these data to estimate occupational exposures
13	Container handling	Personal	Container handling, small containers: 5-gallon to 20L	0.162 - 0.608 (all samples are non-detect; values presented are LOD/2)	14	12-hr TWA	12-hour TWA	(SIA, 2019a)	5161295 - 101 to 105	High	Included – EPA used these data to estimate occupational exposures
14	Container handling	Personal	Container handling, changeout: 55-gallon drum	0.0263 (all samples are non-detect; value presented is LOD/2)	5	8-hr TWA	8-hr TWA	(SIA, 2019a)	5161295 - 101 to 105	High	Included – EPA used these data to estimate occupational exposures
15	Container handling	Personal	Container handling, changeout: 55-gallon drum	0.0020 - 1.544 (all samples are non-detect; values presented are LOD/2)	10	12-hr TWA	12-hour TWA	(SIA, 2019a)	5161295 - 101 to 105	High	Included – EPA used these data to estimate occupational exposures
16	Microelectronics fabrication	Personal	Fab worker: Photolithography maintenance, production operator, routine operator, wet station operator	0.0067 - 0.405 (all samples are non-detect; values presented are LOD/2)	28	12-hr TWA	12-hour TWA	(SIA, 2019a)	5161295 - 110	High	Included – EPA used these data to estimate occupational exposures
17	Maintenance	area	Maintenance activities: filter changeout, cleaning, preventative maintenance	0.00608 - 0.750 (8 of 9 samples are non-detect; values presented are LOD/2)	9	8-hr TWA	8-hr TWA	(SIA, 2019a)	5161295 - 106 to 109	High	Included – EPA used these data to estimate occupational exposures
18	Maintenance	Area	Maintenance activities: filter changeout, cleaning, preventative maintenance	0.0020 - 1.544 (33 of 36 samples are non-detect; values presented are LOD/2)	36	12-hr TWA	12-hour TWA	(SIA, 2019a)	5161295 - 106 to 109	High	Included – EPA used these data to estimate occupational exposures
19	Fabrication area	Personal	Fab area samples: photolithography, polyimide cure oven, wet area	0.0263 (all samples are non-detect; value presented is LOD/2)	2	8-hr TWA	8-hr TWA	(SIA, 2019a)	5161295 - 111	High	Excluded – EPA used personal breathing zone samples to estimate occupational exposures and did assess risk from ONU exposures for this scenario
20	Fabrication area	Personal	Fab area samples: photolithography, polyimide cure oven, wet area	0.130 - 0.284 (all samples are non-detect; values presented are LOD/2)	7	12-hr TWA	12-hour TWA	(SIA, 2019a)	5161295 - 111	High	Excluded – EPA used personal breathing zone samples to estimate exposures
21	Virgin NMP unloading	Personal	Virgin NMP truck off-loading: Pull 6 samples for purity analysis; transfer of virgin NMP from a 10,000-gallon tanker truck to a 10,000-gallon tank in the tank farm. Turn on pump; stay in enclosure upstairs during ~ 2-hour transfer.	4.78	1	8-hr TWA	8-hr TWA	(SIA, 2019a)	5161295 - 113	High	Included – EPA used these data to estimate occupational exposures
22	Waste NMP loading	Personal	Waste truck loading: Transfer of approximately 5,000 gallons of NMP waste from a 10,000-gallon tank to a tanker truck.	0.709 (sample is non-detect; value presented is LOD/2)	1	8-hr TWA	8-hr TWA	(SIA, 2019a)	5161295 - 112	High	Included – EPA used these data to estimate occupational exposures

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.

A.9 Printing and Writing

EPA identified one source containing NMP monitoring data at a screen printing shop. However, this data is presented without any context. This data is presented in Row 1 of Table_Apx A-9 and is from a facility that conducts screen printing, but the sample type, sample duration, and associated worker activities are unknown, thus the data is not used in this risk evaluation.

The data in Rows 2 through 10 are from a compilation of monitoring data by the German Institute for Occupational Safety and Health (IFA). These data are listed as "woodworking, paper, and printing industry" (IFA, 2010). EPA is unsure how NMP is used at the companies that fall within this industry category, as no worker activities or sampling areas are described. Additionally, no sample times are provided in this compilation. Therefore, EPA excluded these data in this risk evaluation.

No other personal monitoring data on the use of NMP-based inks was found. Due to this lack of data, EPA assessed potential inhalation exposures during this scenario using data from NIOSH study on ink mist exposures at a printing shop (Belanger and Coye, 1983). The printing shop did not specifically use NMP-based inks; thus, this study did not monitor for NMP, but rather for ink mists in worker breathing zones. EPA used this ink mist data as surrogate and assumed likely NMP concentrations based on the concentrations of NMP identified in current products described in Section 2.6. The NIOSH study and EPA methodology for using the study results are described further below.

NIOSH conducted sampling at a newspaper printing plant in 1983 (Belanger and Coye, 1983). This printing plant operated five printing presses continuously for 24 hours per day. Specifically, NIOSH conducted personal breathing zone sampling of multiple workers, including printing press operators and assistants, for ink mist. This study consisted of 43 full shift samples, ranging from around 5 to 8 hours, and 5 partial shift samples, all between 3 and 4 hours. These data are summarized in Row 11. EPA translated these sample results into 8-hour TWA and 4-hour TWA concentrations, respectively, by assuming that exposure concentration is zero for the time remaining in the 8 and 4 hour durations. EPA then multiplied these ink mist air concentrations by the identified low-end, mean, and high-end weight fractions of NMP in ink. EPA identified products that range from 1 to 10 weight percent NMP, with a mean NMP concentration of 6.3 weight percent, as described in Section 2.6. From the calculated air concentrations, EPA then calculated central tendency (50^{th} percentile) and worst-case (95^{th} percentile) from these TWA values.

EPA did not find monitoring data on the use of markers or other writing instruments containing NMP. One assessment performed by Australia's National Industrial Chemicals Notification and Assessment Scheme (NICNAS) on the use of consumer products indicates that inhalation exposure from the use of writing inks is assumed negligible due to the small amount of ink, and therefore NMP, used (Australian Government Department of Health, 2016). In addition, the one writing product identified in the "Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: NMP" document and 2017 market profile for NMP indicate that the marker is a weather-resistant (Abt, 2017; U.S. EPA, 2017b). The SDS for this product confirms that the marker is weather-resistant and intended for use on polyurethane tags / labels (http://www.markal.com/assets/1/7/aw_plastic_eartag_white_medtip.pdf). Because, this product is weather-resistant, EPA expects that the primary users will use this product outside, which mitigates the potential for inhalation exposures.

Consistent with the NICNAS assessment approach and the outdoor use of the identified writing product containing NMP, EPA does not assess inhalation exposures during use of NMP writing inks.

Table_Apx A-9. Summary of Parameters for Worker Inhalation Exposure Concentrations During Printing and Writing

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m³) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Screen printing	Unknown	Unknown	7.1 to 22.2	Unknown	Unknown	Unknown	(RIVM, 2013)	3809440 - 119	Unacceptable	Excluded - Sample time and measurement types unknown
2	Unknown	Area	Listed as "woodworking, paper, printing"	50th percentile: below analytical quantification limit [b] 90th percentile: 1 95th percentile: 1.7	40	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 107	Medium	Excluded - sample times and conditions of use are unknown
3	Unknown	Area	Listed as "woodworking, paper, printing"	50th percentile: below analytical quantification limit [b] 90th percentile: 6.76 95th percentile: 26	28	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 163	Medium	Excluded - sample times and conditions of use are unknown
4	Unknown	Personal	Listed as "woodworking, paper, printing"	50th percentile: below analytical quantification limit [b] 90th percentile: 12.56 95th percentile: 120.6	14	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 164	Medium	Excluded - sample times and conditions of use are unknown
5	Unknown	Personal	Listed as "woodworking, paper, printing"	50th percentile: below analytical quantification limit [b] 90th percentile: 3.2 95th percentile: 12.8	39	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 114	Medium	Excluded - sample times and conditions of use are unknown
6	Unknown	Unknown	Listed as "woodworking, paper, printing". Taken in the presence of LEV.	50th percentile: below analytical quantification limit [b] 90th percentile: 1 95th percentile: 3.86	33	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 122	Medium	Excluded - sample times and conditions of use are unknown
7	Unknown	Unknown	Listed as "woodworking, paper, printing". Taken in the presence of LEV.	50th percentile: below analytical quantification limit [b] 90th percentile: 2.35 95th percentile: 3	45	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such	(IFA, 2010)	4271620 - 123	Medium	Excluded - sample times and conditions of use are unknown

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
							that this is comparable to a shift measurement				
8	Unknown	Unknown	Listed as "woodworking, paper, printing". Taken in the absence of LEV.	50th percentile: below analytical quantification limit [b] 90th percentile: 1.7 95th percentile: 1.74	33	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 127	Medium	Excluded - sample times and conditions of use are unknown
9	Unknown	Unknown	Listed as "woodworking, paper, printing". Taken in the absence of LEV.	50th percentile: below analytical quantification limit [b] 90th percentile: 28 95th percentile: 34	45	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 128	Medium	Excluded - sample times and conditions of use are unknown
10	Unknown	Unknown	Listed as "woodworking, paper, printing". Taken in the absence of LEV.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 0.46 95th percentile: 0.95	22	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 155	Medium	Excluded - sample times and conditions of use are unknown
11	Unknown	Personal	Multiple different workers	Range: 0.12 to 3.29	48	Partial and Full Shift	3.3 to 7.9 hours	(Belanger and Coye, 1983)	3101190 - 101	Medium	Included - individual samples were translated to 4-hour or 8-hour TWAs (assuming no exposure for remaining time in shift), then central tendency and worst-case were calculated for PBPK inputs

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.
b – This analytical quantification limit is 0.42 mg/m^3 (IFA, 2010)

A.10 Soldering

EPA did not find inhalation monitoring data specifically related to the use of NMP-based soldering products. The German Institute for Occupational Safety and Health (IFA) compiled monitoring data for multiple industries that use NMP, including the machinery manufacturing industry and the building industry (IFA, 2010). These data are summarized in Table_Apx A-10.

EPA has not identified information describing how NMP is used within the machinery manufacturing industry. However, EPA believes that the operations within the machinery manufacturing industry likely fall into the paint and coatings category, which is assessed in Section 2.5. EPA therefore excludes these data, presented in Rows 1, 2, 3, 5, and 6, from the assessment of this scenario.

The activities associated with the building industry data presented in Row 4 of Table_Apx A-10 are also unknown, and may include soldering, paint stripping, or any other use of NMP within the building industry. EPA therefore excludes these data.

Due to lack of additional information and the low NMP content in the one identified soldering production containing NMP (one to 2.5 weight percent NMP), the potential for worker and ONU inhalation exposures is likely small. In addition, some of the NMP may be destroyed in the soldering process, further mitigating the potential for inhalation exposures. Thus, EPA does not assess potential inhalation exposures during soldering.

Table_Apx A-10. Summary of Inhalation Exposure Concentrations During Soldering

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Manufacture of machinery and vehicles	Area	Unknown activities for the manufacture of parts for motor vehicles and engines.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 5.02 95th percentile: 7.36	16	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 105	Medium	Excluded - conditions of use are unknown; this is likely related to coatings application
2	Manufacture of machinery and vehicles	Personal	Unknown activities for the manufacture of parts for motor vehicles and engines.	50th percentile: 0.3 90th percentile: 1.75 95th percentile: 2.725	15	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 112	Medium	Excluded - conditions of use are unknown; this is likely related to coatings application
3	Manufacture of machinery and vehicles	Unknown	Listed as "Steel construction, manufacture of machinery and vehicles." Work group listed as surface coating, painting."	50th percentile: 0.7 90th percentile: 5.56 95th percentile: 7.36	16	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 156	Medium	Excluded - conditions of use are unknown; this is related to coatings application
4	Building industry	Personal	Unknown activities within the building industry.	50th percentile: 1.5 90th percentile: 6.6 95th percentile: 7.9	11	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 115	Medium	Excluded - conditions of use are unknown
5	Manufacture of machinery and vehicles	Unknown	Unknown activities for the manufacture of parts for motor vehicles and engines. Taken in presence of LEV.	50th percentile: 0.55 90th percentile: 5.8 95th percentile: 7.45	15	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 120	Medium	Excluded - conditions of use are unknown; this is likely related to coatings application
6	Manufacture of machinery and vehicles	Unknown	Unknown activities for the manufacture of parts for motor vehicles and engines. Taken at facilities without LEV.	All measurements were below the analytical quantification limit of 0.42	10	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 126	Medium	Excluded - conditions of use are unknown; this is likely related to coatings application

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.

A.11 Commercial Automotive Servicing

EPA did not find monitoring data for the use of NMP products during automotive servicing. Further, EPA did not find any monitoring data for the use of NMP aerosol products in any industry. To estimate potential worker inhalation exposures during the use of aerosol products that contain NMP, EPA modeled potential occupational inhalation exposures for workers and ONUs using EPA's model for *Occupational Exposures during Aerosol Degreasing of Automotive Brakes*. This model was used because EPA does not have related monitoring data nor throughput parameters (i.e., annual and daily amounts of NMP products used per servicing site). This model includes default parameters for throughput based on information that CARB obtained from industry surveys of automotive brake cleaner manufacturers and automotive repair shops.

EPA used the NMP concentrations of the two aerosol degreasing products identified in Section 2.13.1.1 as inputs to the model. The concentrations of these products are 4.5 and 35 to 40 weight percent. The results of this modeling are near-field and far-field inhalation exposure estimates, which are used as the input parameters used for the PBPK modeling for workers in and ONUs, respectively. Specifically, EPA uses the 50th and 95th percentile model results to represent central tendency and worst-case inhalation exposures, respectively. This model calculates both 8-hour TWA and 1-hour TWA exposure concentrations.

Table_Apx A-11. Aerosol Degreasing Model Results

Statistic	C (mg/m^3)			
	8-hour TWA		1-hour TWA	
	Near-field (Worker) Exposure	Far-field (ONU) Exposure	Near-field (Worker) Exposure	Far-field (ONU) Exposure
Maximum	564.36	128.87	1,504.94	331.33
99th Percentile	72.55	4.20	210.89	12.44
95th Percentile	43.44	1.57	128.76	4.71
50th Percentile	6.39	0.13	19.96	0.40
5th Percentile	0.94	0.01	3.07	0.04
Minimum	0.07	0.00	0.42	0.01
Mean	12.95	0.40	39.13	1.20

A.12 Laboratory use

Table_Apx A-12 shows the inhalation monitoring data that is available in published literature for use of NMP in a laboratory setting. EPA only found one data source that had inhalation monitoring data, which is presented in Row 1. This data is for a two-hour exposure duration at a laboratory that uses NMP as a media in which to dissolve a photoresist formulation for quality testing (Solomon et al., 1996). Specifically, this sample was taken during the preparation of NMP before use (purification), sample preparation (dissolving of solid photoresist into NMP), and sample analysis (operating atomic absorption Spectrophotometer). EPA uses this result as an input into the PBPK model for 2-hour exposure duration.

In addition to this data point, EPA presented modeled potential inhalation exposures during use of NMP in industrial and commercial laboratory settings that were included in the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These modeled exposures are presented in Rows 2 and 3. RIVM included these modeled exposures in the report due to the lack of actual inhalation monitoring data for NMP. In lieu of additional monitoring data, EPA uses the modeled exposure concentration in Row 2 for use of NMP in industrial laboratories with 90 percent efficient LEV as the input into the PBPK model for a typical full-shift, 8-hour exposure duration. EPA uses the modeled exposure in Row 3 for use of NMP in commercial laboratories with 80 percent efficient LVE as the input for worst-case full-shift inhalation exposures. EPA uses Row 3 as worst-case because these data relate to commercial laboratories that use LEV with a lower capture efficiency than those employed by the industrial laboratories represented in Row 2.

Table_Apx A-12. Summary of Inhalation Monitoring Data for Laboratory Use

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Laboratory use	Source notes that this result was obtained in both personal and area samples	Pouring NMP through an ion-exchange column under pressure (for purification); sample preparation and analysis (QC samples of negative photoresist used in the electronics industry that were dissolved in NMP)	0.2	Unknown	Partial Shift	2 hours	(Solomon et al., 1996)	3043623 - 101	Medium	Included - this concentration is used as input into the PBPK model for a 2 hour exposure duration
2	Laboratory use	Modeled using EasyTRA model	Laboratory use in an industrial setting with local exhaust ventilation (90% efficiency).	2.07	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 127	High	Included - this concentration is used as input into the PBPK model for a typical full-shift exposure
3	Laboratory use	Modeled using EasyTRA model	Laboratory use in a commercial setting with local exhaust ventilation (80% efficiency).	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 127	High	Included - this concentration is used as input into the PBPK model for a worst-case full-shift exposure

A.13 Cleaning

Table_Apx A-13 shows inhalation monitoring data that is available in published literature for NMP-based cleaning products. In addition to personal monitoring data, EPA summarized modeled inhalation exposure concentrations from the RIVM *Annex XV Proposal for a Restriction - NMP* report (RIVM, 2013). These exposure concentrations were modeled using the EasyTRA model, which is based on the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC) Targeted Risk Assessment (TRA) tool, and the Stoffenmanager risk assessment software. The ECHA report modeled potential inhalation exposures during generic application scenarios, specifically the dip, roll/brush, and spray application of formulations containing NMP. These modeled inhalation exposure concentrations are presented in Rows 20 to 24 of Table_Apx A-13.

The available data do not always distinguish the specific circumstances and industries in which cleaning activities occur. Note that, where the literature source did not specify the type of cleaning, EPA includes these data in all cleaning occupational exposure scenarios.

For dip cleaning, EPA calculated 8-hour TWA central tendency (based on 50^{th} percentile) and worst-case (based on 95^{th} percentile) estimates for using the mean values listed in Rows 1 – 6, 8 – 13, 17, and 20. For spray / wipe cleaning, EPA calculated 8-hour TWA central tendency and worst-case estimates using the mean values listed in Rows 1 – 6, 17, and 22. Note, EPA used the modeled exposure for NMP that is listed in Row 23 as surrogate for wipe cleaning. EPA did not use the data in Rows 7, 14, and 15 because the sample times are unknown. EPA did not use the data in Rows 16, 18, and 19 because the sample types are area or unknown, which may not be representative of exposures.

Table_Apx A-13. Summary of Inhalation Monitoring Data for Cleaning

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m³) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rational for Inclusion / Exclusion
1	Unknown	Personal	Cleaning of metal parts to remove resin (unknown cleaner application type)	Mean: 0.57 Max: 3.24 [b]	14	8-hour TWA	8 hours	(Nishimura et al., 2009)	735269 - 101	High	Included in 8-hour TWA input summary to PBPK model for dip and spray / wipe cleaning
2	Unknown	Personal	Cleaning of metal parts to remove resin (unknown cleaner application type)	Mean: 0.97 [b]	14	8-hour TWA	8 hours	(Nishimura et al., 2009)	735269 - 101	High	Included in 8-hour TWA input summary to PBPK model for dip and spray / wipe cleaning
3	Unknown	Personal	Cleaning of metal parts to remove resin (unknown cleaner application type)	Mean: 0.69 [b]	14	8-hour TWA	8 hours	(Nishimura et al., 2009)	735269 - 101	High	Included in 8-hour TWA input summary to PBPK model for dip and spray / wipe cleaning
4	Unknown	Personal	Cleaning of metal parts to remove resin (unknown cleaner application type)	Mean: 1.05 [b]	14	8-hour TWA	8 hours	(Nishimura et al., 2009)	735269 - 101	High	Included in 8-hour TWA input summary to PBPK model for dip and spray / wipe cleaning
5	Unknown	Personal	Cleaning of metal parts to remove resin (unknown cleaner application type)	Mean: 0.65 [b]	14	8-hour TWA	8 hours	(Nishimura et al., 2009)	735269 - 101	High	Included in 8-hour TWA input summary to PBPK model for dip and spray / wipe cleaning
6	Unknown	Personal	Cleaning of optical and metal parts (unknown cleaner application type)	Mean: 2.0 Max: 2.8	12	12-hour TWA	12 hours	(Bader et al., 2006)	3539720 - 101	Medium	Included in 8-hour TWA input summary to PBPK model for dip and spray / wipe cleaning
7	Unknown	Unknown	Industrial tank cleaning	Range: 4.1 to 12.4	Unknown	Unknown	Unknown	(RIVM, 2013)	3809440 - 124	High	Excluded – This sample is not representative of the assessed exposure durations
8	Dip cleaning	Personal	Full-shift sampling for volunteers who stayed in the lens cleaning workroom	Range: 0.97 to 1.30 Mean: 1.01 +/- 0.12 [b]	5 (one per day for one worker for a week)	8-hour TWA	8 hours	(Xiaofei et al., 2000)	3562767 - 101	Medium	Included in 8-hour TWA input summary to PBPK model for dip cleaning
9	Dip cleaning	Personal	Workers place parts in basket, put basket in chamber, close chamber, open chamber, remove basket and allow drying in ambient conditions, transfer basket to washing process	Range: 1.14 to 2.80 Mean: 1.70 +/- 0.57 [b]	5 (one per day for one worker for a week)	12-hour TWA	12 hours	(Xiaofei et al., 2000)	3562767 - 101	medium	Included in 8-hour TWA input summary to PBPK model for dip cleaning
10	Dip cleaning	Personal	Workers place parts in basket, put basket in chamber, close chamber, open chamber, remove basket and allow drying in ambient conditions, transfer basket to washing process	Range: 0.57 to 1.62 Mean: 0.97 +/- 0.36 [b]	5 (one per day for one worker for a week)	12-hour TWA	12 hours	(Xiaofei et al., 2000)	3562767 - 101	medium	Included in 8-hour TWA input summary to PBPK model for dip cleaning

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m³) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rational for Inclusion / Exclusion
11	Dip cleaning	Personal	Workers place parts in basket, put basket in chamber, close chamber, open chamber, remove basket and allow drying in ambient conditions, transfer basket to washing process	Range: 0.36 to 0.85 Mean: 0.57 +/- 0.20 [b]	5 (one per day for one worker for a week)	12-hour TWA	12 hours	(Xiaofei et al., 2000)	3562767 - 101	Medium	Included in 8-hour TWA input summary to PBPK model for dip cleaning
12	Dip cleaning	Personal	Workers place parts in basket, put basket in chamber, close chamber, open chamber, remove basket and allow drying in ambient conditions, transfer basket to washing process	Range: 0.97 to 1.14 Mean: 0.77 +/- 0.24 [b]	5 (one per day for one worker for a week)	12-hour TWA	12 hours	(Xiaofei et al., 2000)	3562767 - 101	Medium	Included in 8-hour TWA input summary to PBPK model for dip cleaning
13	Dip cleaning	Personal	Dip cleaning of metal parts. Workers place parts in basket, lower basket, life basket when cleaning complete, and transfer to water tank	Range: 0.16 to 2.39 Mean: 1.34 +/- 0.81 [b]	8	12-hour TWA	12 hours	(Xiaofei et al., 2000)	3562767 - 102	medium	Included in 8-hour TWA input summary to PBPK model for dip cleaning
14	Dip cleaning	Unknown	Immersion cleaning of metal parts	Mean: 1.26 [b]	Unknown	Unknown	Unknown	(BASF, 1993)	3982074 - 101	Low	Excluded – This sample is not representative of the assessed exposure durations
15	Dip cleaning	Unknown	Immersion cleaning of metal parts	Mean: 7.46 [b]	Unknown	Unknown	Unknown	(BASF, 1993)	3982074 - 102	Low	Excluded – This sample is not representative of the assessed exposure durations
16	Unknown	Area	Work group area listed as "cleaning." No additional details are provided.	50th percentile: 0.7 90th percentile: 15 95th percentile: 90	30	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 132	Medium	Excluded – Area samples are not as representative of exposures as personal samples
17	Unknown	Personal	Work group area listed as "cleaning." No additional details are provided.	50th percentile: 2 90th percentile: 12.35 95th percentile: 18.875	23	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 139	Medium	Included in 8-hour TWA input summary calculation for PBPK model for dip and spray / wipe cleaning
18	Unknown	Unknown	Work group area listed as "cleaning." Samples taken in the absence of LEV. No additional details are provided.	50th percentile: 0.4 (below analytical quantification limit of 0.42) 90th percentile: 79.6 95th percentile: 102.1	11	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 143	Medium	Excluded – Unknown sample type. These data may not be representative of exposures

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m³) [a]	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rational for Inclusion / Exclusion
19	Unknown	Unknown	Work group area listed as "cleaning." Samples taken in the presence of LEV. No additional details are provided.	50th percentile: 0.9 90th percentile: 10.85 95th percentile: 13.125	35	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 150	Medium	Excluded – Unknown sample type. These data may not be representative of exposures
20	Dip cleaning	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 117	High	Included in 8-hour TWA input summary calculation for PBPK model for dip cleaning
21	Dip cleaning	Modeled using EasyTRA model	Dip application of substrate into NMP-containing solution	12.4	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 117	High	Excluded - EPA uses monitoring data over modeled data
22	Wipe/spray Cleaning	Modeled using EasyTRA model	Roll/brush application of NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 115	High	Included in 8-hour TWA input summary calculation for PBPK model for wipe/spray cleaning
23	Wipe/spray Cleaning	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. With spray booth.	7.96	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded - EPA uses monitoring data over modeled data
24	Wipe/spray Cleaning	Modeled using Stoffenmanager model	Spray application of NMP-containing solution. Without spray booth.	18.7	Not applicable - this is a modeled exposure	Short-term	4 hours	(RIVM, 2013)	3809440 - 113	High	Excluded - EPA uses monitoring data over modeled data

a – Statistics were calculated by the cited source and are presented here as they were presented in the source.
b – Converted from ppm to mg/m³ by multiplying the measurement in ppm by the molecular weight of NMP (99.133 g/mol) and dividing by molar volume (24.45 L/mol).

A.14 Fertilizer Application

EPA did not find inhalation monitoring data for the application of fertilizers containing NMP. The RIVM *Annex XV Proposal for a Restriction - NMP* report presented the modeled potential inhalation exposures during spray and fog application of agrochemicals (RIVM, 2013). EPA summarized these modeled exposures in Table_Apx A-14. The RIVM *Annex XV Proposal for a Restriction - NMP* report recommends that manual application activities should be limited to four hours per shift or less (RIVM, 2013). Application with more automated equipment and separation of the worker from the sources of exposure can exceed this recommendation. EPA thus assesses both full-shift 8-hour TWA and short-term 4-hour TWA inhalation exposures. EPA did not find data on short-term exposures.

Due to lack of additional information or modeling approaches, EPA uses the full-shift modeled exposures from the RIVM *Annex XV Proposal for a Restriction - NMP* report to represent potential inhalation exposures during this scenario. Specifically, EPA uses the exposure estimate in Row 1 as a central tendency inhalation exposure concentration and the estimate in Row 2 as a worst-case inhalation exposure concentration. These estimates are both full-shift, 8-hour TWA exposures.

Table_Apx A-14. Summary of Worker Inhalation Exposure Concentrations During Fertilizer Application

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Spray or fog application of agrochemicals	Modeled using EasyTRA model	Spray or fog application of agrochemicals by a worker located outside, in a cabin with supplied air.	2.97	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 – 131	High	Included - central tendency
2	Spray or fog application of agrochemicals	Modeled using EasyTRA model	Spray or fog application of agrochemicals by a worker located inside without the use of a cabin.	5.27	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 131	High	Included - worst case

A.15 Wood Preservatives

Table_Apx A-15 shows inhalation monitoring data that are available in published literature for use of NMP-based wood preservative products. In addition to personal monitoring data, EPA presented the modeled potential inhalation exposures during generic roller/brush application of formulations containing NMP found in the RIVM *Annex XV Proposal for a Restriction - NMP* report.

The data presented in Row 1 are applicable to the use of wood preservatives on wooden furniture, not on utility poles as is assessed in this scenario. Additionally, this sample represents indoor air concentration of NMP, not personal worker inhalation exposures during the use of wood preservatives on outdoor utility poles. Thus, this data point is excluded from the risk assessment.

The data presented in Rows 2 through 5 are from a compilation of monitoring data by the German Institute for Occupational Safety and Health (IFA). These data are listed as “processing and treatment of wood,” with specific work group areas listed as “processing, sanding, removal” (IFA, 2010). It is uncertain if the exposure monitoring data are 8-hour TWA values, but IFA indicates that they are representative of shift measurements. However, the listed work group areas indicate worker activities that are not expected to occur during the application of wood preservatives onto utility poles, thus are not likely to be representative of potential worker inhalation exposures during this scenario.

Due to lack of additional data, EPA used the modeled exposure concentration in Row 6 as the typical exposure concentration to which workers may be exposed during the use of wood preservatives.

Table_Apx A-15. Summary of Worker Inhalation Exposure Concentrations During Use of Wood Preservatives

Row	Occupational Exposure Scenario	Type of Sample	Worker Activity or Sampling Location	NMP Airborne Concentration (mg/m^3)	Number of Samples	Type of Measurement	Sample Time	Source	Data Identifier from Data Extraction and Evaluation	Overall Confidence Rating from Data Extraction and Evaluation	Rationale for Inclusion / Exclusion
1	Unknown	Area	Area with furniture that had been coated in a wood preservative mixture	0.142	Unknown	Unknown	Unknown	(NIH, 2017)	3860493 - 102	Low	Excluded – This sample is not representative of exposures during this scenario
2	Processing and treatment of wood	Area	Listed as "processing, sanding, removal." Specific activities and sample areas are unknown.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 49.8 95th percentile: 149.8	24	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 130	Medium	Excluded - the listed activities are not expected to be performed during the application of wood preservatives onto utility poles.
3	Processing and treatment of wood	Personal	Listed as "processing, sanding." Specific activities and sample areas are unknown.	50th percentile: 0.5 90th percentile: 8.4 95th percentile: 13.9	13	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 137	Medium	Excluded - the listed activities are not expected to be performed during the application of wood preservatives onto utility poles.
4	Processing and treatment of wood	Unknown	Listed as "processing, sanding, removal." Specific activities and sample areas are unknown. Samples taken in the presence of LEV.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 5.72 95th percentile: 7.8	12	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 141	Medium	Excluded - the listed activities are not expected to be performed during the application of wood preservatives onto utility poles.
5	Processing and treatment of wood	Unknown	Unknown application type. Unknown area of sampling. Samples were taken in the absence of LEV.	50th percentile: below analytical quantification limit of 0.42 90th percentile: 1 95th percentile: 1	14	Unknown	Unknown - Per source, the sampling time greater than or equal to 1 hour and exposure time is greater than or equal to 6 hours, such that this is comparable to a shift measurement	(IFA, 2010)	4271620 - 148	Medium	Excluded - the listed activities are not expected to be performed during the application of wood preservatives onto utility poles.
6	Brush / Roller Application	Modeled using EasyTRA model	Roll/brush application of NMP-containing solution	4.13	Not applicable - this is a modeled exposure	8-hour TWA	8 hours	(RIVM, 2013)	3809440 - 115	High	Included as PBPK input

A.16 Recycling and Disposal

EPA did not find inhalation monitoring data related to the handling of wastes containing NMP.

Bulk Shipments of Liquid Hazardous Waste

EPA assumes NMP wastes that are generated, transported, and treated or disposed as hazardous waste are done so as bulk liquid shipments. For example, a facility that uses NMP as a processing aid may generate and store the waste processing aid as relatively pure NMP and have it shipped to hazardous waste TSDFs for ultimate treatment, disposal, or recycling. The same monitoring data and modeled data presented in Appendix A.1 for the manufacturing of NMP are also applicable to handling of wastes containing NMP, as these data apply to the transfers (i.e., loading and unloading) of NMP, which occurs at both manufacturing and waste handling sites. These exposure concentrations assume the handling of pure (100 percent) NMP.

Due to the limitations of the available monitoring data and RIVM modeled data discussed in Appendix A.1, EPA modeled exposures for the unloading of NMP from bulk containers (i.e., tank trucks and rail cars) and drums. Note that EPA used the same methodology in this section as that described in Appendix A.1. For bulk containers, the exposure duration is the time required to unload one container, which is half an hour for tank trucks and one hour for rail cars. For the unloading of drums containing NMP, EPA used the *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model* to determine exposure duration. Note that, to determine an exposure duration, EPA first determined throughput of NMP at disposal sites. EPA determined the total production volume for this scenario from 2016 TRI results. Table_Apx A-16 lists the off-site waste transfers reported in the 2016 TRI. EPA uses the total value reported in this table as the production volume for this assessment, excluding off-site transfers to wastewater treatment, as these are expected to occur via sanitary sewer pipeline. For the drum unloading exposure scenario, EPA assumes the waste chemical is typically transported to the non-wastewater treatment and disposal sites in 55-gallon drums and calculates 74,719 total drums per year. 2016 TRI reports 24 waste treatment and disposal sites, resulting in an average of 3,113 drums per site per year.

Assuming 250 days of operation per year and the model's assumed unloading rate of 20 drums/hour, the model determined an exposure duration of 0.6 hr/day for recycling and disposal sites.

Table_Apx A-16. 2016 TRI Off-Site Transfers for NMP

Off-Site Transfer	Mass (lb)
Land Disposal	4,272,199
Wastewater Treatment [a]	2,719,984
Incineration	9,571,479
Recycled	18,709,460
Other	1,724,080
Total	**34,277,218 [b]**

a – Note that EPA does not expect transfers to off-site wastewater treatment to occur via shipped containers but expects these transfers are done via sanitary sewer pipeline.

Off-Site Transfer	Mass (lb)

b – Excluding NMP transferred off-site for wastewater treatment.

EPA uses the calculated PBPK input parameters for full-shift (8-hour TWA) and short-term (acute) worker inhalation exposures presented in Rows 13 through 16 of Table_Apx A-1 in Appendix A.1. See Appendix A.1 for additional information on the calculation of these exposure concentrations.

Municipal Solid Wastes

Certain commercial and consumer conditions of use of NMP may generate solid wastes that are sent to municipal waste combustors or landfills. For example, spent aerosol degreasing cans containing residual NMP used by mechanics or consumers may be disposed as household hazardous waste, which is exempted as a hazardous waste under RCRA. While some municipalities may have collections of household hazardous wastes to prevent the comingling of household hazardous wastes with municipal waste streams, some users may inappropriately dispose of household hazardous wastes in the municipal waste stream.

EPA is not able to quantitatively assess worker or ONU exposures to NMP within municipal solid waste streams. The quantities of NMP are expected to be diluted among the comingled municipal solid waste stream, and uses of NMP, such as aerosol degreasing, result in waste NMP being contained in a sealed can. Exposures to NMP in spent pressurized cans are only expected if the can is punctured during waste handling.

Appendix B Description of Models used to Estimate Worker and ONU Exposures

B.1 Approaches for Estimating Number of Workers

This appendix summarizes the methods that EPA used to estimate the number of workers who are potentially exposed to NMP in each of its conditions of use. The method consists of the following steps:

1. Identify the North American Industry Classification System (NAICS) codes for the industry sectors associated with each scenario.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (U.S. BLS, 2016).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census' (2015) Statistics of U.S. Businesses (SUSB) data on total employment by 6-digit NAICS.
4. Estimate the percentage of employees likely to be using NMP instead of other chemicals (i.e., the market penetration of NMP in the scenario).
5. Estimate the number of sites and number of potentially exposed employees per site.
6. Estimate the number of potentially exposed employees within the scenario.

Step 1: Identifying Affected NAICS Codes

As a first step, EPA identified NAICS industry codes associated with each scenario. EPA generally identified NAICS industry codes for a scenario by:

- Querying the U.S. Census Bureau's *NAICS Search* tool using keywords associated with each scenario to identify NAICS codes with descriptions that match the scenario.
- Referencing EPA Generic Scenarios (GS's) and Organisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESDs) for a scenario to identify NAICS codes cited by the GS or ESD.
- Reviewing Chemical Data Reporting (CDR) data for the chemical, identifying the industrial sector codes reported for downstream industrial uses, and matching those industrial sector codes to NAICS codes using Table D-2 provided in the CDR reporting instructions.

Each scenario section in the main body of this report identifies the NAICS codes EPA identified for the respective scenario.

Step 2: Estimating Total Employment by Industry and Occupation

BLS's (2016) OES data provide employment data for workers in specific industries and occupations. The industries are classified by NAICS codes (identified previously), and occupations are classified by Standard Occupational Classification (SOC) codes.

Among the relevant NAICS codes (identified previously), EPA reviewed the occupation description and identified those occupations (SOC codes) where workers are potentially exposed to NMP. Table_Apx B-1 shows the SOC codes EPA classified as occupations potentially exposed to NMP. These occupations are classified into workers (W) and occupational non-users (O). All other SOC codes are assumed to represent occupations where exposure is unlikely.

Table_Apx B-1. SOCs with Worker and ONU Designations for All Conditions of Use Except Dry Cleaning

SOC	Occupation	Designation
11-9020	Construction Managers	O
17-2000	Engineers	O
17-3000	Drafters, Engineering Technicians, and Mapping Technicians	O
19-2031	Chemists	O
19-4000	Life, Physical, and Social Science Technicians	O
47-1000	Supervisors of Construction and Extraction Workers	O
47-2000	Construction Trades Workers	W
49-1000	Supervisors of Installation, Maintenance, and Repair Workers	O
49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	W
49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	W
49-9010	Control and Valve Installers and Repairers	W
49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	W
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9060	Precision Instrument and Equipment Repairers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-1000	Supervisors of Production Workers	O
51-2000	Assemblers and Fabricators	W
51-4020	Forming Machine Setters, Operators, and Tenders, Metal and Plastic	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W
51-6030	Sewing Machine Operators	O
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O
51-8020	Stationary Engineers and Boiler Operators	W
51-8090	Miscellaneous Plant and System Operators	W
51-9000	Other Production Occupations	W

W = worker designation
O = ONU designation

For dry cleaning facilities, due to the unique nature of work expected at these facilities and that different workers may be expected to share among activities with higher exposure potential (e.g., unloading the dry-cleaning machine, pressing/finishing a dry-cleaned load), EPA made different SOC code worker and ONU assignments for this scenario. Table_Apx B-2 summarizes the SOC codes with worker and ONU designations used for dry cleaning facilities.

Table_Apx B-2. SOCs with Worker and ONU Designations for Dry Cleaning Facilities

SOC	Occupation	Designation
41-2000	Retail Sales Workers	O
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W
51-6030	Sewing Machine Operators	O

SOC	Occupation	Designation
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O

W = worker designation
O = ONU designation

After identifying relevant NAICS and SOC codes, EPA used BLS data to determine total employment by industry and by occupation based on the NAICS and SOC combinations. For example, there are 110,640 employees associated with 4-digit NAICS 8123 (*Drycleaning and Laundry Services*) and SOC 51-6010 (*Laundry and Dry-Cleaning Workers*).

Using a combination of NAICS and SOC codes to estimate total employment provides more accurate estimates for the number of workers than using NAICS codes alone. Using only NAICS codes to estimate number of workers typically result in an overestimate, because not all workers employed in that industry sector will be exposed. However, in some cases, BLS only provide employment data at the 4-digit or 5-digit NAICS level; therefore, further refinement of this approach may be needed (see next step).

Step 3: Refining Employment Estimates to Account for lack of NAICS Granularity
The third step in EPA's methodology was to further refine the employment estimates by using total employment data in the U.S. Census Bureau's (2015) SUSB. In some cases, BLS OES's occupation-specific data are only available at the 4-digit or 5-digit NAICS level, whereas the SUSB data are available at the 6-digit level (but are not occupation-specific). Identifying specific 6-digit NAICS will ensure that only industries with potential NMP exposure are included. As an example, OES data are available for the 4-digit NAICS 8123 *Drycleaning and Laundry Services*, which includes the following 6-digit NAICS:

- NAICS 812310 Coin-Operated Laundries and Drycleaners;
- NAICS 812320 Drycleaning and Laundry Services (except Coin-Operated);
- NAICS 812331 Linen Supply; and
- NAICS 812332 Industrial Launderers.

In this example, only NAICS 812320 is of interest. The Census data allow EPA to calculate employment in the specific 6-digit NAICS of interest as a percentage of employment in the BLS 4-digit NAICS.

The 6-digit NAICS 812320 comprises 46 percent of total employment under the 4-digit NAICS 8123. This percentage can be multiplied by the occupation-specific employment estimates given in the BLS OES data to further refine our estimates of the number of employees with potential exposure.

Table_Apx B-3 illustrates this granularity adjustment for NAICS 812320.

Table_Apx B-3. Estimated Number of Potentially Exposed Workers and ONUs under NAICS 812320

NAICS	SOC CODE	SOC Description	Occupation Designation	Employment by SOC at 4-digit NAICS level	% of Total Employment	Estimated Employment by SOC at 6-digit NAICS level

8123	41-2000	Retail Sales Workers	O	44,500	46.0%	20,459
8123	49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W	1,790	46.0%	823
8123	49-9070	Maintenance and Repair Workers, General	W	3,260	46.0%	1,499
8123	49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W	1,080	46.0%	497
8123	51-6010	Laundry and Dry-Cleaning Workers	W	110,640	46.0%	50,867
8123	51-6020	Pressers, Textile, Garment, and Related Materials	W	40,250	46.0%	18,505
8123	51-6030	Sewing Machine Operators	O	1,660	46.0%	763
8123	51-6040	Shoe and Leather Workers	O	Not Reported for this NAICS Code		
8123	51-6050	Tailors, Dressmakers, and Sewers	O	2,890	46.0%	1,329
8123	51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O	0	46.0%	0
Total Potentially Exposed Employees				**206,070**		**94,740**
Total Workers						**72,190**
Total Occupational Non-Users						**22,551**

Note: numbers may not sum exactly due to rounding.
W = worker
O = occupational non-user
Source: (U.S. BLS, 2016; U.S. Census Bureau, 2015)

Step 4: Estimating the Percentage of Workers Using NMP Instead of Other Chemicals
In the final step, EPA accounted for the market share by applying a factor to the number of workers determined in Step 3. This accounts for the fact that NMP may be only one of multiple chemicals used for the applications of interest. EPA did not identify market penetration data for any conditions of use. In the absence of market penetration data for a given scenario, EPA assumed NMP may be used at up to all sites and by up to all workers calculated in this method as a bounding estimate. This assumes a market penetration of 100%. Market penetration is discussed for each scenario in the main body of this report.

Step 5: Estimating the Number of Workers per Site
EPA calculated the number of workers and occupational non-users in each industry/occupation combination using the formula below (granularity adjustment is only applicable where SOC data are not available at the 6-digit NAICS level):

Number of Workers or ONUs in NAICS/SOC (Step 2) × Granularity Adjustment Percentage (Step 3) = Number of Workers or ONUs in the Industry/Occupation Combination

EPA then estimated the total number of establishments by obtaining the number of establishments reported in the U.S. Census Bureau's SUSB (U.S. Census Bureau, 2015) data at the 6-digit NAICS level.

EPA then summed the number of workers and occupational non-users over all occupations within a NAICS code and divided these sums by the number of establishments in the NAICS code to calculate the average number of workers and occupational non-users per site.

Step 6: Estimating the Number of Workers and Sites for an Occupational Exposure Scenario

EPA estimated the number of workers and occupational non-users potentially exposed to NMP and the number of sites that use NMP in a given scenario through the following steps:

6.A. Obtaining the total number of establishments by:
   i. Obtaining the number of establishments from SUSB (U.S. Census Bureau, 2015) at the 6-digit NAICS level (Step 5) for each NAICS code in the scenario and summing these values; or
   ii. Obtaining the number of establishments from the Toxics Release Inventory (TRI), Discharge Monitoring Report (DMR) data, National Emissions Inventory (NEI), or literature for the scenario.

6.B. Estimating the number of establishments that use NMP by taking the total number of establishments from Step 6.A and multiplying it by the market penetration factor from Step 4.

6.C. Estimating the number of workers and occupational non-users potentially exposed to NMP by taking the number of establishments calculated in Step 6.B and multiplying it by the average number of workers and occupational non-users per site from Step 5.

B.2 Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA exposure models. The model approach is a generic inhalation exposure assessment at industrial facilities that is applicable for any volatile chemical with the following conditions of use:

- Manufacture (loading of chemicals into containers);
- Processing as a reactant/intermediate (unloading of chemicals);
- Processing into formulation, mixture, or reaction products;
- Repackaging; and
- Other similar conditions of use at industrial facilities (e.g., industrial processing aid).

As an example, NMP at a manufacturing facility is expected to be packaged and loaded into a container before distributing to another industrial processing or use site (e.g., formulation sites and sites using NMP as a processing aid). At the industrial processing or use site, NMP is then unloaded from the container into a process vessel before being incorporated into a mixture or otherwise processed/used. For the model, EPA assumes NMP is unloaded into tank trucks and railcars and transported and distributed in bulk. EPA also assumes the chemical is handled as a pure substance (100 percent concentration).

Because NMP is volatile (vapor pressure above 0.01 torr at room temperature), fugitive emissions may occur when NMP is loaded into or unloaded from a tank truck or railcar. Sources of these emissions include:

- Displacement of saturated air containing NMP as the container/truck is filled with liquid;
- Emissions of saturated air containing NMP that remains in the loading arm, transfer hose, and related equipment; and
- Emissions from equipment leaks from processing units such as pumps, seals and valves.

These emissions result in subsequent exposure to workers involved in the transfer activity. The following subsections address these emission sources.

B.2.1 Displacement of Saturated Air Inside Tank Trucks and Railcars

For screening-level assessments, EPA typically uses the *EPA/OAQPS AP-42 Loading Model* to conservatively assess exposure during container unloading activities (U.S. EPA, 2013a). The model estimates release to air from the displacement of air containing chemical vapor as a container/vessel is filled with liquid (U.S. EPA, 2013a). The model assumes the unloading activity displaces an air volume equal to the size of the container, and that displaced air is either 50 percent or 100 percent saturated with chemical vapor (U.S. EPA, 2013a).

Industrial facilities often install and operate a vapor capture system and control device (or vapor balancing system) for loading/unloading operations. As such, vapor losses from displacement of air is likely mitigated by the use of such systems. Actual fugitive emissions are likely limited to any saturated vapor that remain in the hose, loading arm, or related equipment after being disconnected from the truck or railcar. This emission source is addressed in the next subsection.

B.2.2 Emissions of Saturated Air that Remain in Transfer Hoses/Loading Arm

After loading is complete, transfer hoses and/or loading arms are disconnected from tank trucks and railcars. Saturated air containing the chemical of interest that remains in transfer equipment may be released to air, presenting a source of fugitive emissions. The quantity of NMP released will depend on concentration in the vapor and the volume of vapor in the loading arm/hose/piping.

Table_Apx B-4 presents the dimensions for several types of loading systems according to an OPW Engineered Systems catalog (Systems, 2014). OPW Engineered Systems (2014) specializes in the engineering, designing, and manufacturing of systems for loading and unloading a wide range of materials including petroleum products, liquefied gases, asphalt, solvents, and hazardous and corrosive chemicals. These systems include loading systems, swivel joints, instrumentation, quick and dry-disconnect systems, and safety breakaways. Based on the design dimensions, the table presents the calculated total volume of loading arm/system and assumes the volume of vapor containing NMP equals the volume of the loading arm/system.

Chemical-specific transport container information was not available; therefore, EPA assumed a default approach with the "central tendency" as tank truck loading/unloading and the "high-end" as railcar loading/unloading. Central tendency and high-end approaches are based on the expected transfer arm volume (and therefore, potential exposure concentration). To estimate the high-end transfer arm volume, EPA calculated the 95th percentile of the OPW Engineered Systems loading arms volumetric data resulting in a high-end value of 17.7 gallons. For the central tendency tank truck scenario, EPA assumed a 2-inch diameter, 12-ft long transfer hose. This hose has a volume of 2.0 gallons.

Once the volume is known, the emission rate, E_T (g/s), can be calculated as follows:

Equation_Apx B-1

$$\boldsymbol{E_T = \frac{f \times MW \times 3{,}786.4 \times V_h \times X \times VP}{t_{disconnect} \times T \times R \times 3{,}600 \times 760}}$$

Default values for Equation_Apx B-1 can be found in Table_Apx B-5.

Table_Apx B-4. Example Dimension and Volume of Loading Arm/Transfer System

	Length of Loading Arm/Connection (in) [a]				Volume, V_h (gal) [b]			
OPW Engineered Systems Transfer Arm	**2-inch**	**3-inch**	**4-inch**	**6-inch**	**2-inch**	**3-inch**	**4-inch**	**6-inch**
Unsupported Boom-Type Bottom Loader	149.875	158.5	165.25	191.75	2.0	4.9	9.0	23.5
"A" Frame Loader M-32-F	153.75	159.75	164.5	NA	2.1	4.9	8.9	NA
"A" Frame Hose Loader AFH-32-F	180.75	192.75	197.5	NA	2.5	5.9	10.7	NA
CWH Series Counterweighted Hose Loader	NA	NA	309	NA	NA	NA	16.8	NA
Spring Balanced Hose Loader SRH-32-F	204.75	216.75	221.5	NA	2.8	6.6	12.0	NA
Spring Balanced Hose Loader LRH-32-F	NA	270	277.625	NA	NA	8.3	15.1	NA
Top Loading Single Arm Fixed Reach	201.75	207.75	212.5	NA	2.7	6.4	11.6	NA
Top Loading Scissor Type Arm	197.875	206.5	213.25	NA	2.7	6.3	11.6	NA
Supported Boom Arm B-32-F	327.375	335	341.5	NA	4.5	10.3	18.6	NA
Unsupported Boom Arm GT-32-F	215.875	224.5	231.25	NA	2.9	6.9	12.6	NA
Slide Sleeve Arm A-32F	279	292.5	305.125	NA	3.8	9.0	16.6	NA
Hose without Transfer Arm								
Hose (EPA judgment)	120	--	--	--	1.6	--	--	--

Source: (Systems, 2014)

a – Total length includes length of piping, connections, and fittings.

b – Calculated based on dimension of the transfer hose/connection, $V_h = \pi r^2 L$ (converted from cubic inch to gallons).

Table_Apx B-5. Default Values for Calculating Emission Rate of N-Methylpyrrolidone from Transfer/Loading Arm

Parameter	Parameter Description	Default Value	Unit
E_T	Emission rate of chemical from transfer/loading system	Calculated from model equation	g/s
f	Saturation factor[a]	1	dimensionless
MW	Molecular weight of the chemical	99.1	g/mol
V_h	Volume of transfer hose	See Table_Apx B-4	gallons
r	Fill rate[a]	2 (tank truck) 1 (railcar)	containers/hour
$t_{disconnect}$	Time to disconnect hose/couplers (escape of saturated vapor from disconnected hose or transfer arm into air)	0.25	hour
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	0.345	torr
T	Temperature	298	K
R	Universal gas constant	82.05	atm-cm^3/gmol-K

a – Saturation factor and fill rate values are based on established EPA release and inhalation exposure assessment methodologies (U.S. EPA, 2013a).

B.2.3 Emission from Leaks

During loading/unloading activities, emissions may also occur from equipment leaks from valves, pumps, and seals. Per EPA's *Chapter 5: Petroleum Industry* of AP-42 (U.S. EPA, 2015a) and EPA's

Protocol for Equipment Leak Emission Estimates (U.S. EPA, 1995), the following equation can be used to estimate emission rate E_L, calculated as the sum of average emissions from each process unit:

Equation_Apx B-2

$$E_L = \sum(F_A \times WF_{TOC} \times N) \times \frac{1,000}{3,600}$$

Parameters for calculating equipment leaks using Equation_Apx B-2 can be found in Table_Apx B-6.

Table_Apx B-6. Parameters for Calculating Emission Rate of N-Methylpyrrolidone from Equipment Leaks

Parameter	Parameter Description	Default Value	Unit
E_L	Emission rate of chemical from equipment leaks	Calculated from model equation	g/s
F_A	Applicable average emission factor for the equipment type	See Table_Apx B-7	kg/hour-source
WF_{TOC}	Average weight fraction of chemical in the stream	1	dimensionless
N	Number of pieces of equipment of the applicable equipment type in the stream	See Table_Apx B-7	Source

To estimate emission leaks using this modeling approach, EPA modeled a central tendency loading rack scenario using tank truck loading/unloading and a high-end loading rack scenario using railcar loading/unloading as discussed in Appendix A.1. EPA used engineering judgment to estimate the type and number of equipment associated with the loading rack in the immediate vicinity of the loading operation. EPA assumes at least one worker will be near the loading rack during the entire duration of the loading operation.

Table_Apx B-7 presents the average emission factor for each equipment type, based on the synthetic organic chemical manufacturing industry (SOCMI) emission factors as provided by EPA's 1995 Protocol (U.S. EPA, 1995), and the likely number of pieces of each equipment used for each chemical loading/unloading activity, based on EPA's judgment. Note these emission factors are for emission rates of total organic compound emission and are assumed to be applicable to NMP. In addition, these factors are most valid for estimating emissions from a population of equipment and are not intended to be used to estimate emissions for an individual piece of equipment over a short period of time.

Table_Apx B-7. Default Values for F_A and N

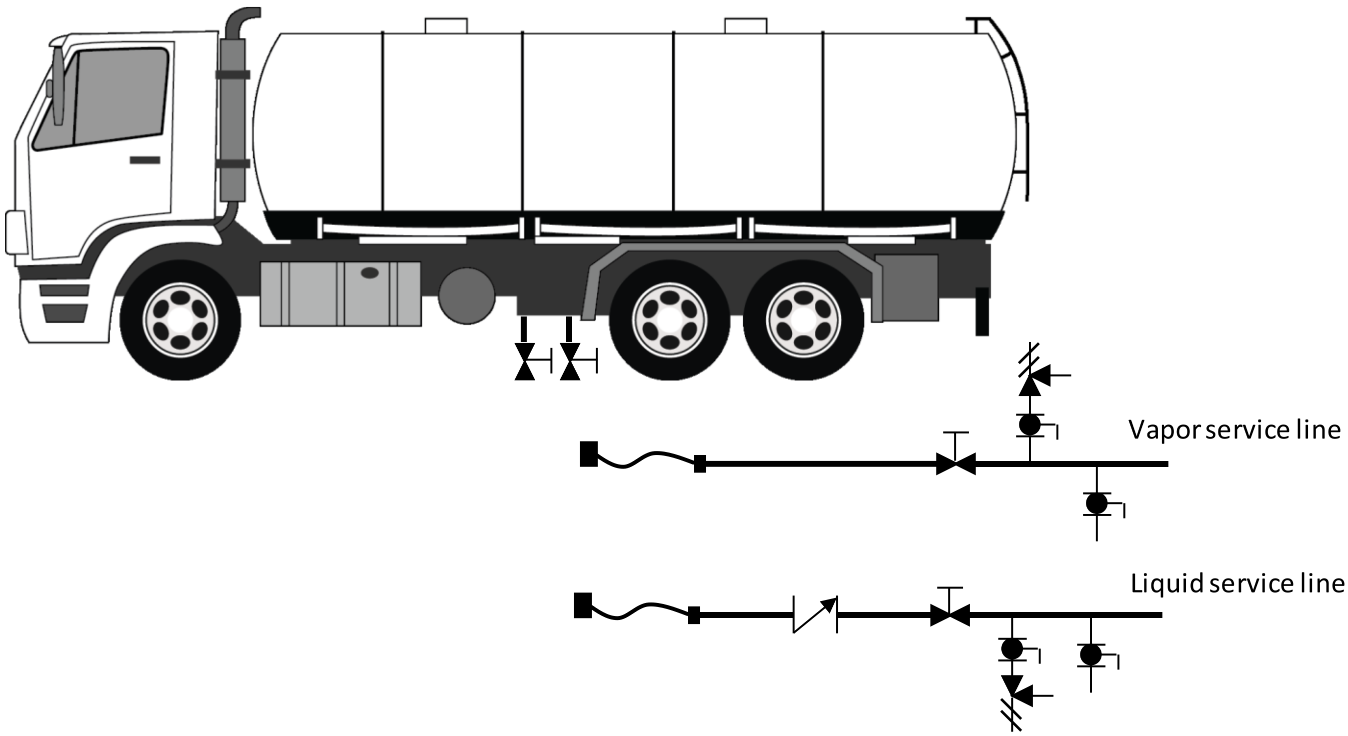
Equipment Type	Service	SOCMI Emission Factor, F_A (kg/hour-source) [a]	Number of Equipment, N (central tendency)	Number of Equipment, N (high-end)
Valves	Gas Light liquid Heavy liquid	0.00597 0.00403 0.00023	3 (gas) -- 5 (heavy liquid)	3 (gas) -- 10 (heavy liquid)
Pump seals [b]	Light liquid Heavy liquid	0.0199 0.00862	--	--
Compressor seals	Gas	0.228	--	--
Pressure relief valves	Gas	0.104	1	1
Connectors	All	0.00183	2	3
Open-ended lines	All	0.0017	--	--
Sampling connections	All	0.015	2	3

Source: (U.S. EPA, 1995)
a – SOCMI average emission factors for total organic compounds from EPA's 1995 Protocol (U.S. EPA, 1995). "Light liquid" is defined as "material in a liquid state in which the sum of the concentration of individual constituents with a vapor pressure over 0.3 kilopascals (kPa) at 20 °C is greater than or equal to 20 weight percent". "Heavy liquid" is defined as "not in gas/vapor service or light liquid service." Since NMP has a vapor pressure of 0.345 mmHg (0.046 kPa) at 25 °C, EPA modeled NMP liquid as a light liquid.
b – The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

EPA assumed the following equipment are used in loading racks for the loading/unloading of tank trucks and railcars. Figure_Apx B-1 illustrates an example tank truck and unloading rack equipment.

- Tank Truck Loading/Unloading:
  - Liquid Service:
    - Four valves (modeled as valves in heavy liquid service)
    - One safety relief valve (modeled as valve in heavy liquid service)
    - One bleed valve or sampling connection
    - One hose connector
  - Vapor Service:
    - Three valves (modeled as valves in gas service)
    - One pressure relief valve
    - One bleed valve (modeled as a sampling connection)
    - One hose connector
- Railcar Loading/Unloading
  - Liquid Service: EPA assumed, for the high-end scenario, two parallel liquid service lines, each using the same equipment as assumed for tank trucks. Therefore, a total of:
    - Eight valves (modeled as valves in heavy liquid service)
    - Two safety relief valves (modeled as valve in heavy liquid service)
    - Two bleed valves or sampling connections
    - Two transfer arm connectors
  - Vapor Service: EPA assumed a single line in vapor service with the same equipment as assumed for tank trucks.
    - Three valves (modeled as valves in gas service)
    - One pressure relief valve

- One bleed valve (modeled as a sampling connection)
- One transfer arm connector



Figure_Apx B-1. Illustration of Transfer Lines Used During Tank Truck Unloading and Associated Equipment Assumed by EPA

B.2.3.1 Exposure Estimates

The vapor generation rate, *G*, or the total emission rate over time, can be calculated by aggregating emissions from all sources:

- During the transfer period, emissions are only due to leaks, with emission rate $G = E_L$.
- After transfer, during the disconnection of the hose(s), emissions are due to both leaks and escape of saturated vapor from the hose/transfer arm with emission rate $G = E_T + E_L$.

The vapor generation rate can then be used with the *EPA/OPPT Mass Balance Inhalation Model* to estimate worker exposure during loading/unloading activities (U.S. EPA, 2013a). The *EPA/OPPT Mass Balance Inhalation Model* estimates the exposure concentration using Equation_Apx B-3 and the default parameters found in Table_Apx B-8 (U.S. EPA, 2013a). Table_Apx B-9 presents exposure estimates for NMP using this approach. These estimates assume one unloading/loading event per day and NMP is loaded/unloaded at 100% concentration. The loading operation occurs in an outdoor area with minimal structure, with wind speeds of 9 mph (central tendency) or 5 mph (high-end).

Equation_Apx B-3

$$C_m = \frac{C_v}{V_m}$$

Table_Apx B-8. Parameters for Calculating Exposure Concentration Using the EPA/OPPT Mass Balance Model

Parameter	Parameter Description	Default Value	Unit
C_m	Mass concentration of chemical in air	Calculated from model equation	mg/m^3
C_v	Volumetric concentration of chemical in air	Calculated as the lesser of: $\frac{170{,}000 \times T \times G}{MW \times Q \times k}$ or $\frac{1{,}000{,}000 \times X \times VP}{760}$	ppm
T	Temperature of air	298	K
G	Vapor generation rate	E_L during transfer period E_T+E_L after transfer/during disconnection of hose/transfer arm	g/s
MW	Molecular weight of the chemical	99.1	g/mol
Q	Outdoor ventilation rate	237,600 (central tendency) $26{,}400 \times \left(60 \times \frac{vz}{5280}\right)$ (high-end)	ft^3/min
vz	Air speed	440	ft/min
k	Mixing factor	0.5	dimensionless
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	0.345	torr
V_m	Molar volume	24.45 @ 25°C, 1 atm	L/mol

EPA also calculated acute and 8-hour TWA exposures as shown in Equation_Apx B-4 and Equation_Apx B-5, respectively. The acute TWA exposure is the weighted average exposure during the entire exposure duration per shift, accounting for the number of loading/unloading events per shift. The 8-hour TWA exposure is the weighted average exposure during an entire 8-hour shift, assuming zero exposures during the remainder of the shift. EPA assumed one container is loaded/unloaded per shift: one tank truck per shift for the central tendency scenario and one railcar per shift for the high-end scenario.

Equation_Apx B-4

$$Acute\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{h_{shift}}$$

Equation_Apx B-5

$$8 - hr\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{8}$$

Where:

$C_{m(leak\ only)}$ = Airborne concentration (mass-based) due to leaks during unloading while hose connected (mg/m^3)

$C_{m(leak\ and\ hose)}$ = Airborne concentration (mass-based) due to leaks and displaced air during hose disconnection (mg/m^3)

h_{event} = Exposure duration of each loading/unloading event (hour/event); calculated as the inverse of the fill rate, *r*: 0.5 hour/event for tank trucks and 1 hour/event for railcars

h_{shift} = Exposure duration during the shift (hour/shift); calculated as h_{event} x N_{cont}: 0.5 hour/shift for tank trucks and 1 hour/shift for railcars

$t_{disconnect}$ = Time duration to disconnect hoses/couplers (during which saturated vapor escapes from hose into air) (hour/event)

N_{cont} = Number of containers loaded/unloaded per shift (event/shift); assumed one tank truck per shift for central tendency scenario and one railcar per shift for high-end scenario

Table_Apx B-9. Calculated Emission Rates and Resulting Exposures of N-Methylpyrrolidone from the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model

Scenario	E_L (g/s)	E_T (g/s)	E_L + E_T (g/s)	C_m (leaks only) (mg/m^3)	C_m (leaks and hose vapor) (mg/m^3)	Acute TWA (mg/m^3) [a]	8-hour TWA (mg/m^3)
Central Tendency	0.044	1.52E-05	0.044	0.76	0.76	0.76	0.047
High-End	0.049	1.37E-04	0.049	1.52	1.53	1.52	0.19

a – Acute TWA exposure is a 0.5-hour TWA exposure for the central tendency scenario and a 1-hour TWA exposure for the high-end scenario.

B.3 Drum Loading and Unloading Release and Inhalation Exposure Model Approach and Parameters

This appendix presents the approach for central tendency and high-end inhalation exposure estimation for the loading and unloading of pure (100%) NMP from 55-gallon drums. This approach applies a stochastic modeling approach to the *EPA/OAQPS AP-42 Loading Model*, which estimates air releases during container loading and unloading, and the *EPA /OPPT Mass Balance Model*, which estimates inhalation exposures resulting from air releases (U.S. EPA, 2013a).

This approach is intended to assess air releases and associated inhalation exposures associated with indoor container loading scenarios at industrial and commercial facilities. Inhalation exposure to chemical vapors is a function of the chemical's physical properties, ventilation rate of the container loading area, type of loading method, and other model parameters. While physical properties are fixed for a chemical, some model parameters, such as ventilation rate (Q), mixing factor (k), and vapor saturation factor (f), are expected to vary from one facility to another. This approach addresses variability for these parameters using a Monte Carlo simulation.

An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data or engineering judgment to address the variability in ventilation rate (Q), mixing factor (k), vapor saturation factor (f), and exposed working years per lifetime (WY). A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0 (Palisade, Ithaca, New York). The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed 100,000 iterations of the model to capture the range of possible input values, including values with low probability of occurrence.

From the distribution resulting from the Monte Carlo simulation, EPA selected the 95th and 50th percentile values to represent a high-end exposure and central tendency exposure level respectively. The statistics were calculated directly in @Risk. The following subsections detail the model design equations and parameters used for Inhalation exposure estimates.

B.4 Model Air Release and Inhalation Exposure Equations

The average vapor generation rate needed to estimate inhalation exposure concentration with the *EPA/OPPT Mass Balance Model* is calculated from the following *EPA/OAQPS AP-42 Loading Model* equation for vapor generation rate.

Equation_Apx B-6

$$G = \frac{f \times MW \times (3{,}785.4 \times V_c) \times r \times X \times \frac{VP}{760}}{3{,}600 \times T \times R}$$

Where:

G	=	Average vapor generation rate [g/s]
F	=	Saturation factor [Dimensionless]

MW	=	Molecular weight of chemical [g/mol]
V_c	=	Container volume [gallon]
r	=	Container loading/unloading rate [number of containers/hr]
X	=	Vapor pressure correction factor [Dimensionless], assumed equal to weight fraction of component
VP	=	Vapor pressure (at temperature, T) [mmHg]
T	=	Temperature [K]
R	=	Universal gas constant [atm-cm^3/mol-K]

The *EPA/OPPT Mass Balance Model* uses Equation_Apx B-7 to calculate the volumetric concentration of the chemical in air, using the vapor generation rate calculated above.

Equation_Apx B-7

$$C_v = \frac{170{,}000 \times T \times G}{MW \times Q \times k}$$

Where:

C_v	=	Volumetric concentration of chemical vapor in air [ppm]
T	=	Temperature [K]
G	=	Average vapor generation rate [g/s]
MW	=	Molecular weight of chemical [g/mol]
Q	=	Ventilation rate [ft^3/min]
K	=	Mixing factor [Dimensionless]

The *EPA/OPPT Mass Balance Model* then uses Equation_Apx B-8 to estimate mass concentration of the chemical vapor in air (mg/m^3):

Equation_Apx B-8

$$C_m = \frac{C_v \times MW}{V_m}$$

Where:

C_m	=	Mass concentration of chemical vapor in air [mg/m^3]
C_v	=	Volumetric concentration of chemical vapor in air [ppm]
MW	=	Molecular Weight of chemical [g/mol]
V_m	=	Molar volume [L/mol]

The estimated mass concentration in air is the short-term inhalation exposure concentration. This short-term exposure is subsequently used in Equation_Apx B-9 to estimate the 8-hour TWA exposure concentration.

Equation_Apx B-9

$$C_{8-hr} = \frac{C_m \times t_{unload}}{8\,\frac{hr}{day}}$$

Where:

$C_{8\text{-}hr}$ = contaminant concentration in air (8-hour TWA) [mg/m^3]
C_m = Mass concentration of chemical vapor in air [mg/m^3]
t_{unload} = total unloading time for all drums per day [hr/day]

B.5 Number of Containers and Short-Term Exposure Duration Equations

The short-term exposure duration, t_{unload}, is the length of time workers spend unloading NMP from drums in a given day. To determine the exposure duration, the number of drums loaded or unloaded at a given site per day is first calculated with Equation_Apx B-10.

Equation_Apx B-10

$$N_{drum\_site\_day} = \frac{PV_{gal/yr}}{V_c \times N_{sites} \times OD}$$

Where:

$N_{drum\_site\_day}$ = Number of drums loaded / unloaded per site per day [drum/site-day]
$PV_{gal/yr}$ = Production volume for the scenario in gallons of NMP per year [gal/yr]
V_c = Volume of container [gallons/drum]
N_{sites} = Number of sites [sites]
OD = Operating days [day/yr]

To calculate the production volume in gallons of NMP per year for Equation_Apx B-10, the production volume in pounds per year (included in Table_Apx B-10) is converted with Equation_Apx B-11.

Equation_Apx B-11

$$PV_{gal/yr} = \frac{PV_{lb/yr} \times 453.6 \frac{g}{lb}}{\rho \times 3{,}785 \frac{cm^3}{gal}}$$

Where:

$PV_{gal/yr}$ = Production volume for the scenario in gallons of NMP per year [gal/yr]
$PV_{lb/yr}$ = Production volume for the scenario in pounds of NMP per year [lb/yr]
ρ = density of NMP [g/cm^3]

Finally, EPA determined the short-term exposure duration using the number of drums calculated in Equation_Apx B-10.

Equation_Apx B-12

$$t_{unload} = \frac{N_{drum\_site\_day}}{r}$$

Where:

t_{unload} = Total unloading time for all drums per day [hr/site-day]
$N_{drum\_site\_day}$ = Number of drums loaded / unloaded per site per day [drum/site-day]
r = Drum fill rate [drums/hr]

B.6 Model Input Parameters

Table_Apx B-10 summarizes the model parameters and their values for the Monte Carlo simulation. High-end and central tendency exposure are estimated by selecting the 50th and 95th percentile values from the output distribution.

Table_Apx B-10. Summary of Parameter Values and Distributions Used in the Inhalation Exposure Model

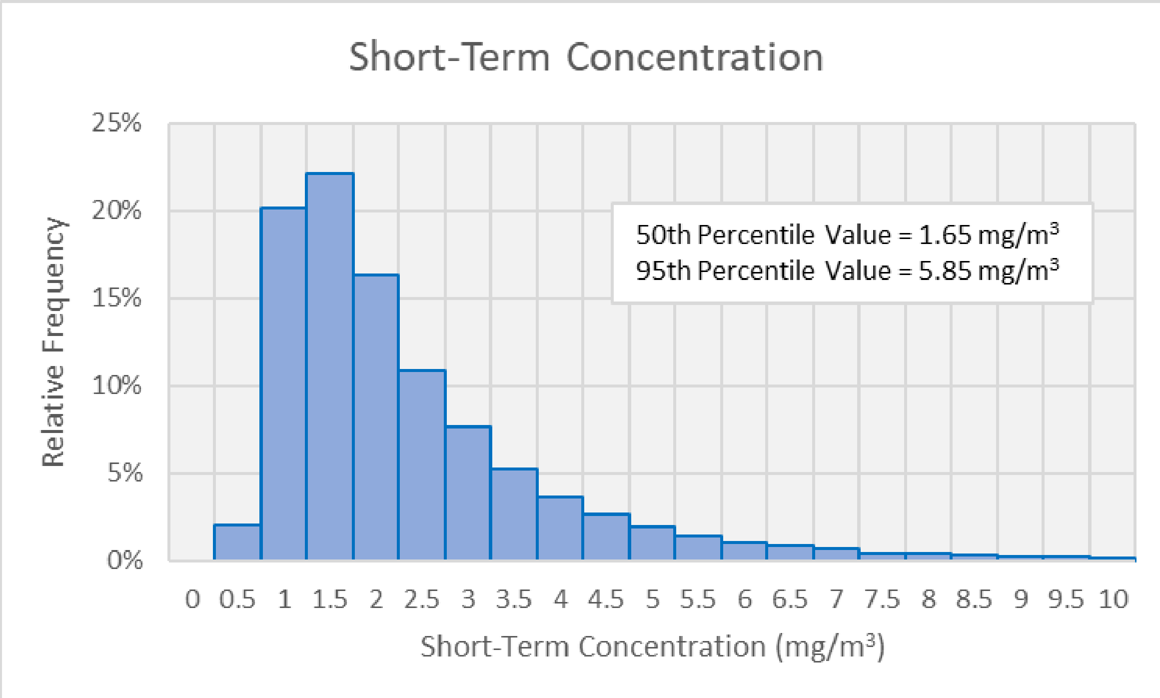
Input Parameter	Symbol	Unit	Constant Model Parameter Values	Variable Model Parameter Values				Rational / Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Molecular Weight	MW	g/mol	99.1	—	—	—	—	Physical property
Vapor Pressure at 298 K	VP	mmHg	0.345	—	—	—	—	Physical property
Molar Volume at 298 K	V_m	L/mol	24.46	—	—	—	—	Physical constant
Gas Constant	R	atm-cm^3/mol-K	82.05	—	—	—	—	Physical constant
Temperature	T	K	298	—	—	—	—	Process parameter
Vapor Pressure Correction Factor	X	Dimensionless	1	—	—	—	—	Process parameter
Mole Fraction of Chemical	x_i	Dimensionless	1	—	—	—	—	Process parameter, refer to Appendix A for additional information
Production Volume	$PV_{lb/yr}$	lb/yr	Manufacture and Repackaging: 161,000,000 Chemical Processing and Formulation: 80,500,000 Recycling and Disposal: 34,227,218	—	—	—	—	Process parameter, refer to Appendix A for additional information
Number of sites	N_{sites}	sites	Manufacture and Repackaging: 33 Chemical Processing and Formulation: 94 Recycling and Disposal: 24	—	—	—	—	Process parameter, refer to Appendix A for additional information
Operating Days	OD	day/yr	250	—	—	—	—	Process parameter, based on schedule of five days per week and 50 weeks per year

Input Parameter	Symbol	Unit	Constant Model Parameter Values	Variable Model Parameter Values				Rational / Basis
			Value	Lower Bound	Upper Bound	Mode	Distribution Type	
Container Volume	V_c	Gallons/drum	55	—	—	—	—	Value is determined by the selected container type for given exposure scenario (U.S. EPA, 2013a)
Container Loading/Unloading Rate	r	Containers / hr	20	—	—	—	—	Value is determined by the selected container type (U.S. EPA, 2013a)
Ventilation Rate	Q	ft^3/min	—	500	10,000	3,000	Triangular	U.S. EPA (2013a) indicates: 1. General ventilation rates in industry ranges from a low of 500 ft^3/min to over 10,000 ft^3/min; a typical value is 3,000. 2. Mixing Factor ranges from 0.1 to 1. 3. Saturation factor ranges from 0.5 for submerged loading to 1.45 for splash loading. Underlying distribution of these parameters are not known, EPA assigned triangular distributions, since triangular distribution requires least assumptions and is completely defined by range and mode of a parameter.
Mixing Factor	k	Dimensionless	—	0.1	1	0.5	Triangular	
Saturation Factor	f	Dimensionless	—	0.5	1.45	0.5	Triangular	

—: Not Applicable

B.7 Monte Carlo Simulation Results

The probability density function for the short-term exposure concentration values resulting from the simulation are depicted in Figure_Apx B-2. Specifically, EPA used the 50th and 95th percentile short-term exposure concentration values to represent central tendency and high-end inhalation exposure potential.



Figure_Apx B-2. Graphical Probability Density Function of Monte Carlo Simulation Results

The 50th and 95th percentile short-term exposure concentration values are the same for all conditions of use. However, the 8-hour TWA exposure concentration values vary based on the production volume and number of sites for each scenario. The short-term and 8-hour TWA inhalation exposure concentrations are summarized for each scenario for which this model was used in Table_Apx B-11.

Table_Apx B-11. Drum Loading and Unloading Inhalation Exposure Simulation Results

Occupational Exposure Scenario	8-hour TWA Exposure (mg/m^3)		Short-Term Exposure (mg/m^3)		Number of Drums per Site per Day (drums/site-day)	Short-Term Exposure Duration (hr/day)
	50th Percentile	95th Percentile	50th Percentile	95th Percentile		
Manufacturing	0.427	1.510	1.65	5.85	41.3	2.064
Repackaging	0.427	1.510	1.65	5.85	41.3	2.064
Chemical Processing, Excluding Formulation	0.075	0.265	1.65	5.85	7.3	0.362
Formulation	0.075	0.265	1.65	5.85	7.3	0.362
Recycling and Disposal	0.125	0.441	1.65	5.85	12.1	0.603

B.8 Brake Servicing Near-Field/Far-Field Inhalation Exposure Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. The model was developed through review of the literature and consideration of existing EPA exposure models. This model uses a near-field/far-field approach (AIHA, 2009), where an aerosol application located inside the near-field generates a mist of droplets, and indoor air movements lead to the convection of the droplets between the near-field and far-field. Workers are assumed to be exposed to NMP droplet concentrations in the near-field, while occupational non-users are exposed at concentrations in the far-field.

The model uses the following parameters to estimate exposure concentrations in the near-field and far-field:

- Far-field size;
- Near-field size;
- Air exchange rate;
- Indoor air speed;
- Concentration of NMP in the aerosol formulation;
- Amount of degreaser used per brake job;
- Number of degreaser applications per brake job;
- Time duration of brake job;
- Operating hours per week; and
- Number of jobs per work shift.

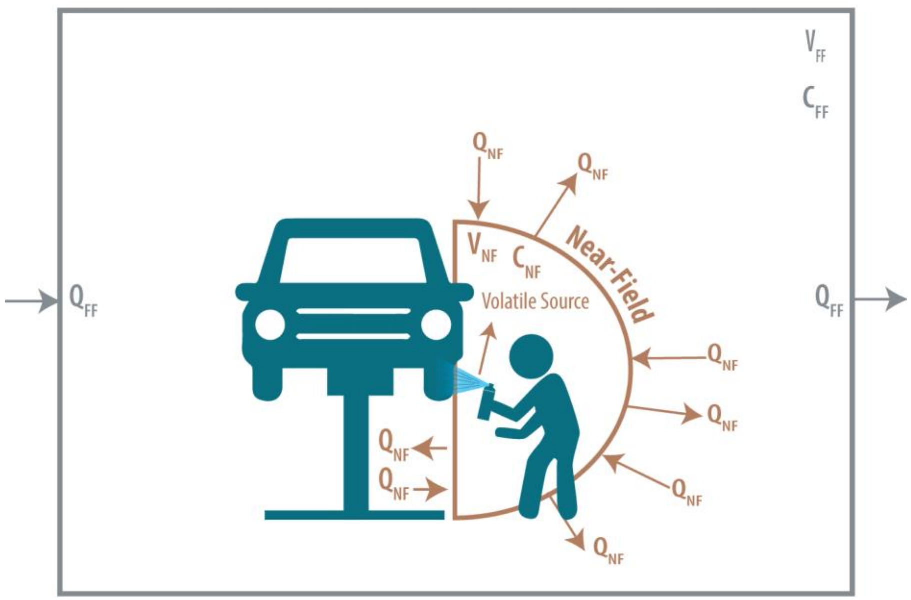
An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence).

Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk. The 95th percentile value was selected to represent high-end exposure level, whereas the 50th percentile value was selected to represent central tendency exposure level. The following subsections detail the model design equations and parameters for the brake servicing model.

B.8.1 Model Design Equations

In brake servicing, the vehicle is raised on an automobile lift to a comfortable working height to allow the worker (mechanic) to remove the wheel and access the brake system. Brake servicing can include inspections, adjustments, brake pad replacements, and rotor resurfacing. These service types often involve disassembly, replacement or repair, and reassembly of the brake system. Automotive brake cleaners are used to remove oil, grease, brake fluid, brake pad dust, or dirt. Mechanics may occasionally use brake cleaners, engine degreasers, carburetor cleaners, and general purpose degreasers interchangeably (CARB, 2000). Automotive brake cleaners can come in aerosol or liquid form (CARB, 2000): this model estimates exposures from aerosol brake cleaners (degreasers).

Figure_Apx B-3 illustrates the near-field/far-field modeling approach as it was applied by EPA to brake servicing using an aerosol degreaser. The application of the aerosol degreaser immediately generates a mist of droplets in the near-field, resulting in worker exposures at a NMP concentration C_{NF}. The concentration is directly proportional to the amount of aerosol degreaser applied by the worker, who is standing in the near-field-zone (i.e., the working zone). The volume of this zone is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF}) determines how quickly NMP dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to NMP at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the NMP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly NMP dissipates out of the surrounding space and into the outside air.



Figure_Apx B-3. The Near-Field/Far-Field Model as Applied to the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model

In brake servicing using an aerosol degreaser, aerosol degreaser droplets enter the near-field in non-steady "bursts," where each burst results in a sudden rise in the near-field concentration. The near-field and far-field concentrations then decay with time until the next burst causes a new rise in near-field concentration. Based on site data from automotive maintenance and repair shops obtained by CARB (CARB, 2000) for brake cleaning activities and as explained in Sections B.8.2.5 and B.8.2.9 below, the model assumes a worker will perform an average of 11 applications of the degreaser product per brake job with five minutes between each application and that a worker may perform one to four brake jobs per day each taking one hour to complete. EPA modeled two scenarios: one where the brake jobs occurred back-to-back and one where brake jobs occurred one hour apart. In both scenarios, EPA assumed the worker does not perform a brake job, and does not use the aerosol degreaser, during the first hour of the day.

EPA denoted the top of each five-minute period for each hour of the day (e.g., 8:00 am, 8:05 am, 8:10 am, etc.) as $t_{m,n}$. Here, m has the values of 0, 1, 2, 3, 4, 5, 6, and 7 to indicate the top of each hour of the day (e.g., 8 am, 9 am, etc.) and n has the values of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 to indicate the top of each five-minute period within the hour. No aerosol degreaser is used, and no exposures occur, during the first hour of the day, $t_{0,0}$ to $t_{0,11}$ (e.g., 8 am to 9 am). Then, in both scenarios, the worker begins the first brake job during the second hour, $t_{1,0}$ (e.g., 9 am to 10 am). The worker applies the aerosol degreaser at the top of the second 5-minute period and each subsequent 5-minute period during the hour-long brake job (e.g., 9:05 am, 9:10 am,…9:55 am). In the first scenario, the brake jobs are performed back-to-back, if performing more than one brake job on the given day. Therefore, the second brake job begins at the top of the third hour (e.g., 10 am), and the worker applies the aerosol degreaser at the top of the second 5-minute period and each subsequent 5-minute period (e.g., 10:05 am, 10:10 am,…10:55 am). In the second scenario, the brake jobs are performed every other hour, if performing more than one brake job on the given day. Therefore, the second brake job begins at the top of the fourth hour (e.g., 11 am), and the worker applies the aerosol degreaser at the top of the second 5-minute period and each subsequent 5-minute period (e.g., 11:05 am, 11:10 am,…11:55 am).

In the first scenario, after the worker performs the last brake job, the workers and occupational non-users (ONUs) continue to be exposed as the airborne concentrations decay during the final three to six hours until the end of the day (e.g., 4 pm). In the second scenario, after the worker performs each brake job, the workers and ONUs continue to be exposed as the airborne concentrations decay during the time in which no brake jobs are occurring and then again when the next brake job is initiated. In both scenarios, the workers and ONUs are no longer exposed once they leave work.

Based on data from CARB (CARB, 2000), EPA assumes each brake job requires one 14.4-oz can of aerosol brake cleaner as described in further detail below. The model determines the application rate of NMP using the weight fraction of PCE in the aerosol product. EPA uses a uniform distribution of weight fractions for NMP based on facility data for the aerosol products in use (CARB, 2000).

The model design equations are presented below in Equation_Apx B-13 through Equation_Apx B-33.

Near-Field Mass Balance

Equation_Apx B-13

$$V_{NF}\frac{dC_{NF}}{dt} = C_{FF}Q_{NF} - C_{NF}Q_{NF}$$

Far-Field Mass Balance

Equation_Apx B-14

$$V_{FF}\frac{dC_{FF}}{dt} = C_{NF}Q_{NF} - C_{FF}Q_{NF} - C_{FF}Q_{FF}$$

Where:

V_{NF} = near-field volume;
V_{FF} = far-field volume;
Q_{NF} = near-field ventilation rate;
Q_{FF} = far-field ventilation rate;
C_{NF} = average near-field concentration;
C_{FF} = average far-field concentration; and

t = elapsed time.

Solving Equation_Apx B-13 and Equation_Apx B-14 in terms of the time-varying concentrations in the near-field and far-field yields Equation_Apx B-15 and Equation_Apx B-16, which EPA applied to each of the 12 five-minute increments during each hour of the day. For each five-minute increment, EPA calculated the initial near-field concentration at the top of the period ($t_{m,n}$), accounting for both the burst of NMP from the degreaser application (if the five-minute increment is during a brake job) and the residual near-field concentration remaining after the previous five-minute increment ($t_{m,n-1}$; except during the first hour and $t_{m,0}$ of the first brake job, in which case there would be no residual NMP from a previous application). The initial far-field concentration is equal to the residual far-field concentration remaining after the previous five-minute increment. EPA then calculated the decayed concentration in the near-field and far-field at the end of the five-minute period, just before the degreaser application at the top of the next period ($t_{m,n+1}$). EPA then calculated a 5-minute TWA exposure for the near-field and far-field, representative of the worker's and ONUs' exposures to the airborne concentrations during each five-minute increment using Equation_Apx B-25 and Equation_Apx B-26. The *k* coefficients (Equation_Apx B-17 through Equation_Apx B-20) are a function of the initial near-field and far-field concentrations, and therefore are re-calculated at the top of each five-minute period. In the equations below, where the subscript "m, n-1" is used, if the value of n-1 is less than zero, the value at "m-1, 11" is used and where the subscript "m, n+1" is used, if the value of n+1 is greater than 11, the value at "m+1, 0" is used.

Equation_Apx B-15

$$C_{NF,t_{m,n+1}} = \left(k_{1,t_{m,n}} e^{\lambda_1 t} + k_{2,t_{m,n}} e^{\lambda_2 t}\right)$$

Equation_Apx B-16

$$C_{FF,t_{m,n+1}} = \left(k_{3,t_{m,n}} e^{\lambda_1 t} - k_{4,t_{m,n}} e^{\lambda_2 t}\right)$$

Where:

Equation_Apx B-17

$$k_{1,t_{m,n}} = \frac{Q_{NF}\left(C_{FF,0}(t_{m,n}) - C_{NF,0}(t_{m,n})\right) - \lambda_2 V_{NF} C_{NF,0}(t_{m,n})}{V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx B-18

$$k_{2,t_{m,n}} = \frac{Q_{NF}\left(C_{NF,0}(t_{m,n}) - C_{FF,0}(t_{m,n})\right) + \lambda_1 V_{NF} C_{NF,0}(t_{m,n})}{V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx B-19

$$k_{3,t_{m,n}} = \frac{(Q_{NF} + \lambda_1 V_{NF})(Q_{NF}\left(C_{FF,0}(t_{m,n}) - C_{NF,0}(t_{m,n})\right) - \lambda_2 V_{NF} C_{NF,0}(t_{m,n}))}{Q_{NF} V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx B-20

$$k_{4,t_{m,n}} = \frac{(Q_{NF} + \lambda_2 V_{NF})(Q_{NF}\left(C_{NF,0}(t_{m,n}) - C_{FF,0}(t_{m,n})\right) + \lambda_1 V_{NF} C_{NF,0}(t_{m,n}))}{Q_{NF} V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx B-21

$$\lambda_1 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) + \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

Equation_Apx B-22

$$\lambda_2 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) - \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

Equation_Apx B-23

$$C_{NF,o}(t_{m,n}) = \begin{cases} 0, \;\; m = 0 \\ \frac{Amt}{V_{NF}}\left(1{,}000\frac{mg}{g}\right) + C_{NF}(t_{m,n-1}), \;\; n > 0 \; for\ all\ m\ where\ brake\ job\ occurs \end{cases}$$

Equation_Apx B-24

$$C_{FF,o}(t_{m,n}) = \begin{cases} 0, \;\; m = 0 \\ C_{FF}(t_{m,n-1}), \;\; for\ all\ n\ where\ m > 0 \end{cases}$$

Equation_Apx B-25

$$C_{NF,\text{ 5-min TWA, }t_{m,n}} = \frac{\left(\frac{k_{1,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_2} + \frac{k_{2,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_2}\right) - \left(\frac{k_{1,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_1} + \frac{k_{2,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_1}\right)}{t_2 - t_1}$$

Equation_Apx B-26

$$C_{FF,\text{ 5-min TWA, }t_{m,n}} = \frac{\left(\frac{k_{3,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_2} + \frac{k_{4,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_2}\right) - \left(\frac{k_{3,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_1} + \frac{k_{4,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_1}\right)}{t_2 - t_1}$$

After calculating all near-field/far-field 5-minute TWA exposures (i.e., $C_{NF,\text{ 5-min TWA, }t_{m,n}}$ and $C_{FF,\text{ 5-min TWA, }t_{m,n}}$) for each five-minute period of the work day, EPA calculated the near-field/far-field 8-hour TWA concentration and 1-hour TWA concentrations following the equations below:

Equation_Apx B-27

$$C_{NF,\text{ 8-hr }TWA} = \frac{\sum_{m=0}^{7}\sum_{n=0}^{11}\left[C_{NF,\text{5-min }TWA,t_{m,n}} \times 0.0833\ hr\right]}{8\ hr}$$

Equation_Apx B-28

$$C_{NF,\text{ 8-hr }TWA} = \frac{\sum_{m=0}^{7}\sum_{n=0}^{11}\left[C_{FF,\text{5-min }TWA,t_{m,n}} \times 0.0833\ hr\right]}{8\ hr}$$

Equation_Apx B-29

$$C_{NF,\text{1-hr}\,TWA} = \frac{\sum_{n=0}^{11}\left[C_{NF,\text{5-min}\,TWA,t_{m,n}} \times 0.0833\ hr\right]}{1\ hr}$$

Equation_Apx B-30

$$C_{FF,\text{1-hr}\,TWA} = \frac{\sum_{n=0}^{11}\left[C_{FF,\text{5-min}\,TWA,t_{m,n}} \times 0.0833\ hr\right]}{1\ hr}$$

EPA calculated rolling 1-hour TWA's throughout the workday and the model reports the maximum calculated 1-hour TWA.

To calculate the mass transfer to and from the near-field, the free surface area (FSA) is defined to be the surface area through which mass transfer can occur. The FSA is not equal to the surface area of the entire near-field. EPA defined the near-field zone to be a hemisphere with its major axis oriented vertically, against the vehicle, and aligned through the center of the wheel (see Figure_Apx 7). The top half of the circular cross-section rests against, and is blocked by, the vehicle and is not available for mass transfer. The FSA is calculated as the entire surface area of the hemisphere's curved surface and half of the hemisphere's circular surface per Equation_Apx B-31, below:

Equation_Apx B-31

$$FSA = \left(\frac{1}{2} \times 4\pi R_{NF}^2\right) + \left(\frac{1}{2} \times \pi R_{NF}^2\right)$$

Where: R_{NF} is the radius of the near-field

The near-field ventilation rate, Q_{NF}, is calculated in Equation_Apx B-32 from the indoor wind speed, v_{NF}, and FSA, assuming half of the FSA is available for mass transfer into the near-field and half of the FSA is available for mass transfer out of the near-field:

Equation_Apx B-32

$$Q_{NF} = \frac{1}{2} v_{NF} FSA$$

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx B-33:

Equation_Apx B-33

$$\boldsymbol{Q_{FF} = V_{FF} AER}$$

Using the model inputs described in Appendix B.8.2, EPA estimated NMP inhalation exposures for workers in the near-field and for occupational non-users in the far-field. EPA then conducted the Monte Carlo simulations using @Risk (Version 7.0.0). The simulations applied 100,000 iterations and the Latin Hypercube sampling method.

B.8.2 Model Parameters

Table_Apx B-12 summarizes the model parameters and their values for the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. Each parameter is discussed in detail in the following subsections.

Table_Apx B-12. Summary of Parameter Values and Distributions Used in the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	m^3	—	—	206	70,679	3,769	Triangular	Distribution based on data collected by CARB (CARB, 2006).
Air exchange rate	AER	hr^{-1}	—	—	1	20	3.5	Triangular	(Demou et al., 2009) identifies typical AERs of 1 hr^{-1} and 3 to 20 hr^{-1} for occupational settings without and with mechanical ventilation systems, respectively. (Hellweg et al., 2009) identifies average AERs for occupational settings utilizing mechanical ventilation systems to be between 3 and 20 hr^{-1}. (Golsteijn et al., 2014) indicates a characteristic AER of 4 hr^{-1}. Peer reviewers of EPA's 2013 TCE draft risk assessment commented that values around 2 to 5 hr^{-1} may be more likely (U.S. EPA, 2013a), in agreement with (Golsteijn et al., 2014). A triangular distribution is used with the mode equal to the midpoint of the range provided by the peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}).
Near-field indoor wind speed	v_{NF}	ft/hr	1,037	50^{th} percentile	—	—	—	Lognormal	Lognormal distribution fit to commercial-type workplace data from Baldwin and Maynard (1998).
		cm/s	8.78	50^{th} percentile	—	—	—	Lognormal	
Near-field radius	R_{NF}	m	1.5	—	—	—	—	Constant Value	Constant.
Starting time for each application period	t_1	hr	0	—	—	—	—	Constant Value	Constant.

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
End time for each application period	t_2	hr	0.0833	—	—	—	—	Constant Value	Assumes aerosol degreaser is applied in 5-minute increments during brake job.
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	Constant.
NMP weight fraction	wtfrac	wt frac	—	—	0.045	0.40	—	Discrete	Discrete distribution of NMP-based aerosol product formulations based on products identified in EPA (U.S. EPA, 2017b).
Degreaser Used per Brake Job	W_d	oz/ job	14.4	—	—	—	—	Constant Value	Based on data from CARB (CARB, 2000).
Number of Applications per Job	N_A	Applications/ job	11	—	—	—	—	Constant Value	Calculated from the average of the number of applications per brake and number of brakes per job.
Amount Used per Application	Amt	g NMP/ application	—	—	1.7	14.8	—	Calculated	Calculated from wtfrac, W_d, and N_A.
Operating hours per week	OHpW	hr/week	—	—	40	82.5	—	Lognormal	Lognormal distribution fit to the operating hours per week observed in CARB (CARB, 2000) site visits.
Number of Brake Jobs per Work Shift	N_J	jobs/site-shift	—	—	2	4	—	—	Calculated from the average number of brake jobs per site per year, OHpW, and assuming 52 operating weeks per year and 8 hours per work shift.

B.8.2.1 Far-Field Volume

The far-field volume is based on information obtained from CARB (2000) from site visits of 137 automotive maintenance and repair shops in California. CARB (2000) indicated that shop volumes at the visited sites ranged from 200 to 70,679 m^3 with an average shop volume of 3,769 m^3. Based on this data EPA assumed a triangular distribution bound from 200 m^3 to 70,679 m^3 with a mode of 3,769 m^3 (the average of the data from CARB (2000).

CARB measured the physical dimensions of the portion of the facility where brake service work was performed at the visited facilities. CARB did not consider other areas of the facility, such as customer waiting areas and adjacent storage rooms, if they were separated by a normally closed door. If the door was normally open, then CARB did consider those areas as part of the measured portion where brake servicing emissions could occur (CARB, 2000). CARB's methodology for measuring the physical dimensions of the visited facilities provides the appropriate physical dimensions needed to represent the far-field volume in EPA's model. Therefore, CARB's reported facility volume data are appropriate for EPA's modeling purposes.

B.8.2.2 Air Exchange Rate

The air exchange rate (AER) is based on data from (Golsteijn et al., 2014; Demou et al., 2009; Hellweg et al., 2009), and information received from a peer reviewer during the development of the 2014 *TSCA Work Plan Chemical Risk Assessment Trichloroethylene: Degreasing, Spot Cleaning and Arts & Crafts Uses* (U.S. EPA, 2013a). (Demou et al., 2009) identifies typical AERs of 1 hr^{-1} and 3 to 20 hr^{-1} for occupational settings without and with mechanical ventilation systems, respectively. Similarly, (Hellweg et al., 2009) identifies average AERs for occupational settings using mechanical ventilation systems to vary from 3 to 20 hr^{-1}. (Golsteijn et al., 2014) indicates a characteristic AER of 4 hr^{-1}. The risk assessment peer reviewer comments indicated that values around 2 to 5 hr^{-1} are likely (U.S. EPA, 2013a), in agreement with Golsteijn, et al. (2014) and the low end reported by (Demou et al., 2009) and (Hellweg et al., 2009). Therefore, EPA used a triangular distribution with the mode equal to 3.5 hr^{-1}, the midpoint of the range provided by the risk assessment peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}), with a minimum of 1 hr^{-1}, per (Demou et al., 2009) and a maximum of 20 hr^{-1} per (Demou et al., 2009) and (Hellweg et al., 2009).

B.8.2.3 Near-Field Indoor Air Speed

Baldwin and Maynard (1998) measured indoor air speeds across a variety of occupational settings in the United Kingdom. Fifty-five work areas were surveyed across a variety of workplaces.

EPA analyzed the air speed data from Baldwin and Maynard (1998) and categorized the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. EPA fit separate distributions for these industrial and commercial settings and used the commercial distribution for facilities performing aerosol degreasing.

EPA fit a lognormal distribution for both data sets as consistent with the authors observations that the air speed measurements within a surveyed location were lognormally distributed and the population of the mean air speeds among all surveys were lognormally distributed. Since lognormal distributions are bound by zero and positive infinity, EPA truncated the distribution at the largest observed value among all of the survey mean air speeds from Baldwin and Maynard (1998).

EPA fit the air speed surveys representative of commercial facilities to a lognormal distribution with the following parameter values: mean of 10.853 cm/s and standard deviation of 7.883 cm/s. In the model, the lognormal distribution is truncated at a maximum allowed value of 202.2 cm/s (largest surveyed mean air speed observed in Baldwin and Maynard (1998) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

Baldwin and Maynard (1998) only presented the mean air speed of each survey. The authors did not present the individual measurements within each survey. Therefore, these distributions represent a distribution of mean air speeds and not a distribution of spatially-variable air speeds within a single workplace setting. However, a mean air speed (averaged over a work area) is the required input for the model.

B.8.2.4 Near-Field Volume

EPA defined the near-field zone to be a hemisphere with its major axis oriented vertically, against the vehicle, and aligned through the center of the wheel (see Figure_Apx 1). The near-field volume is calculated per Equation_Apx B-34. EPA defined a near-field radius (R_{NF}) of 1.5 meters, approximately 4.9 feet, as an estimate of the working height of the wheel, as measured from the floor to the center of the wheel.

Equation_Apx B-34

$$V_{NF} = \frac{1}{2} \times \frac{4}{3} \pi R_{NF}^3$$

B.8.2.5 Application Time

EPA assumed an average of 11 brake cleaner applications per brake job (see Section B.8.2.9). CARB observed, from their site visits, that the visited facilities did not perform more than one brake job in any given hour (CARB, 2000). Therefore, EPA assumed a brake job takes one hour to perform. Using an assumed average of 11 brake cleaner applications per brake job and one hour to perform a brake job, EPA calculates an average brake cleaner application frequency of once every five minutes (0.0833 hr). EPA models an average brake job of having no brake cleaner application during its first five minutes and then one brake cleaner application per each subsequent 5-minute period during the one-hour brake job.

B.8.2.6 Averaging Time

EPA was interested in estimating 8-hr TWAs for use in risk calculations; therefore, a constant averaging time of eight hours was used.

B.8.2.7 NMP Weight Fraction

EPA reviewed the *Use and Market Profile for N-methylpyrrolidone (NMP)* report (Abt, 2017) for aerosol degreasers that contain NMP. EPA (U.S. EPA, 2017b) identifies two aerosol cleaners that overall range in NMP content from 4.5 to 40 weight percent. The identified aerosol cleaners are a gun bore cleaner and a resin remover. EPA includes these aerosol cleaners in the estimation of NMP content as EPA uses this brake servicing model as an exposure scenario representative of all commercial-type aerosol degreaser applications.

EPA used a discrete distribution to model the NMP weight fraction based on the number of occurrences of each product type. EPA modeled a 50% probability of occurrence for each of the two aerosol cleaner products. The gun bore cleaner (Break-Free bore cleaning foam) contains 4.5 weight percent NMP and the resin remover (Slide resin remover) contains 35 to 40 weight percent. EPA used a uniform distribution to model the NMP weight fraction within the resin remover.

B.8.2.8 Volume of Degreaser Used per Brake Job

CARB (2000) assumed that brake jobs require 14.4 oz of aerosol product. EPA did not identify other information to estimate the volume of aerosol product per job; therefore, EPA used a constant volume of 14.4 oz per brake job based on CARB (2000).

B.8.2.9 Number of Applications per Brake Job

Workers typically apply the brake cleaner before, during, and after brake disassembly. Workers may also apply the brake cleaner after brake reassembly as a final cleaning process (CARB, 2000). Therefore, EPA assumed a worker applies a brake cleaner three or four times per wheel. Since a brake job can be performed on either one axle or two axles (CARB, 2000), EPA assumed a brake job may involve either two or four wheels. Therefore, the number of brake cleaner (aerosol degreaser) applications per brake job can range from six (3 applications/brake x 2 brakes) to 16 (4 applications/brake x 4 brakes). EPA assumed a constant number of applications per brake job based on the midpoint of this range of 11 applications per brake job.

B.8.2.10 Amount of NMP Used per Application

EPA calculated the amount of NMP used per application using Equation_Apx B-35. The calculated mass of perchloroethylene used per application ranges from 1.7 to 14.8 grams.

Equation_Apx B-35

$$Amt = \frac{W_d \times wtfrac \times 28.3495 \frac{g}{oz}}{N_A}$$

Where:

Amt	=	Amount of NMP used per application (g/application);
W_d	=	Weight of degreaser used per brake job (oz/job);
Wtfrac	=	Weight fraction of NMP in aerosol degreaser (unitless); and
N_A	=	Number of degreaser applications per brake job (applications/job).

B.8.2.11 Operating Hours per Week

CARB (2000) collected weekly operating hour data for 54 automotive maintenance and repair facilities. The surveyed facilities included service stations (fuel retail stations), general automotive shops, car dealerships, brake repair shops, and vehicle fleet maintenance facilities. The weekly operating hours of the surveyed facilities ranged from 40 to 122.5 hr/week. EPA fit a lognormal distribution to the surveyed weekly operating hour data. The resulting lognormal distribution has a mean of 16.943 and standard deviation of 13.813, which set the shape of the lognormal distribution. EPA shifted the distribution to the right such that its minimum value is 40 hr/week and set a truncation of 122.5 hr/week (the truncation is set as 82.5 hr/week relative to the left shift of 40 hr/week).

B.8.2.12 Number of Brake Jobs per Work Shift

CARB (2000) visited 137 automotive maintenance and repair shops and collected data on the number of brake jobs performed annually at each facility. CARB calculated an average of 936 brake jobs performed per facility per year. EPA calculated the number of brake jobs per work shift using the average number of jobs per site per year, the operating hours per week, and assuming 52 weeks of operation per year and eight hours per work shift using Equation_Apx B-36 and rounding to the nearest integer. The calculated number of brake jobs per work shift ranges from one to four.

Equation_Apx B-36

$$N_J = \frac{936\,\frac{jobs}{site\text{-}year} \times 8\,\frac{hours}{shift}}{52\,\frac{weeks}{yr} \times OHpW}$$

Where:

N_J	=	Number of brake jobs per work shift (jobs/site-shift); and
OHpW	=	Operating hours per week (hr/week).