ADDENDA

ASHRAE Addendum d to
ASHRAE Guideline 28-2016

Air Quality within Commercial Aircraft

Approved by ASHRAE on May 25, 2021.

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Cognizant TC: 9.3 (Lead), Transportation Air Conditioning and
4.3 (Co-Cognizant), Ventilation Requirements and Infiltration
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FOREWORD

Addendum d updates the information in Section 8.1.2.6, "Organophosphates," and Table 8.2.4c, "Aircraft Sampling Data for Tricresylphosphate Isomers (TCP) and Tributylphosphate Isomers (TBP)." It also introduces a new Table 8.2.4d, "Lab Analysis Studies for Tricresylphosphate Isomers (TCPs)," which summarizes published laboratory analyses of TCPs in aviation engine oils.

Note: In this addendum, changes to the current standard are indicated in the text by underlining (for additions) and ~~strikethrough~~ (for deletions) unless the instructions specifically mention some other means of indicating the changes.

Addendum d to Guideline 28-2016

Revise Section 8.1.2.6 as shown below.

8.1.2.6 Organophosphates. ~~Organophosphates have a variety of potential sources. Tricresylphosphates (TCPs) are used in turbine engine oils and some hydraulic fluids, typically 1% to 5% TCP by weight.~~ On aircraft, researchers have measured the presence of airborne organophosphate compounds, which are added to engine oils and hydraulic fluids and may be used as flame retardants in cabin interiors such as foams, fabrics, and carpets (EASA 2017a). Other unidentified sources of organophosphates may also exist in the ambient air. Crew members and passengers could potentially be exposed to organophosphates in oil and hydraulic fluid when the cabin supply air is contaminated with those compounds. Maintenance workers may also be exposed to these organophosphates when they work on relevant aircraft systems (Solbu et al. 2010). One cabin-air-monitoring survey of 69 flights without documented oil/hydraulic fluid contamination reported the presence of a complex mixture of airborne organophosphates (EASA 2017a). The mean total concentration of organophosphates was 1.139 μg/m^3 on 61 aircraft equipped with bleed air supply systems and 0.820 μg/m^3 on 8 aircraft equipped with a bleedless air supply system.

Tricresyl phosphates (TCPs) are presently used in most turbine engine oils and some hydraulic fluids, typically at concentrations of less than 3% by weight according to manufacturer safety data sheets (SDSs). One publication reported 2.23% to 5.59% TCPs (five isomers) in samples of 8 different types of aviation engine oils (OHRCA 2014). Another publication reported 1.5% to 2.8% TCPs (five isomers) in samples of two different types of aviation engine oils (EASA 2017b). A third publication reported approximately 2.5% total TCPs in samples of four different types of aviation engine oils (Denola et al. 2008). There is one aviation engine oil product line that contains phenol, isopropylated, phosphate (CAS no. 68937-41-7) instead of TCPs (Nyco 2017).

Cresol mixtures with reduced ortho isomer content are used as precursors in the production of TCP blends (Henschler 1958; Denola et al. 2008). An analysis of widely used engine oils reported that more than 99% of the TCPs in the oils were meta and para isomers (OHRCA 2014). An industry standard for the TCP blends added to engine oils recommends that not more than 0.2% of the total TCPs are ortho isomers (SAE 2018), although there is no regulation for TCP content ~~Although the ortho isomer of TCP—triorthocresyl phosphate (TOCP)—has often been studied in the past,~~ T~~t~~here are a total of ~~10~~six ortho ~~different~~ isomers of TCP, including triorthocresyl phosphate. ~~the~~ The three monoorthocresyl phosphates (MOCPs) and ~~the~~ two diorthocresyl phosphates (DOCPs) are, respectively, five and ten times more toxic than TOCP (Mackerer et al. 1999; Henschler~~, and Bayer,~~ 1958). Another study found similar toxicities to TOCP (Hine et al.,1954). Henschler noted that the apparent contradiction of results may possibly be explained by the fact that Hine et al. did not use uniform animal material, and the two tested mixed esters (oop and opp) may have been prepared from cresol mixtures and not by systematic synthesis. The Hine et al. report contains no information on isomer preparation. There is evidence that the MOCPs and DOCPs are present in higher concentrations than the TOCP in these engine oils (Mackerer and Ladov,1999). In a laboratory analysis of the TCP isomers in an aircraft turbine oil, the authors reported a total ortho isomer content between 13 and 150 mg/L of the total TCPs and noted that the mono ortho isomers are the predominant ortho isomers of TCP (Denola et al. 2008). A short summary of sampling data for TCPs onboard either military or commercial aircraft published from 1988 to 2019 is provided in Table 8.2.4c, while a summary of TCP content of aviation oils and hydraulic fluids from 2008 to 2017 is provided in Table 8.2.4d. The MOCP and DOCP isomers may be present in the turbine oils in concentrations sufficient to be of concern for health and are reported to be in many synthetic jet engine oils in significantly higher concentrations than TOCP. A commercial aircraft oil manufacturer advised the Australian Senate in 2000 that MOCP was in the TCP at 3070 ppm, DOCP at 6 ppm, and TOCP at 5 ppb (Mackerer and Ladov 1999). For example, Table 8.1.2.6.1 lists the approximate amounts of these isomers for one oil blend at a given condition. Depending on the method of analysis of semivolatile compounds, isomers may be difficult to distinguish from one another (Henschler and Bayer 1958). Typical commercial- grade TCP is a complex mixture of different isomers, all of which are neurotoxicants, with some more potent than others. There is also evidence that when heated to temperatures above 480°F (250°C) in a laboratory, TCPs can react with trimethyl propane esters of carboxylic acids present in the base stock of some engine lubricants and form the potent neurotoxin trimethylol propane phosphate (TMPP) (Wright 1996).These are not regulated by Title 14 CFRs, and the only occupational health guideline available is for TOCP.

According to relevant product SDSs, hydraulic fluids contain a mixture of organophosphates (varying by product) that may include tributyl phosphate (TBP, 0% to 80%), triisobutyl phosphate (60% to 99%), dibutylphenyl phosphate (40% to 70%), butyldiphenyl phosphate (10% to 30%), and triphenyl phosphate (1% to 5%). Tributyl phosphate (TBP) isomers come predominantly from hydraulic fluid since these isomers are the primary constituent of this fluid. By evaluating test data, the observer can determine whether the most likely source of the organo- phosphate is oil or hydraulic fluid. As an example, the EPA method for sampling for organophosphates is by drawing air through adsorbent cartridges and/or filters consisting of polyurethane foam and solid adsorbent medium.

The EPA method for sampling organophosphates is by drawing air through adsorbent cartridges and/or filters consisting of polyurethane foam and solid adsorbent medium. In the EPA method, the sampled mass is solvent desorbed and then analyzed with GC-MS. Based on current analytical methodologies, a large sample volume is necessary to detect relevant concentrations of these organophosphate compounds on aircraft. a sample volume of at least 20 ft3 (500 L) should be adequate to address a target concentration of 0.01 mg/m3 TCP isomers. However, in order to achieve sample results above the detection limits, researchers have found that it is often necessary to collect a substantially larger sample volume (e.g., several cubic metres). This cannot typically be achieved in a short period of time without the use of high-volume samplers., which occupy 0.05 to 0.1 m3 (2 to 4 ft3) of space and may be noisy.

Revise Table 8.2.4c as shown.

Table 8.2.4c Aircraft Sampling Data for Tricresylphosphate Isomers (TCP) and Tributylphosphate Isomers (TBP)

~~Source~~Reference (see Note a)	**Description of Sampling/Analysis and Summary of Data ~~Sampling Methodology~~**
Schuchardt et al. (2019)	The authors reviewed TCP sampling data collected on 177 commercial flights from 2013 to 2016. TCPs had been sampled during taxi out/takeoff/climb, cruise, and descent/landing/taxi in, respectively. Authors sorted the sampling data into three groups: (1) “smell events” (*N*=17), which they defined as 2+ independent instances of oil-related odor reported by crew or passengers; (2) “technical cabin air contamination events” (*N*=18), which they defined as flights that included at least one phase with “elevated TCP release”; and (3) other (*N*=142). Average TCP concentration did not correlate with smell events as defined, but it is not known if crews/passengers were trained to recognize and report oil fumes in order to facilitate reliable event reporting. Data on mechanical discrepancies and reported symptoms (if any) were not provided. Data were reported for individual models/engines with average TCP concentrations ranging from 0.007 μg/m^3 to 0.058 μg/m^3, and 95th percentile TCP concentrations ranging from 6 ng/m^3 to 1670 ng/m^3. In some cases, the mean and 95th percentile concentrations were reported for a single flight, and in other cases the mean and 95th percentile concentrations were averaged across multiple flights (ranging from 2 to 48). No ortho isomers of TCP were detected.
Rosenberger et al. (2018)	Authors collected air sampling on 17 flights operated by one airline, including 12 flights equipped with a standard HEPA filter on the recirculated airstream and five flights equipped with an additional, newly installed charcoal-based filter on the recirculated airstream. On one flight, there was a “slight smell” of dirty socks in the flight deck at top of climb, but no information regarding any reported symptoms or relevant mechanical defects, failures, or overservicing. The range of average TCP levels during taxi/takeoff/climb, cruise, and descent/landing, respectively, were reported as LOD to 0.981 μg/m^3. No ortho isomers of TCP were detected.
EASA (2017a)	Researchers collected 461 air samples using isotope labeled PUF/sorbent cartridges method during 61 flights on bleed-air aircraft and 55 air samples using the same methods during 8 flights on bleed-free aircraft. No fume events were reported during any of the flights. Samples were collected with a flow rate of 3.5 L/min with total sample volumes ranging from 60 to 500 L during taxi out, take off/climb, descent/landing, or the entire flight. The sampling durations were generally not defined. TCP isomer detection limits ranged from 0.2 ng/m^3 to 10 ng/m^3. The air samples were subsequently analyzed for 10 TCP isomers (oop/omm were combined). TmCP, TpCP, TmmpCP, and TmppCP were detected in 31% to 64% of samples on the bleed-air aircraft and 55% to 84% of samples on the bleed-free aircraft (Table 16). No ortho isomers were detected in any sample. Mean total TCP concentrations were reported as 0.009 μg/m^3 on the bleed-air aircraft and 0.020 μg/m^3 on the bleed-free aircraft, and maximum total concentrations were reported as 1.515 μg/m^3 on the bleed-air aircraft and 0.403 μg/m^3 on the bleed-free aircraft.
Space et al. (2017)	An industry and government research team (NASA VIPR) injected engine oil into the AP1 boroscope port of the number-one engine intended to simulate a forward bearing failure. A rate of 1200 g/h was injected over 30 minutes into the core flow of the engine during three different trials: one trial without a bleed-air cleaner downstream, and two trials with different bleed-air cleaners downstream. Bleed air was extracted through a port downstream of the second heat exchanger, sampled using PUF/XAD cartridges, and subsequently analyzed by GC/MS per EPA method TO-13A. Analyses were performed for TmCP, TpCP, and ToCP. Additionally, other tentatively identified TCP isomers were measured at low ppb concentrations. At the above rate of injection, trace levels of TmCP and TpCP were detected (<1ppb). No ToCP was detected (DL=0.1 ppb). In each of the air-cleaner trials, the levels of TmCP and TpCP were further reduced. It was also observed that contaminant concentrations were reduced between the locations upstream and downstream of the tested air purification technology; a portion of this reduction is independent of the air purification technology and results from the complex routing of the air lines.

Table 8.2.4c Aircraft Sampling Data for Tricresylphosphate Isomers (TCP) and Tributylphosphate Isomers (TBP) ***(Continued)***

~~**Source**~~**Reference (see Note a)**	**Description of Sampling/Analysis and Summary of Data** ~~**Sampling Methodology**~~
Rosenberger et al. (2013)	Researchers collected 90 air samples on nine aircraft operated on 26 nonfume-event flights, each for periods ranging from 15 minutes to 5 hours. The samples were collected on filters and PUR foams and analyzed using GC-MS. Total TCP concentrations ranged from 0.017 to 0.167 µg/m^3. The range of ToCP levels was reported as 0.001 to 0.065 µg/m^3 (DL=0.002 µg/m^3). Detectable levels of mono- and di-ortho isomers of TCP were not found (DL=0.002 µg/m^3). ToCP as a fraction of total TCPs could not be calculated because of how the data were presented.
Spengler et al. (2012)	FAA CoE ACER university researchers collected 71 air samples during 63 commercial flights using a sampling pump with quartz filter in a cassette stored under a seat in the economy section of the cabin. Air samples were collected starting at 10,000 ft during climb and ending at 10,000 ft during descent, so conditions during APU/engine start, taxi out, takeoff, early climb, final descent, and taxi in were not assessed. No fume incidents were documented on these 63 flights. All of the air samples were analyzed for TmCP, TpCP, and ToCP. Additionally, 36 samples were tested for the remaining two meta/para isomers of TCP which, along with TmCP, are predominately added to commercial aviation engine oils. Only one sample contained detectable TCP (TmCP) at a concentration of 1 ppt. The LOD ranged from 0.4 to 0.9 ng/sample.
Crump et al. (2011)	A study of various airborne contaminants during five minutes of each phase of 100 commercial flights without documented fume events reported that in more than 95% of the cabin air samples, ToCP and non-ortho TCPs were not detectable. The researchers reported the presence of an oily or fuel odor on 19 flights, but no smoke was visible. Detectable levels of one or more TCP isomer was measured during one or more phase of 23 flights. On those flights, five-minute average ToCP concentrations ranged from nondetectable (ND) to 22.8 µg/m^3 (higher levels during climb phase) and non-ortho TCPs ranged from ND to 28.5 µg/m^3 (higher levels during descent phase). ToCP as a fraction of total TCPs ranged from 10% to 60%, depending on the aircraft type, which is orders of magnitude higher than the industry standard, which recommends that total ortho isomer content not exceed 0.2% of total TCPs. In a subsequent publication, the authors suggested that the reported ToCP concentration could have been overestimated due to a chromatographic overlap with other ortho isomers (Wolkoff et al. 2016).
DeNola et al. (2011)	A total of 78 air samples were collected inflight and during ground operations on 46 military aircraft (trainer, fighter, transport) using sorbent tubes packed with Porapak Q and cellulose filters and analyzed with GC/MS and PFPD. Sampling duration on the ground ranged from 1.2 minutes (LOD=1.06 µg/m^3) to 6 hours (LOD=0.009 µg/m^3). Sampling duration inflight ranged from 20 minutes (LOD=0.137 µg/m^3) to 2.2 hours (LOD=0.027 µg/m^3). On those aircraft, nine incidents of smoke/odor were identified. Of the 78 samples, 48 were <LOD for meta/para TCPs and all were <LOD for the ortho TCPs (LOD=3 µg/L). The highest total TCP concentration was 51.3 µg/m^3 (6.6 minute average, measured in the cockpit with canopy open, coincident with oil spill near APU intake) where smoke was observed, and the second highest was 21.7 µg/m^3 (nine-minute average during a ground engine run). Both were detected on a Fighter Trainer type aircraft with a significantly smaller cockpit compared to commercial aircraft, which elevated their concentration. The highest concentration detected on a cargo transport was 0.26 µg/m^3. Most detectable samples were <5 µg/m^3 TCPs. Data were consistent with crew reports that bleed-air contamination is most evident during high engine power. Hanhela (2005) has additional information based upon a preliminary report.

Table 8.2.4c Aircraft Sampling Data for Tricresylphosphate Isomers (TCP) and Tributylphosphate Isomers (TBP) *(Continued)*

~~Source~~Reference (see Note a)	Description of Sampling/Analysis and Summary of Data ~~Sampling Methodology~~
Solbu et al. (2011)	A total of 95 samples were collected during 47 non-fume-event flights on 40 aircraft (six different models). TCP was detected in four of 95 air samples (maximum concentration = 0.29 $\mu g/m^3$), all from propeller-driven aircraft with no ortho isomers detected. Multiple butyl phosphate variants were also detected in the air samples (TiBP 50% 96 ng/dm^2/day, 90% 390 ng/dm^2/day), (TnBP 50% 970 ng/dm^2/day, 90% 3100 ng/dm^2/day), (DBPP 50% 210 ng/dm^2/day, 90% 410 ng/dm^2/day) (TPP 50% < LOQ, 90% 6.2 ng/dm^2/day), (TCP 50% < LOQ, 90% < LOQ). TCPs were detected in 31% of 32 samples on one jet aircraft type (LOQ 0.05 ng/dm^2). TCPs were also detected in 92% of 12 samples on one propeller aircraft type (LOQ 0.18 ng/dm^2) and 8% of 12 samples on a different propeller aircraft type (LOQ 0.07 ng/dm^2). TCPs were detected in 39% of a total of 108 wipe and activated carbon cloth samples. TCPs were detected in all six tested HEPA filters. each from a different aircraft but of the same model. In five of the samples, the median was 2.6 ng TCPs/g of filter per hour of operation (averaged over the 130 to 470 hours service duration). In the remaining sample, the filter contained 42 ng/g/h, suggesting one or more fume events had occurred. No ortho isomers were detected in the wipe, carbon cloth, and HEPA filter samples. The TCP concentration was also measured during ground testing in an airplane with turbine oil leakage that had contaminated the bleed air. The median TCP concentration was an order of magnitude higher (5.5 $\mu g/m^3$) compared to after the engine was replaced (0.47 $\mu g/m^3$).
Muir et al. (2008)	~~Concentrations were reported as a 10–18 minute average based on approximately 1.2 L of air/sample. Ground operations: TBPs: <2–42 $\mu g/m^3$; oil fumes: 11–14 $\mu g/m^3$; TCPs: 0.6–1.3 $\mu g/m^3$. In-flight, transient oil fume event was reported in flight deck on B757. Oil odor noticeable for one minute and ultrafine particle levels increased for two minutes. Exposure was reported as an 18-minute average, so the peak TCP/oil exposures during this sample period could be underestimated by a factor of 10 (p. 71). Oil fumes: 5 $\mu g/m^3$; TCPs: 0.04 $\mu g/m^3$.~~ The UK Department for Transport paid Cranfield University researchers to test different sampling and analytical methods to characterize selected airborne contaminants during onboard fume events, including TCPs and TBP. Samples were collected using Solid Phase Microextract (SPME) fibers, diffusion sorption tubes, and a proprietary sampling device intended to capture SVOCs with analysis via GC-MS. These sampling methods were deployed on an aircraft on the ground with and without the APU and ECS running, and on an aircraft during ground operations and throughout a short test flight. Each reported concentration of TCPs and TBP was averaged over a sampling period of 10 to 18 minutes. In the hanger test, TBP was detected in all samples and conditions (<2 to 42 $\mu g/m^3$). The proprietary device detected 0.6 to 1.3 $\mu g/m^3$ TCPs when the APU/ECS were on. During the flight test, the researchers captured a transient fume event at the top of climb. An oily odor was reported for one minute, and the ultrafine particle count increased for two minutes. The average TCP concentration was 0.04 $\mu g/m^3$, but the time course/peak TCP concentration during the 1 to 2 minute event was not characterized.
van Netten (2005)	The author reported ~~Q~~qualitative GC-MS analysis of seven samples, including five onboard aircraft filters (flight deck roof filter, two lavatory filters, pre-filter from recirculated airstream, and HEPA filter in recirculated airstream), ~~flight deck roof filter, recirculated air prefilter, HEPA filter, lavatory ceiling filter, flight deck wall, and pilot's~~ one pair of crew uniform trousers, and a wipe sample extract from the flight deck wall. Six of the seven samples ~~all~~ tested positive for ~~at least one~~ TCP~~ isomer~~.
Hanhela et al. (2005)	The authors conducted a Royal Australian Air Force investigation into cockpit air contamination ~~in military~~ on the Hawk, F-111, and Hercules C-130 aircraft (*N*=80, Table 2~~59~~). The highest concentrations of TCPs were 0.0217 and 0.049 mg/m^3 on the Hawk aircraft. The remaining samples were <0.004 mg/m^3. The 0.049 mg/m^3 sample had been collected in the cockpit when the canopy was open while there was an oil spill near the APU intake. Sampling also identified ~~TCP oil additives,~~ phenyl-naphthylamine and dioctyldiphenylamine (jet engine oil) and trialkylphosphates (hydraulic fluid). ~~The majority of TCP samples were <4 $\mu g/m^3$ with two exceptions (22 $\mu g/m^3$, 49 $\mu g/m^3$).~~ The authors recommended that total TCPs be kept below 1 $\mu g/m^3$.

Table 8.2.4c Aircraft Sampling Data for Tricresylphosphate Isomers (TCP) and Tributylphosphate Isomers (TBP) ***(Continued)***

~~Source~~Reference (see Note a)	Description of Sampling/Analysis and Summary of Data ~~Sampling Methodology~~
CAA (2004)	~~As part of an investigation into pilot incapacitation, a U.K. regulator sampled duct linings on two commercial aircraft and identified TCP oil additives ranging from 24.7 to 73.5 µg TCP/g oil in ducts. See Chapter 2, Appendix A, Table 1.~~ The UK Civil Aviation Authority sent the UK Defense Science and Technology Lab (DSTL) samples of ducting from three cabin air supply systems: one ducting sample was new/clean, and the other two samples had been removed from two different aircraft with a history of fume and odor events. The researchers used solvents to extract the carbonaceous deposits in the ducts and the compounds absorbed into the duct insulation lining, and they performed a TCP analysis using GC-FPD. In solvent extractions of the duct samples, they measured 0.5 to 1 µg ToCP/g of ducting, 23.1 to 68.1 µg TpCP/g of ducting, and 0.8 to 8.1 µg of TpCP per g of ducting (Table 1). At 350°F thermal desorption, they identified four TCP isomers (TmCP, TpCP, TmmpCP, and TppmCP) in the particulate material that lined the ducting (Tables 8 and 9). These isomers matched the data for a sample of engine oil used by that airline (Table 7). The researchers then exposed the ducting material to heat (27°C to 100°C) and humidity (25% to 100% RH) to identify any products that could be liberated into the aircraft air-conditioning system and delivered to the cabin and flight deck. Under those test conditions, airborne TCPs were not detectable.
SHK (2001) and Michaelis (2007)	After a reported oil fume event on a commercial flight during which the captain had reported incapacitation, the Swedish accident investigation agency (SHK) recommended that the engine manufacturer assess the quality of the bleed air supplied by the engine that had an oil seal leak. The manufacturer's test plan is described in Appendix 4 to the SHK investigative report (SHK 2001). A qualitative summary of the bleed-air sampling data collected on the engine test stand is described in Sec. 1.16.4 of SHK, 2001. The TCP sampling data were not cited in the SHK report, but SHK provided a spreadsheet of the sampling data to the summary author upon request. The highest mixed-isomer TCP (CAS 1330-78-5) was reported during climb (22 µg/m^3), and ToCP was not detectable. In addition, the SHK recommended that the engine manufacturer assess the quality of the bleed air supplied by the replacement engine during subsequent test flights. The manufacturer's test plan is described in Section 1.16.6 of SHK (2001), and a qualitative summary of the test data is described in Section 1.16.7 of SHK (2001). The TCP sampling data were not cited in the SHK report, but SHK provided a spreadsheet of the sampling data to the summary author upon request. The highest mixed-isomer TCP (CAS 1330-78-5) concentration was reported during climb (4.9 µg/m^3), and ToCP was not detectable.
~~Fox (2000a) as referenced in (Michaelis 2007)~~	~~In response to a request from its airline customer, Honeywell replaced the engine on a BAe146 with a reported oil fume event where the captain had been incapacitated in flight and conducted engine bleed air monitoring on the incident aircraft with the new engine. Honeywell measured oil-based contaminants in the bleed air supplied by that engine. TOCP was < DL, other TCP isomers (CASRN 1330-78-5) were detected at a maximum concentration of 4.9 µg/m^3, and TPP isomers were identified at a maximum concentration of 20 µg/m^3.~~
~~Fox (2000b) as referenced in (Michaelis 2007)~~	~~In response to a request from its airline customer, Honeywell removed the engine from a BAe146 with a reported oil fume event where the captain had been incapacitated in flight. Honeywell measured the oil-based contaminants in the bleed air supplied by that engine. TOCP was < DL, other TCP isomers (CAS 1330-78-5) were detected at a maximum concentration of 22 µg/m^3, and TPP isomers were identified at a maximum concentration of 8 µg/m^3.~~
Kelso et al. (1988)	~~The authors identified oil vapor and TCPs in the air filter bags in the air duct system of a Hercules aircraft and recommended that charcoal filters be installed in the bleed airstream.~~ The authors collected air samples on four military transport aircraft (one during ground operations and three inflight) and a coalescer bag sample on one of the aircraft. They extracted the coalescer bag samples with hexane and analyzed it by GC-TSD (thermionic specific detection) for phosphorus and nitrogen-based compounds. The authors did not detect TCPs in cabin air samples but did find traces of engine oil constituents, including TCPs, in the coalescer bag sample.

Table 8.2.4c Aircraft Sampling Data for Tricresylphosphate Isomers (TCP) and Tributylphosphate Isomers (TBP) ***(Continued)***

~~Source~~Reference (see Note a)	Description of Sampling/Analysis and Summary of Data ~~Sampling Methodology~~
Michaelis (2007)	~~Additional sampling data is referenced in this publication's Appendix 10, "Air Monitoring Research Summary." See pp. 741–776.~~ Appendix 10, "Air Monitoring Research Summary," summarizes some TCP sampling data collected on commercial and military aircraft, in addition to lab analyses, dating from 1979 to 2006.

Note a: For complete bibliographic information on the sources listed here, see Section 9, "References."

Table Abbreviations:
CAS~~RN~~ = chemical abstract service reference number
DL = ~~detectable level~~ detection limit
ND = nondetectable
TCP = tricresyl phosphate
(o = ortho, m = metal; p = para)
TPP = ~~tetra-phenyl-porphyrin~~ triphenyl phosphate

Add new Table 8.2.4d as shown.

Table 8.2.4d Lab Analysis Studies for Tricresylphosphate Isomers (TCPs)

Reference (see Note a)	Description of Sampling/Analysis and Summary of Data
EASA (2017b)	EASA heated oils to 370°C and performed GC/MS on three oils (two new, one used). total TCP concentrations ranged from 1.5% to 2.8% with no ortho-cresol isotopes detected. Four isomers were detected: mmm (2.5 to 4.1 g/kg), mmp (5.6 to11 g/kg), mpp (5.2 to 9.5 g/kg), and ppp (1.7 to 2.9 g/kg) (Table 4.7). This was reported to align with the SDS sheets from the suppliers. The research team also reported that the mass fraction ratio of the TCP isomers in the oil vapor was similar to the original oils.
Megson et. al (2016)	An analytical study on TCP isomers and their mass spectra as detected in Mobil Jet Oil II. The results show four TCP isomers were present at detectable levels in fresh oil—mmm-TCP, mmp-TCP, ppm-TCP, and ppp-TCP—with a detection limit of 0.00005%.
OHRCA (2014)	Researchers analyzed the percentage (by weight) of five TCP isomers in eight aviation engine oils and three aviation hydraulic fluids. The relative percentage of each of these five isomers was also reported. The five reported TCP isomers were mmm, mmp, mpp, ppp, and ooo. The total TCP content for these five isomers ranged from 2.23% to 5.69% per unit weight of oil. Three TCP isomers were consistently dominant: mmp (46% to49%), mpp (20% to 34%), and mmm (16% to 32%). Conversely, the ppp isomer content ranged from ND to 0.3%, and the ooo isomer content ranged from ND to 0.02%. The mono and di ortho isomer content was not reported because chemical standards were not available. The TCP content of each hydraulic fluid was nondetectable as expected (per the product SDSs).
Denola et. al (2008)	An analytical study on TCP content and its isomer distribution in a commercial aircraft turbine engine oil. All ten isomers could be detected (although two were combined—oop, omm) by the analytical method developed. Total TCP content in the commercial oil was found to be around 25 g/kg (2.5%). Total ortho-cresol content of oil samples manufactured during the nine years prior to this publication was found to be less than 50 mg/kg (0.005%).In the oils analyzed, the ortho isomers were represented by the mono-ortho (oxx) form at concentrations of 13 to 150 mg/kg. The concentrations of tri-o-cresyl phosphate isomer (ooo-isomer) and the di-o-cresyl phosphate isomers (oox-isomers) were found to be below the levels of detection based on simple calculations.

a. For complete bibliographic information on the sources listed here, see Section 9, "References."

Abbreviations:
CASRN = chemical abstract service reference number
DL = detection limit
ND = non-detectable
TCP = tricresyl phosphate
(o = ortho, m = metal, p = para)
TPP = triphenyl phosphate

Revise Section 9 as shown below. The remainder of Section 9 is unchanged.

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Revise Informative Appendix B as shown. The remainder of Appendix B is unchanged.

INFORMATIVE APPENDIX B
REFERENCES FOR APPENDIX A AND RELEVANT BIBLIOGRAPHY

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ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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