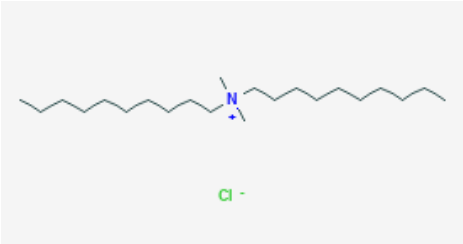
Updated EHS Summary of Didecyl Dimethyl Ammonium Chloride (DDAC) for the MA TURA Science Advisory Board Meeting – January 14, 2021

CAS #: 7173-51-5  	**NAME:** Didecyl Dimethyl Ammonium Chloride **Synonym[1]s:** DDAC, Didecyldimethylammonium chloride, N-decyl-N,N-dimethyldecan-1-aminium chloride **RTECS #[2]:** **EINECS #[3]:** 230-525-2 **Molecular Weight[4]**: 362.1 g/mol **Molecular Formula[5]:** $C_{22}H_{48}ClN$ **Pesticide Code:** 69149 **Chemical Family:** Quaternary amines **Related CAS #'s:** 20256-56-8 (Parent) (see list at end of summary) **EPA Group 1 Quat Cluster:** The alkyl or hydroxyalkyl (straight chain) substituted Quats
PHYSICAL CHARACTERISTICS	
Primary Use	Cleaning products, disinfectants, bactericidal and fungicidal biocide. Several applications including, swimming pools and aquatic areas, industrial processes, wood treatment, healthcare and food handling and storage. Products containing DDAC are formulated as liquid ready-to-use soluble concentrates and the ratio of DDAC in various end use products can range anywhere from 0.08% to 80% DDAC. There are 279 registered products that contain DDAC, but 5 main structurally similar quaternary ammonium compounds. Production volume data from 2011 through 2014 indicate that approximately 99 million pounds of DDAC are sold per year in the United States[1]. "Due to their amphiphilic nature, QACs act as detergents or surface-active agents against microorganisms. QACs target bacterial cell membranes through electrostatic interactions between the positively charged head group and negatively charged cytoplasmic membrane, adsorption, and then permeation of side chains into the intramembrane region. The lipid layer of enveloped viruses makes them sensitive to the hydrophobic activity of QACs" (Hora, 2020).
Physical state, odor at room temperature & pressure	Clear yellow liquid with an ethanolic or mushroom-like odor [in aqueous solution][1] White slight yellowish solid powder with a mushroom-like odor[6]
Melting point; Boiling point	**MP:** 228.81˚C[1] **BP:** >180 °C; decomposes before boiling at 1 atm /OECD Guideline 103[7]
Solubility	Completely soluble in water[1]
Specific Gravity	
SAFETY/PHYSICAL HAZARDS	

Vapor Pressure	2.33 x 10^{-11} mm Hg[1] <4.3X10-5 mm Hg at 25 °C, <1.1X10-5 mm Hg at 20 °C /OECD Guideline 104[6]
Flammability	
Flashpoint	A study was conducted to determine the flash point of the test substance 'didecyldimethylammonium chloride' (DDAC), using a closed crucible according to DIN ISO 2719, EU Method A.9 (Flash-Point). The test substance was been determined to have a flash point of 26.4°C at 103.6 kPa[6].
Flammability Rating	
Auto Ignition Point	
Combustion products	
Explosivity (UEL, LEL, shock sensitive)	
Oxidizer	
Corrosivity	
pH	pH = 6.8 to 6.9 at 25 °C in a 29.5% water solution[6]
Reactivity	
Viscosity	
Odor Threshold	
Particle size, shape, respirable fraction	
Other physical hazards associated with process: Heat, gases under pressure, noise, vibration, ergonomic hazard	When heated to decomposition it emits very toxic fumes of nitrogen oxides, ammonia, and hydrogen chloride[8]
HEALTH HAZARDS	
Acute Toxicity	
Oral LD_{50}	EPA Toxicity Category II[1] LD_{50} (combined) = 238 mg/kg[1] LD_{50} (combined) = 262 mg/kg[1]
Dermal LD_{50}	EPA Toxicity Category III[1] LD_{50} (male) = 3140 mg/kg[1] LD_{50} (female) = 2730 mg/kg[1] LD_{50} (combined) = 2930 mg/kg[1]
Inhalation LC_{50}	EPA Toxicity Category II[1] LC_{50} = 0.07 mg/L[1]
Intraperitoneal LD_{50}	
Chronic or Sub-chronic Toxicity	
IARC rating	

Carcinogenicity	
Neurotoxicity	
Developmental/Reproductive Toxicity	"Breeding pairs exposed for six months to a QAC disinfectant exhibited decreases in fertility and fecundity: increased time to first litter, longer pregnancy intervals, fewer pups per litter and fewer pregnancies. Significant morbidity in near term dams was also observed. Exposure to a common QAC disinfectant mixture significantly impaired reproductive health in mice. The study demonstrated that ADBAC + DDAC exposure is toxic to both male and female fertility. Female mice exposed to ADBAC + DDAC exhibited decreased reproductive capacity with reduced ovulation and fewer estrus cycles. Male mice exposed to ADBAC + DDAC exhibited significantly decreased sperm concentration and motility" (Melin, 2014).[9] "Neural tube defects (NTD) were seen in both rats and mice following ambient exposure to the QAC's containing disinfectant in the mouse room. NTDs were also observed in mice dosed with the disinfectant at 60 or 120 mg/kg/day in feed, or with ADBAC+DDAC chemical by gavage at 7.5, 15, or 30 mg/kg/day. Mice received ambient exposure for 2 weeks or ambient and gavage. NTDs were seen with ADBAC and DDAC dosed acutely by oral gavage, chronically in feed, and ambiently through the use of disinfectant in the mouse room. Both ambient and ambient plus gavage groups exhibited significantly increased levels of NTDs compared with unexposed controls" (Hrubec, 2017).[10] Note also QAC industry critique of Hrubec 2017 study[11]
Genotoxicity/Mutagenicity	
Endocrine Disruption	Females exposed to ADBAC + DDAC demonstrated significantly decreased ovulatory capacity, spent less time in estrus, and progressed through fewer estrus cycles compared to controls. ADBAC + DDAC may have reduced estrus length and frequency through disruption of estrogen-regulated processes. ADBAC + DDAC treated mice had significantly fewer estrus cycles over the evaluation period. This correlates directly with our 6 month breeding trial which observed significantly fewer litters produced in ADBAC + DDAC treated mice. These two findings reinforce that ADBAC + DDAC disrupt reproductive function in female mice (Melin, 2016).[12]
Thyroid	
Immunotoxicity	"DDAC induced significant irritancy (0.5 and 1%), evaluated by ear swelling in female Balb/c mice. Initial evaluation of the sensitization potential was conducted using the local lymph node assay (LLNA) at

	concentrations ranging from 0.0625–1%. A concentration dependent increase in lymphocyte proliferation was observed with a calculated EC3 value of 0.17%. Dermal exposure to DDAC did not induce increased production of IgE as evaluated by phenotypic analysis of draining lymph node B-cells (IgE + B220+) and measurement of total serum IgE levels. Additional phenotypic analyses revealed significant and dose-responsive increases in the absolute number of B-cells, CD4 + T-cells, CD8 + T-cells and dendritic cells in the draining lymph nodes, along with significant increases in the percentage of B-cells (0.25% and 1% DDAC) at Day 10 following 4 days of dermal exposure. There was also a significant and dose-responsive increase in the number of activated CD44 + CD4 + and CD8 + T-cells and CD86 + B-cells and dendritic cells following exposure to all concentrations of DDAC." "There was a significant increase in the percentage of B-cells in the absence of increasing IgE+ B-cells in the DLN and total IgE in the serum. TDI was included in these experiments as a chemical that induces a prototypical TH2 (IgE-mediated) hypersensitivity response. Although only a single concentration of TDI (1%) was included, it fell into the concentration range that was examined for DDAC, specifically activation percentages of the immune cell subsets examined. The percentage of activated CD8+ T cells in the DLN was higher for DDAC compared to TDI for all concentrations tested. In contrast, the percentage of activated B-cells in the DLN was strikingly higher for TDI than for any concentration of DDAC. These findings demonstrate a lack of increase in both local and total IgE, along with an increased percentage of activated CD8+ T-cells in the DLN following exposure; this data suggests that DDAC may induce a T-cell or TH1-mediated hypersensitivity response. Due to the emergence of a ''new generation'' of QAC that are structurally heterogeneous and potentially exhibit increased immunogenicity compared to their predecessors, it is imperative to analyze the immunotoxicological effects of these compounds. The immunological consequences of these types of mixed exposures has not thoroughly been studied" (Anderson, 2016).[11]
Liver	Significant decreases in percentage body weight (11% at 0.5% and 14% at 1%) were observed at Day 10 following a 4-day DDAC exposure regimen. Although no statistically significant changes in organ weight were observed following exposure to any tested concentrations of DDAC, a decreasing trend (Linear Trend Test, p50.01 and p50.05, respectively) in thymus and liver weight (but not percentage of body weight) was observed at Day 10 following a 4-day exposure (Anderson,

	2016).[13]
Other organ toxicity	
Skin, Eye and Respiratory Effects	
*Irritant – **S**kin, **E**ye, or **R**espiratory*	EPA Toxicity Category I: highly irritating to the skin and eyes[1]
*Corrosive – **S, E,** or **R***	EU Harmonised classification: Skin Corr. 1B[14]
*Permanent Damage – **S, E,** or **R***	A study examined the pulmonary defense system following a single intratracheal instillation of DDAC (60 and 150 mg/kg) in C57BL/6J mice. Those authors found that exposure to the high dose induced lung injury as early as 1-d post-exposure, as evidenced by increased lactate dehydrogenase (LDH) activity and protein concentrations in the bronchoalveolar (BAL) fluid. There was also an increase in total cells in the BAL (specifically macrophages, neutrophils and lymphocytes), along with increases in interleukin (IL)-6 production by 7-days post exposure. The authors also suggested that DDAC exposure altered oxidative stress and antimicrobial markers (evaluated by gene expression) in the lungs and systemic co-exposure with lipopolysaccharide (LPS) generated a further enhancement in pulmonary inflammation suggesting a potential increase in susceptibility to bacterial agents (Ohnuma, 2011).[15]
*Sensitizer– **S** & **R***	DDAC was identified as an irritant and strong sensitizing chemical. The lowest concentrations that induced a significant increase in lymphocyte proliferation (0.25%) were below concentrations that resulted in significant increases in ear swelling (0.5%). In addition, there was a significant increase in the percentage of B-cells in the absence of increasing IgE+ B-cells in the DLN and total IgE in the serum. TDI was included in these experiments as a chemical that induces a prototypical TH2 (IgE-mediated) hypersensitivity response (Anderson, 2016).[16]
Asthmagen – Initiator or Exacerbator	AOEC listed as an asthmagen and sensitizer[17] "There are reports in the literature of work-related asthma associated with exposure to cleaning agents and disinfectants and some of these reports relate to the use of QUATS. The earliest reports include a case of a laundry worker who developed asthma after using a disinfectant containing QACs (Innocenti, 1978), a pharmacist who had asthma attacks when contacting a floor cleaning solution containing QACs (Burge, 1994) and a worker who had occupational asthma caused by prolonged exposure to cleaning agents containing QACs (Bernstein, 1994). Three more cases were reported in Purohit (2000) of nurses who experienced asthma symptoms when preparing a 10% solution of disinfectant containing QAC, cleaning surgical instruments in a tray with a QAC disinfectant, and entering a room where a solution of

	disinfectant containing 40% QAC was kept. In a multistate report of 401 cases of pesticide related illness of health care workers (Mehler et al, 2010), QACs were involved in the most cases (151) followed by glutaraldehyde (101) and sodium hypochlorite (71). In terms of occupation, janitors and housekeepers had the most cases (95), followed by nursing/medical assistants (64) and health technicians (59)"[1]. "Exposure to QACs increased significantly the risk of reported physician-diagnosed asthma and nasal symptoms at work (adjusted OR = 7.5 and 3.2, respectively). No significant association was found with other exposures such as latex glove use, chlorinated products/bleach or glutaraldehyde" (Gonzalez, 2013). "Cleaning products that induced a positive specific inhalation challenge (SIC) contained quaternary ammonium compounds (n=10), glutaraldehyde (n=3), both of these agents (n=1) and ethanolamines (n=2). Positive SICs were associated with a significant decrease in the median (IQR) value of the provocative concentration of histamine causing a 20% fall in FEV1 (PC20) from 1.4 (0.2–4.2) mg/mL at baseline to 0.5 (0.4–3.0) mg/mL after the challenge and a significant increase in sputum eosinophils from 1.8 (0.8–7.2)% at baseline to 10.0 (4.1–15.9)% 7 h after the challenge exposure while these parameters did not significantly change in participants with a negative SIC. The results also suggest that quaternary ammonium compounds are the principal cause of sensitizer-induced occupational asthma among cleaners."[18]
Skin Absorption, Kp	
LOAEL	Incidental Oral (Short-Term) LOAEL (developmental) = 20 mg/kg/day based on increased incidence of skeletal variations.[1]
NOAEL	Incidental Oral (Short-Term) NOAEL (developmental) = 10/mg/kg/day[1]
Benchmark Dose Response (BMD)	
Toxicokinetics	
Metabolites	
Synergistic or Antagonistic Effects	
Environmental and Human Health Exposure and Risk Values	
RfC/RfD	"The acute RfD is **0.1 mg/kg/day** for females (13-50 years). This endpoint is based on a developmental toxicity study in rats with a reported NOAEL of 10 mg/kg/day. This study indicated increased incidence of skeletal variations at the LOAEL of 20 mg/kg/day. The chronic RfD is 0.1 mg/kg/day. This is based on increased incidence of clinical observation signs in males and females and decreased total

	cholesterol levels in females at 20 mg/kg/day in the chronic toxicity study in dogs. An uncertainty factor of 100 (10X for interspecies extrapolation and 10X for intraspecies variability) was applied to the NOAEL to obtain the acute and chronic RfDs."[1]
ATSDR-MRL	MRL of 0.1 mg/kg for all food commodities covered by the EU MRL legislation for DDAC[19]
Adverse Effect Levels: DNEL, PNEC, PNEL	PNEC (ug/L) = 2.8[20]
Health Based Exposure Limits	
NIOSH-REL/IDLH/Ceiling Limits	
OSHA-PEL	
ACGIH TLV-TWA	
TLV-STEL	
Biomonitoring Action Limits	
Drinking Water Standards	
Other	FIFRA Requirements (40 CFR 180.940): Residues of the following chemical substances are exempted from the requirement of a tolerance when used in accordance with good manufacturing practice as ingredients in an antimicrobial pesticide formulation, provided that the substance is applied on a semi-permanent or permanent food-contact surface (other than being applied on food packaging) with adequate draining before contact with food. ... (c) The following chemical substances when used as ingredients in an antimicrobial pesticide formulation may be applied to: Food-processing equipment and utensils. 1-Decanaminium, N-decyl-N,N-dimethyl-, chloride is included on this list. Limit: When ready for use, the end-use concentration is not to exceed 200 ppm of active quaternary compound.[21] Use data indicate that the general population may be exposed to DDAC via dermal contact with consumer products containing this compound. The use as an antimicrobial product on food contact surfaces, treatment of mushroom houses, and application to food-grade eggs may result in pesticide residues in human food. Residues from the use of DDAC for food contact sanitization on treated surfaces, such as food utensils, countertops, equipment, and appliances, can migrate to food coming into contact with the treated surfaces and can be ingested by humans.[1] Since the 2006 RED, 781 individual human health incidents have been reported for DDAC in OPP's Incident Data System (IDS) from August 1,

	2006 to March 3, 2017. • A maintenance worker at a gas station used an ADBAC/DDAC disinfectant product. Another worker there was allegedly exposed to it and developed respiratory distress and ultimately died. She previously had chronic obstructive pulmonary disease. • An airline employee developed respiratory distress resulting in death. Chemical exposure to an ADBAC/DDAC product and three other cleaning products was the potential cause. No other details were provided. • A person deliberately inhaled a fabric and air deodorizer. This person had a history of inhalant abuse. • A 68-year dementia patient in a nursing home ingested an ABDAC/DDAC disinfectant product that was being used to clean wheelchairs during the overnight shift. • An individual ingested an ADBAC/DDAC powder product along with another nonpesticidal cleaning product in a correctional facility.
ENVIRONMENTAL & ECO-SYSTEM HAZARDS	
PBT	
Bioaccumulation	
BAF	
BCF	A measured BCF of 81 in fish suggests bioconcentration in aquatic organisms is moderate.[1]
BMF	
Ecological Toxicity	
Aquatic Toxicity: LC_{50}, EC_{50}, ErC_{50}, NOAEC/NOEC	Short term toxicity to fish was evaluated according to OECD Guideline 203 and EU Method C.1 under GLP conditions. Seven fish per concentration were exposed to 0.18, 0.32, 0.56, 1.0 or 1.8 mg/L of a commercial product containing 50% DDAC for 96 h. The test was conducted under semi-static conditions, with the test solution being renewed after 48 h. No analytical dose verification was performed and all values mentioned are nominal. The highest concentration causing no mortality (NOEC) after 96 h was 0.56 mg/L whereas 100% mortality occurred within 2 h at 1.8 mg/L. There were no effects on behavior during the exposure period, except for the fish at 1.0 mg/L which showed reduced activity after 6 h. The **96 h LC50** of the test substance was **0.49 mg a.i./L**[6]**.** A long-term toxicity study with aquatic invertebrates (*Daphnia magna*) was carried out according to OECD Guideline 211, in compliance with GLP. The following nominal concentrations were used: 0, 0.005, 0.0125,

	0.032, 0.08 and 0.2 mg /L, corresponding to mean measured values of 0, 0.0031, 0.0078, 0.020, 0.047 and 0.124 mg/L. The test conditions were semi-static, with renewal every second day and over the weekend after three days. Animals were checked daily for immobilisation of parent daphnids by gently shaking the test vessel. From the day of the first brood, observations (aborted, living and dead progeny) were also made at each concentration. The day of brood release and the number of living and dead neonates per brood or abortions were noted. Any other abnormal observations were also recorded. Under the study conditions, results (based on mortality as well as reproduction, expressed as measured concentrations of active ingredient) were as follows: **NOEC = 0.021 mg/L, LOEC = 0.047 mg/L, EC50 = 0.031 mg/L** (Thomas, 2004)[6]. **EPA Final Work Plan Data:** Freshwater fish: Acute LC_{50} = 190 ug ai/L (**highly toxic**) Freshwater fish: Chronic NOAEC =32 ai/L Freshwater invertebrates: Acute EC_{50} = 18 ug ai/L (**very highly toxic**) Freshwater invertebrates: Chronic NOAEC = 10 ug ai/L Marine fish: Acute LC_{50} = 960 ug ai/L (**highly toxic**) Marine invertebrates Acute EC_{50} = 69 ug ai/L (**very highly toxic**)
Mammalian Toxicity: LC_{50}, EC_{50}, ErC_{50}, NOAEC/NOEC	
Wildlife Toxicity: LC_{50}, EC_{50}, ErC_{50}, NOAEC/NOEC	LC50; Species: Anas platyrhynchos (Mallard duck) age 10 days; diet >5620 ppm for 8 days[22] LC50; Species: Anas platyrhynchos (Mallard duck) diet >3500 ppm for 8 days[15]
General degradation	log K_{ow} = 2.59 at 20 °C, pH 7[6]; log K_{ow} - 4.66 at 25°C (EpiSuite)[1] High log K_{ow} indicates DDAC is relatively hydrophobic and potential for sorption to soil and sediment, noting complicating factor of amphiphilic nature of surfactants. In aqueous media offering the potential for both sorption and biodegradation, there is conflicting information about which of these processes would be expected to predominate. In aerobic and anaerobic aquatic metabolism studies, DDAC was stable to microbial degradation under aerobic and anaerobic conditions in water and sediment, indicating that sorption would predominate, while other tests showed ready biodegradability in the absence of clay, indicating that biodegradation would predominate. There is also uncertainty about biodegradation during wastewater treatment, in terms of sorbing to

	sludge biomass and potential toxicity to activated sludge microorganisms. [1] The available data indicates that DDAC is hydrolytically stable under abiotic and buffered conditions over the pH 5-9 range; also stable to photodegradation in water at pH7 (calculated half life of 227 days) [1]
Breakdown/degradation /combustion products	Potential for QACs in wastewater to form n-nitrosamine disinfection byproducts (e.g., N-Nitrosodimethylamine or NDMA, a potent carcinogen), particularly if chloramine is used as the disinfecting agent. This is likely of greatest concern for direct or indirect potable reuse scenarios,[23] as most n-nitrosamines breakdown via photolysis in surface waters.
Anaerobic degradation	
Aerobic degradation	DDAC was found to be stable with very little degradation in aerobic soils during a year-long metabolism study using sandy loam soil. The calculated half-life for aerobic soil degradation was 1,048 days. DDAC is not considered to be degradable since it did not exhibit greater that 60% degradation within a 10-day window.[1]
Other observable ecological effects (e.g. BOD)	
Fate and Transport: Aquatic	QACs have been detected worldwide in domestic wastewater, sludge, treated effluent, surface water, and sediment. It is expected that the majority of QAC applications leads to their eventual release (~75%) into sewers and WWTPs. Though QACs are removed from the liquid stream during conventional wastewater treatment, these compounds are still detected in aquatic environments, and at higher concentrations in locations downstream of the discharge of municipal WWTP effluents, hospital, and industrial effluents (Hora, 2020).[24] "While biodegradation of QACs has been shown to occur in laboratory studies, their removal in wastewater treatment plants (WWTPs) is likely driven by sorption to activated sludge. Consequently, QACs have been detected world-wide in WWTP influent, effluent, and sludge samples with concentrations typically in the high and low µg L−1 range for influents and effluents, respectively, as well as in the mid-to-high µg g−1 range for sewage sludge. As evident from these results as well as detection of QACs in river water samples, QACs are not completely removed during wastewater treatment and are released into the natural environment. Concern about the presence of QACs in the

	environment arises from the potential of these compounds to promote antibiotic resistance and serve as precursors for disinfection by-products. In addition, the degradation of QACs in the natural environment by both microorganisms and photolysis is slow, resulting in accumulation of significant amounts of these compounds in sediments." [25]
Fate and Transport: Terrestrial	
Fate and Transport: Atmospheric	Data from a random cage monitoring during QAC use and in the months after use of QAC disinfectants was discontinued, provided evidence that these chemicals may persist in the environment (Hrubec, 2017).
Transport Issues	Immobile in soil[1]
Factors affecting bioavailability	
Global Environmental Impacts	
Ozone Depletion Potential (ODP)	
Global Climate Change	
Greenhouse Gas Production	
Acid Rain Formation	
Special Reports	
EU/Other Countries	*Danger!* According to the **harmonised classification and labelling** (CLP00) approved by the European Union, this substance causes severe skin burns and eye damage and is harmful if swallowed. **Additionally**, the classification provided by companies to ECHA in **REACH registrations** identifies that this substance is toxic if swallowed, is very toxic to aquatic life, is toxic to aquatic life with long lasting effects, causes serious eye damage, is a flammable liquid and vapour and may cause drowsiness or dizziness[6].

Number of EPA Registered Products that contain DDAC- 2017 FWP

PC code	CAS Number	Ingredient Name	Number of Active Antimicrobial Product Registrations as of 3/14/17 [1]	Number of Active Conventional Product Registrations as of 3/14/17 [1]
069149	7173-51-5	Didecyl dimethyl ammonium chloride	260	1
069165	32426-11-2	1-Decanaminium, N,N-dimethyl-N-octyl-, chloride	133	1
069166	5538-94-3	1-Octanaminium, N,N-dimethyl-N-octyl-, chloride	146	1
069173	68607-28-3	Oxydiethylenebis(alkyl* dimethyl ammonium chloride) *(as in fatty acids of coconut oil)	4	0
129012	61789-18-2	Alkyl* trimethyl ammonium chloride *(as in fatty acids of coconut oil)	1	0

[1] USEPA/Office of Pesticide Programs; Didecyl Dimethyl Ammonium Chloride (DDAC) Final Work Plan, Registration Review: Initial Docket Case Number 3003, March 2017. Docket Number EPA-HQ-OPP-2015-0740

[2] www.toxplanet.com; RTECS for Didecyldimethylammonium chloride (7173-51-5).

[3] www.toxplanet.com; Chemical Identity Page for Didecyldimethylammonium chloride (7173-51-5).

[4] www.toxplanet.com; Chemical Identity Page for Didecyldimethylammonium chloride (7173-51-5).

[5] www.toxplanet.com; Chemical Identity Page for Didecyldimethylammonium chloride (7173-51-5).

[6] ECHA; Didecyldimethylammonium chloride (7173-51-5). Registered Data Dossier. Helsinki, Finland: European Chemicals Agency. Accessed at: https://echa.europa.eu/registration-dossier/-/registered-dossier/5864/4/2

[7] ECHA; Didecyldimethylammonium chloride (7173-51-5). Registered Data Dossier. Helsinki, Finland: European Chemicals Agency.

[8] Lewis, R.J. Sr. (ed) Sax's Dangerous Properties of Industrial Materials. 11th Edition. Wiley-Interscience, Wiley & Sons, Inc. Hoboken, NJ. 2004., p. 1230

[9] Melin, V. E., Potineni, H., Hunt, P., Griswold, J., Siems, B., Werre, S. R., & Hrubec, T. C. (2014). Exposure to common quaternary ammonium disinfectants decreases fertility in mice. *Reproductive Toxicology*, *50*, 163–170. https://doi-org.umasslowell.idm.oclc.org/10.1016/j.reprotox.2014.07.071

[10] Hrubec TC, Melin VE, Shea CS, et al. Ambient and Dosed Exposure to Quaternary Ammonium Disinfectants Causes Neural Tube Defects in Rodents. *Birth Defects Res*. 2017;109(14):1166-1178. doi:10.1002/bdr2.1064

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[14] ECHA harmonized classification of chemicals for 7173-51-5 didecyldimethylammonium chloride; accessed at: https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/134913

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[17] Association of Occupational and Environmental Clinics (AOEC) Exposure code lookup for Didecyl Dimethyl Ammonium Chloride (CAS 7173-51-5) accessed on 8/17/20: http://www.aoecdata.org/ExpCodeLookup.aspx

[18] Vandenplas, O., D'Alpaos, V., Evrard, G., Jamart, J.,Thimpont, J., Huaux, F., Renauld, J., (2013) Asthma related to cleaning agents: a clinical insight. *British Medical Journal* (http://dx.doi.org/10.1136/bmjopen-2013-003568

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[20] NICNAS (2015). National Industrial Chemicals Notification and Assessment Scheme (NICNAS) Inventory Multi-tiered Assessment and Prioritization (IMAP) framework, Mono-and di-alkyl quaternary ammonium surfactants: Environmental tier II assessment

[21] 40 CFR 180.940(c) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations.

[22] USEPA, Office of Pesticide Programs; Pesticide Ecotoxicity Database (2000) on N-Decyl-N,N'-dimethyl-1-decanaminium chloride (7173-51-5).

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