BEFORE THE NATIONAL GREEN TRIBUNAL,

PRINCIPAL BENCH AT NEW DELHI

O.A. NO. 717 OF 2024

IN THE MATTER OF:

New Item titled "**People are Breathing in Cancer -Causing Chemicals in their cars study Find**" appearing in NDTV.com

Dated 08.05.2024 .... *SUO-MOTO*

Versus

UNION OF INDIA & ORS. ... RESPONDENTS

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Filed by:

Shashwat

M/s. SIKRI & COMPANY
ADVOCATES FOR RESPONDENT NO. 3
229, LAWYERS CHAMBERS,
DELHI HIGH COURT
NEW DELHI 110003
MOBILE No. 9671444468, 9311331805
EMAIL: SIKRICO@SIKRILAW.COM

Place: New Delhi
Dated: 10.09.2024

BEFORE THE NATIONAL GREEN TRIBUNAL,

PRINCIPAL BENCH AT NEW DELHI

O.A. No. 717 of 2024

IN THE MATTER OF:

News Item titled **"People Are Breathing In Cancer-Causing Chemicals in their cars study find"** appearing in NDTV.com dated 08.05.2024 ..... *SUO-MOTO*

Versus

UNION OF INDIA & ORS. ...RESPONDENTS

REPLY ON BEHALF OF RESPONDENT No. 3 - INDIAN COUNCIL OF MEDICAL RESEARCH (ICMR) TO THE *SUO-MOTO* ORIGINAL APPLICATION UNDER THE NATIONAL GREEN TRIBUNAL ACT, 2010:

डॉ. आर. लक्ष्मीनारायणन / Dr. R. LAKSHMINARAYANAN
उप महानिदेशक (प्रशा.) / Deputy Director General (Admn.)
भारतीय आयुर्विज्ञान अनुसंधान परिषद
Indian Council of Medical Research
स्वास्थ्य अनुसंधान विभाग (स्वास्थ्य एवं परिवार कल्याण मंत्रालय)
Department of Health Research (Min. of Health & FW)
Government of India

Most Respectfully Showeth:

I, Dr. R. Lakshminarayanan, s/o Mr. Rajarathnam, aged about 59 years, presently working as Deputy Director General (Admn.), Indian Council of Medical Research (ICMR), V. Ramalingaswami Bhawan, Ansari Nagar, New Delhi-110029, do hereby solemnly affirm and state as under:

1. That I am presently working as Deputy Director General (Admn.), Indian Council of Medical Research (ICMR), and authorized to file this Reply Affidavit on behalf of Respondent No. 3.

2. That save as expressly admitted herein and save what are matters of record, each and every contention made in the present Original Application shall be deemed to have been emphatically and specifically denied and disputed.

That liberty is further craved in making such other and further submission/filing Additional Affidavits as may be required in the

NOTARY
ALAKA NAYAK
Advocate
Reg. No. : 10639
Area : Delhi
Period 28/06/2024
to 27/06/2029
GOVT OF INDIA

facts of the case subsequently or as may be directed by this Hon'ble Tribunal.

4. That the answering Respondent - Indian Council of Medical Research (ICMR), New Delhi, the apex body in India for the formulation, coordination and promotion of biomedical research, is one of the oldest medical research bodies in the world.

5. That this Hon'ble Tribunal has taken cognisance of the present matter, keeping in view the *News Item titled "People Are Breathing In Cancer-Causing Chemicals in their cars study find" appearing in NDTV.com dated 08.05.2024.*

A copy of the *News Item titled "People Are Breathing In Cancer-Causing Chemicals in their cars study find" appearing in NDTV.com dated 08.05.2024*, is annexed herewith as **Annexure R-1.**

6. That this Hon'ble Tribunal vide order dated 02.07.2024, has been pleased to implead the answering Respondent in the instant Original Application on the issue involved in the present matter, which has been highlighted in para 2, 3 and 4 of the said order issued by this Hon'ble Tribunal, and the same is reproduced herein below:

"2. The matter relates to a research study published in Environmental Science & Technology that asserts the presence of cancer causing chemicals in the car. As per the article, researchers analyzed the cabin air of 101 electric, gas and hybrid cars with a model year between 2015 and 2022. It was found that 99% of cars contained a flame retardant called TCIPP, which is under investigation by the US National Toxicology Program as a potential car-

3

cinogen. Most cars also had two more flame retardants, TDCIPP and TCEP, which are considered carcinogenic.

3. The news item highlights that these flame retardants are linked to neurological and reproductive harms as well. It states that since an average driver spends about an hour in the car every day, this is a significant public health issue. This is particularly concerning for drivers with longer commutes as well as child passengers, who breathe more air pound for pound than adults.

डॉ. आर. लक्ष्मीनारायणन / Dr. R. LAKSHMINARAYANAN
उप महानिदेशक (प्रशा.) / Deputy Director General (Admn.)
भारतीय आयुर्विज्ञान अनुसंधान परिषद
Indian Council of Medical Research
स्वास्थ्य अनुसंधान विभाग (स्वास्थ्य एवं परिवार कल्याण मंत्रालय)
Department of Health Research (Min. of Health & FW)
भारत सरकार / Government of India
अंसारी नगर, नई दिल्ली-110029 / Ansari Nagar, New Delhi-110029

4. The news item further alleges that the study found that the levels of toxic flame retardants were highest in the summer as heat increases the release of chemicals from the car materials. The researchers said that the source of the cancer-causing compounds in the cabin air is seat foam. Car manufacturers add the chemicals to seat foam and other materials to meet an "outdated" flammability standard with no proven fire-safety benefit. It further alleges that flame retardants contribute to their very high cancer rates. Filling products with these harmful chemicals does little to prevent fires for most uses and instead makes the blazes smokier and more toxic for victims."

7. That it is submitted that according to the research studies, including scattered reports on the probable carcinogenicity of the mentioned compounds viz tris (1-chloro-2-propyl) phosphate (TCIPP) and Tris (1,3-dichloro-2-propyl) phosphate (TDCIPP) in humans, TDCIP was added to the California Proposition 65 (Prop 65) List in 2011 and has been banned in certain products. This listing has resulted in a substitution of TCIPP in place of TDCIPP. That the Evidence is limited to enlist both of them as carcinogenic for humans in any of the group enlisted by the International Agency for Research on Cancer (IARC).

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That Tris (2-chloroethy) phosphate-TCEP is enlisted in Group 3 which is not classifiable as carcinogenic to humans (agents classified by the IARC monographs, volumes 1-136).However, if safer alternatives are available, they should be promoted.

That a copy of relevant pages of research paper titled *"EVIDENCE ON THE CARCINOGENICITY OF TRIS(1,3-DICHLORO-2-PROPYL) PHOSPHATE"*, published by Reproductive and Cancer Hazard Assessment Branch Office of Environmental Health Hazard Assessment California Environmental Protection Agency, is annexed herewith as **ANNEXURE R-1.**

That a copy of the research paper titled "Flame Retardant Exposure in Vehicles Is Influenced by Use in Seat Foam and Temperature", published in journal "Environmental Science & Technology" is annexed herewith as **ANNEXURE R-3**.

That a copy of the list of agents classified by IARC Monographs as carcinogenic to humans, is annexed herewith as **ANNEXURE R-4.**

8. **RE: <u>PRAYER</u>:**

That the present reply and the submissions contained herein may please be considered and taken on record.

DEPONENT

NOTARY
ALAKA NAYAK
Advocate
Reg. No. : 10639
Area : Delhi
Period 28/06/2024
to 27/06/2029
GOVT. OF INDIA

डॉ. आर. लक्ष्मीनारायणन / Dr. R. LAKSHMINARAYANAN
उप महानिदेशक (प्रशा.) / Deputy Director General (Admn.)
भारतीय आयुर्विज्ञान अनुसंधान परिषद
Indian Council of Medical Research
स्वास्थ्य अनुसंधान विभाग (स्वास्थ्य एवं परिवार कल्याण मंत्रालय)
Department of Health Research (Min. of Health & FW)
भारत सरकार / Government of India
अंसारी नगर, नई दिल्ली-110029 / Ansari Nagar, New Delhi-110029

I identified the deponent who has signed in my presence.

VERIFICATION:

I, Dr. R. Lakshminarayanan, s/o Mr. Rajarathnam, aged about 59 years, presently working as Deputy Director General (Admn.), Indian Council of Medical Research (ICMR), V. Ramalingaswami Bhawan, Ansari Nagar, New Delhi-110029, do hereby solemnly affirm and declare, that the above reply has been drafted by our counsel as per instructions and the contents of the reply are true and correct as per official record and the best of my knowledge and belief. No part of it is false and nothing material has been concealed there from.

Verified at New Delhi, on 9th day of September, 2024.

DEPONENT

डॉ. आर. लक्ष्मीनारायणन/Dr. R. LAKSHMINARAYANAN
उप महानिदेशक (प्रशा.) / Deputy Director General (Admn.)
भारतीय आयुर्विज्ञान अनुसंधान परिषद
Indian Council of Medical Research
स्वास्थ्य अनुसंधान विभाग (स्वास्थ्य एवं परिवार कल्याण मंत्रालय)
Department of Health Research (Min. of Health & FW)
Government of India
V. Ramalingaswami Bhawan, Ansari Nagar, New Delhi-110029

Respondent

Through

M/s. SIKRI & COMPANY
ADVOCATES FOR RESPONDENT NO. 5
229, LAWYERS CHAMBERS,
DELHI HIGH COURT
NEW DELHI 110003

10 SEP 2024

Place: New Delhi MOBILE No. 9671444468, 9311331805
Dated: 10-09-2024 EMAIL: SIKRICO@SIKRILAW.COM

NOTARY
ALAKA NAYAK
Advocate
Regd. No. : 10639
Area : Delhi
Period 28/06/2024
to 27/06/2029
GOVT. OF INDIA

CERTIFIED THAT THE DEPONENT
Shri/Smt./Km. Dr. R. Lakshminarayan
S/o, W/o R/o Rajarathnam
Identified by
Has solemnly affirmed before me at
Delhi on 10 SEP 2024 at 10:25 a.m.
That the contents of the affidavit which have been read & explained to him/her are true & correct to his/her knowledge

10 SEP 2024

Annexure-1

Item No. 07 Court No. 1 (6)

BEFORE THE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI

Original Application No. 717/2024

News Item titled "People Are Breathing In Cancer-Causing Chemicals in their cars study find" appearing in NDTV.com dated 08.05.2024

Date of hearing: 02.07.2024

CORAM: HON'BLE MR. JUSTICE PRAKASH SHRIVASTAVA, CHAIRPERSON
HON'BLE MR. JUSTICE ARUN KUMAR TYAGI, JUDICIAL MEMBER
HON'BLE DR. A. SENTHIL VEL, EXPERT MEMBER

ORDER

1. This original application is registered *suo-motu* on the basis of the news item titled "People Are Breathing In Cancer-Causing Chemicals in their cars study find" appearing in NDTV.com dated 08.05.2024.

2. The matter relates to a research study published in Environmental Science & Technology that asserts the presence of cancer causing chemicals in the car. As per the article, researchers analysed the cabin air of 101 electric, gas and hybrid cars with a model year between 2015 and 2022. It was found that 99% of cars contained a flame retardant called TCIPP, which is under investigation by the US National Toxicology Program as a potential carcinogen. Most cars also had two more flame retardants, TDCIPP and TCEP, which are considered carcinogenic.

3. The news item highlights that these flame retardants are linked to neurological and reproductive harms as well. It states that since an average driver spends about an hour in the car every day, this is a significant public health issue. This is particularly concerning for drivers

(7)

with longer commutes as well as child passengers, who breathe more air pound for pound than adults.

4. The news item further alleges that the study found that the levels of toxic flame retardants were highest in the summer as heat increases the release of chemicals from the car materials. The researchers said that the source of the cancer-causing compounds in the cabin air is seat foam. Car manufacturers add the chemicals to seat foam and other materials to meet an "outdated" flammability standard with no proven fire-safety benefit. It further alleges that flame retardants contribute to their very high cancer rates. Filling products with these harmful chemicals does little to prevent fires for most uses and instead makes the blazes smokier and more toxic for victims.

5. The above matter indicates violation of the Air (Prevention and Control of Pollution) Act, 1981 and the Environment Protection Act, 1986.

6. The news item raises substantial issue relating to compliance of the environmental norms and implementation of the provisions of scheduled enactment.

7. Power of the Tribunal to take up the matter *suo-motu* has been recognized by the Hon'ble Supreme Court in the matter of *"Municipal Corporation of Greater Mumbai vs. Ankita Sinha & Ors." reported in 2021 SCC Online SC 897.*

8. Hence, we implead the following as respondents in the matter:

   i. Central Pollution Control Board, Through its Member Secretary Parivesh Bhawan, East Arjun Nagar, Delhi-110032.

(8)

ii. Ministry of Environment Forest and Climate Change, Through its Secretary Indira Paryavaran Bhawan Jorbagh Road, New Delhi – 110 003 INDIA.

iii. Indian Council of Medical Research, Through its Secretary V Ramalingaswami Bhawan, PO Box No. 4911, Ansari Nagar, New Delhi-110029.

iv. Ministry of Heavy Industries through its Secretary Udyog Bhawan, Rafi Marg, New Delhi- 110011

9. Let notice be issued to the above respondents for filing their response at least one week before the next date of hearing.

10. List on 12.09.2024.

Prakash Shrivastava, CP

Arun Kumar Tyagi, JM

Dr. A. Senthil Vel, EM

July 02, 2024
O.A No. 717/2024
HB

True Copy

ANNEXURE R-2

9

EVIDENCE ON THE CARCINOGENICITY OF

TRIS(1,3-DICHLORO-2-PROPYL) PHOSPHATE

July 2011

Reproductive and Cancer Hazard Assessment Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

resins, plastics, textile coatings, and rubber for use in the U.S. and Europe (IPCS, 1998; NRC, 2000). As a flame retardant, TDCPP is an additive, meaning it is not chemically reacted but physically combined with the material being treated.

Most of TDCPP's current use can be attributed to flexible polyurethane foams for upholstered furniture and automotive products such as seat cushions and headrests (European Commission, 2009). TDCPP was commonly used in children's sleepwear in the 1970s until manufacturers voluntarily withdrew it in 1977 due to concerns regarding its mutagenicity (CPSC, 1977; IPCS, 1998). More recently, in order to meet California's upholstered furniture flammability standard, Technical Bulletin 117 (California Bureau of Home Furnishings and Thermal Insulation, 2000), TDCPP has been used as a replacement for the flame retardant pentabromodiphenyl ether (pentaBDE), which was banned in 2006 (California Health and Safety Code, Section 108922). A 2011 study identified TDCPP in more than a third of the 101 baby products analyzed (*e.g.*, car seats, changing table pads) (Stapleton *et al.*, 2011).

The use of TDCPP as an additive flame retardant suggests it may be released from the treated product throughout the product life cycle into the indoor environment (*e.g.*, in dust), leading to human exposure (Marklund *et al.*, 2003; U.S. EPA, 2005; Stapleton *et al.*, 2009). Indeed, TDCPP has been detected in household dust in the U.S. and abroad (Stapleton *et al.*, 2009, Takigami *et al.*, 2009; Marklund *et al.*, 2003; Meeker and Stapleton, 2010).

In a study of 50 homes in Boston, Massachusetts, concentrations of TDCPP in dust were comparable to, and in some cases higher than, concentrations of polybrominated diphenyl ethers, with a geometric mean of 1.89 micrograms per gram (µg/g) of dust (maximum: 56.08 µg/g) (Stapleton *et al.*, 2009). TDCPP was detected in both dust and air samples in a variety of indoor environments such as homes, day care centers, hospital wards and offices in Sweden (Marklund *et al.*, 2003).

TDCPP's use as a flame retardant and plasticizer for many decades has resulted in widespread distribution in the environment. In a study of 139 streams across the U.S., including California, TDCPP was detected in over half (Kolpin *et al.*, 2002). An analysis of Swedish sewage treatment facilities found detectable concentrations of TDCPP in the influents, effluents and sludge from each of the plants studied (Marklund *et al.*, 2005).

Biomonitoring studies have detected TDCPP in human tissues. In the 1980s, levels were measured in human adipose tissue (maximum of 260 nanograms (ng)/g) (LeBel and Williams, 1983; LeBel *et al.*, 1989) and in human seminal plasma (Hudec *et al.*, 1981). More recently, TDCPP was detected in the lipids of human milk with a median level of 4.3 ng/g and a maximum level of 5.3 ng/g (Sundkvist *et al.*, 2010).

3 DATA ON CARCINOGENICITY

3.1 Carcinogenicity Studies in Humans

An unpublished retrospective cohort cancer mortality study of workers employed at a TDCPP manufacturing plant for the years 1956 to 1980 was conducted by Stauffer

(11)

Chemical Company (Stauffer Chemical Company, 1983b, as described by the European Commission, 2009, and ATSDR, 2009). The cohort consisted of 289 workers. Ten deaths were reported in the cohort over the course of the study period. Three deaths due to lung cancer were observed among the ten deaths (deaths from other malignant cancers were observed by the study authors, but not described in the European Commission, 2009, and ATSDR, 2009 reports). When the observed deaths from the study were compared to a similar population of U.S. males, standard mortality ratios (SMR) were higher than expected for all cancers and lung cancer, although p-values were not calculated due to small sample size. The average time-weighted concentration of TDCPP in air within the work environment was assessed at the end of the study period and described as very low (0.4–0.5 $\mu g/m^3$). The authors concluded that although the SMR from lung cancer was higher than expected, overall there was no evidence linking the lung cancers to TDCPP exposure because all three cases with lung cancer were heavy to moderate cigarette smokers. Small sample size and the inability to account for confounding factors make it difficult to draw conclusions from this study.

3.2 Carcinogenicity Studies in Animals

A review of the scientific literature regarding the carcinogenicity of TDCPP in experimental animals identified one set of studies conducted in rats.

Male and female Sprague-Dawley CD rats (60/sex/group) were fed a diet containing TDCPP at concentrations intended to achieve dose rates of 0, 5, 20, or 80 mg TDCPP/kg-day (Bio/dynamics, 1981; Freudenthal and Henrich, 2000). Ten male and female rats from each group were sacrificed after 12 months on the diet for interim evaluation. At 24 months, all remaining surviving animals were sacrificed. At both 12 and 24 months, control and high-dose animals were examined microscopically for lesions in a broad suite of tissues. However, for animals in the low- and mid-dose groups only the liver, kidneys, testes, and adrenal glands were examined microscopically at the 12- and 24-month sacrifices.

Survival among male rats in the high-dose group (80 mg/kg-day) was significantly lower compared to control male rats. Among high-dose male rats, body weights were 20% lower than control animals at the end of the study. Body weights of high-dose male rats were significantly lower than control rats throughout the study. Survival was not significantly affected by TDCPP treatment in female rats at any dose. Body weights of high-dose female rats were also significantly lower that control rats throughout the study, with a similar 20% decrease in body weight observed by the end of the study. Food intake was not affected by treatment in either male or female rats.

Among male rats treated with TDCPP, benign and malignant tumors were seen (see Table 1 below for all tumor incidence data). Statistically significant increases were observed in the high-dose group for hepatocellular adenoma ($p < 0.01$), hepatocellular carcinoma ($p < 0.05$), and combined hepatocellular adenoma and carcinoma ($p < 0.01$) by pairwise comparison with the control group. The incidences across dose groups showed statistically significant positive trends with dose for adenomas ($p < 0.001$), carcinomas ($p < 0.01$), and combined adenomas and carcinomas ($p < 0.001$). Three hepatocellular adenomas were also observed in high-dose male rats at the 12-month interim sacrifice.

ANNEXURE R-3

Environmental Science & Technology

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(12)

Article

Flame Retardant Exposure in Vehicles Is Influenced by Use in Seat Foam and Temperature

Rebecca M. Hoehn, Lydia G. Jahl, Nicholas J. Herkert, Kate Hoffman, Anna Soehl, Miriam L. Diamond, Arlene Blum, and Heather M. Stapleton*

Cite This: *Environ. Sci. Technol.* 2024, 58, 8825−8834

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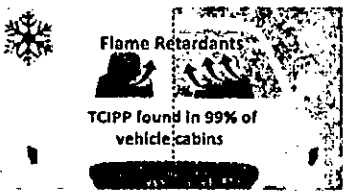
ABSTRACT: Flame retardants (FRs) are added to vehicles to meet flammability standards, such as US Federal Motor Vehicle Safety Standard FMVSS 302. However, an understanding of which FRs are being used, sources in the vehicle, and implications for human exposure is lacking. US participants (n = 101) owning a vehicle of model year 2015 or newer hung a silicone passive sampler on their rearview mirror for 7 days. Fifty-one of 101 participants collected a foam sample from a vehicle seat. Organophosphate esters (OPEs) were the most frequently detected FR class in the passive samplers. Among these, tris(1-chloro-isopropyl) phosphate (TCIPP) had a 99% detection frequency and was measured at levels ranging from 0.2 to 11,600 ng/g of sampler. TCIPP was also the dominant FR detected in the vehicle seat foam. Sampler FR concentrations were significantly correlated with average ambient temperature and were 2−5 times higher in the summer compared to winter. The presence of TCIPP in foam resulted in ~4 times higher median air sampler concentrations in winter and ~9 times higher in summer. These results suggest that FRs used in vehicle interiors, such as in seat foam, are a source of OPE exposure, which is increased in warmer temperatures.



KEYWORDS: *human exposure, wristband, silicone passive sampler, vehicle, flame retardant, organophosphate ester, TCPP, TCIPP, flammability standards*

INTRODUCTION

A wide range of flame retardant (FR) chemicals are intentionally used in electronics, furnishings, and building materials to meet flammability standards.[1] Most FRs are used in an additive manner (i.e., not chemically bound), and many are semivolatile, indicating that they can be present in both the gas phase and partially in the condensed phase (e.g., particles and surfaces), depending on environmental conditions. As a result, they are released over time into air and dust from the products and materials to which they were added.[2] Given that the release of FRs from products is a function of vapor pressure and thermodynamic partitioning, this process is predicted to be temperature-dependent, and thus FR release will increase with increasing temperature. Releases of FRs from products have contributed to human exposure[3−6] and health concerns,[7] which are especially important to consider when designing or re-evaluating flammability standards.[1]

Many FRs have been investigated regarding their toxicity and impact on human health. Polybrominated diphenyl ethers (PBDEs) were extensively used in furniture, electronics, and vehicles until the early 2000s,[8] when their use began being restricted due to negative health effects and persistence in the environment.[9] PBDE exposure in humans has been associated with developmental neurotoxicity,[10] thyroid hormone dysregulation,[11] and reproductive toxicity.[12] Although certain FR classes, including PBDEs, have been restricted for use in consumer products in the United States,[13] the use of nonrestricted FRs is still the most affordable way to comply with flammability standards. Other FRs, such as alternative brominated flame retardants (BFRs) and organophosphate ester flame retardants (OPEs), are now commonly used to replace phased-out compounds. OPEs in particular have become increasingly popular and are commonly used in polyurethane foam,[14] home furnishings,[9] building materials,[2] textiles,[2] electronics,[15] and vehicles.[16] Studies have now shown that exposure to certain OPEs is associated with altered birth outcomes,[17] reproductive harm,[18] and carcinogenicity.[19−21] A well-known OPE, tris(1,3-dichloro-2-propyl) phosphate (TDCIPP), has been associated with negative health effects,[22] including decreased fertility, altered thyroid hormone function, and cancer,[19] leading to its addition to the California EPA Prop 65 list in 2011.

FRs have been detected in many consumer products,[23,24] and our prior research[6] found that the presence of PBDE-treated foam in residential furniture was associated with significantly higher levels of PBDEs in both indoor dust and in the serum of individuals living in those homes. Despite

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Revised: February 20, 2024
Accepted: April 4, 2024
Published: May 7, 2024

evidence of exposure from consumer products, personal vehicles remain an understudied source. 91% of Americans commute to work in a personal vehicle, with the average driver spending 55 min of their day in a vehicle.[25] Many infants and children are also transported to and from school, childcare, and doctor's appointments in personal vehicles, making vehicles a likely route of exposure for this vulnerable population.

Previous research has suggested that commuting may contribute to FR exposure. Reddam et al.[26] assessed the chemical exposures of commuters in Southern California using silicone wristbands and found that exposure to TDCIPP was correlated with the amount of time spent using vehicular transportation (personal vehicle, public transport, rideshare, etc.). TDCIPP has also been identified in vehicle dust at higher concentrations than other indoor microenvironments, such as bedrooms[27] and offices.[27,28] Several chlorinated and non-halogenated OPEs have also been identified in dust[29] and cabin air filters[30] from vehicles. These findings warrant further study of the vehicle microenvironment, especially regarding the types of FRs present in recently manufactured vehicles and the extent of human exposure. In personal vehicles, the US National Highway Traffic Safety Administration (NHTSA) Federal Motor Vehicle Safety Standard (FMVSS) 302 dictates the required burn resistance of materials in vehicle interiors. This standard remains the same as when it was first introduced in the 1970s and is likely met through the use of additive FRs, though it does not prescribe which FRs could or should be used. There is a need to understand which FRs are being used in current vehicles and their potential for human exposure.

This study used silicone passive samplers to characterize FR chemicals present in personal vehicles as well as to assess the relationship between ambient temperature and FR levels in cabin air. To the authors' knowledge, this is the first study to use silicone passive samplers to assess FRs in vehicle cabins. We also characterized FRs in foam from vehicle seats and determined whether there was an association with cabin air levels. Because our prior research[6] found that PBDEs in residential furniture foam were associated with elevated PBDEs in house dust and human serum, we hypothesized that the presence of OPEs in vehicle seats would lead to higher levels of OPEs in cabin air. We also hypothesized that the release of FRs from materials and hence air concentrations would increase with increasing temperatures.

■ MATERIALS AND METHODS

Recruitment and Study Population. Participants were invited to the study via an advertisement in the Green Science Policy Institute newsletter. Inclusion criteria included living in the United States and owning a vehicle of model year 2015 or newer. Interested participants submitted information about their vehicle model year, engine type, and zip code. Participants were selected to target a wide geographic distribution of vehicle locations as well as different engine types: ~50% internal combustion engines (n = 49), 25% electric (n = 26), and 25% hybrid (n = 26). This study was reviewed by the Duke University Institutional Review Board and determined to be "exempt human subjects research" because it focused on the vehicles as subjects rather than human participants.

Samples were collected in both the winter and summer months to assess the effect of temperature on levels of FRs in cabin air. The first set of sampling kits was sent to 101 participants in February and March of 2022 for deployment from February to May, and a subset of participants (n = 54) were sent a second kit in July or August of 2022 for deployment between July and September. Each participant indicated the zip code where their vehicle was stored during the deployment of the silicone sampler and the date and time at which the sampler was deployed and removed. Deployment dates were used to extract average daily temperatures from the National Oceanic and Atmospheric Administration (NOAA) online Climate Database.[31] Daily temperatures were averaged over the 7-day course of sampler deployment to obtain an average ambient temperature experienced by each vehicle.

Silicone Sampler Deployment and Collection. Participants were mailed a sampling kit containing an instruction sheet, nitrile or vinyl gloves, a silicone sampler (precleaned via Soxhlet extraction), zip ties, precleaned (i.e., combusted) aluminum foil, a Ziplock bag, and a preaddressed, stamped envelope to return the samples. Participants were surveyed regarding the make, model, and partial VIN number of their vehicle. VIN numbers were used to validate production years and engine type and to obtain data on the vehicle manufacturing location.

Participants used zip ties to suspend a silicone sampler from their vehicle's rearview mirror for 7 days. After 7 days, the participant wrapped the sampler in the included aluminum foil, placed it in the Ziplock bag, and mailed it back to the laboratory (see the SI for a copy of the instructions provided to each participant). Participants wore gloves whenever they handled the silicone samplers. Upon receipt at the laboratory, samplers were transferred to airtight trace-clean glass vials and stored at −20 °C until analysis.

Foam Sample Collection. Each participant was asked to collect a small (~1 cm) piece of foam from the front seat of their vehicle during one of two collection periods. Generally, this involved participants reaching underneath the vehicle seat to access the unupholstered foam following instructions included in their sampling kit (see SI). A total of 52 foam samples were collected and returned to the laboratory wrapped in precleaned aluminum foil. Upon receipt at the laboratory, foam samples were placed in airtight, trace-clean glass vials and stored at room temperature until analysis.

Silicone Sampler Processing. Full details on the silicone sampler pretreatment (i.e., cleaning) and analysis after deployment can be found in the Supporting Information. Briefly, silicone sampler segments (~0.7 g) were spiked with a suite of isotopically labeled internal standards (Table S1), extracted using 50:50 hexane:acetone, and concentrated with purified nitrogen prior to GC−MS analysis. 48 analytes were analyzed via GC−MS, and one analyte (2,4,6-tribromophenol) was analyzed via LC−MS following a solvent exchange to methanol. Table S2 gives a full list of targeted analytes in silicone samplers and their CAS numbers. GC−MS and LC−MS parameters can also be found in the Supporting Information.

Foam Processing. Foam samples from vehicle seats were extracted using previously published methods.[32] Briefly, ~50 mg of foam was extracted via sonication for 10 min in 2 mL of dichloromethane. This process was performed twice, and extracts were combined and concentrated on a nitrogen evaporator (N-evap) to a volume of ~1 mL. Foam extracts were analyzed for 15 compounds (BFRs and OPEs) in full scan mode using two different GC−MS systems, including an Agilent Gas Chromatograph (Model 7890A)−Mass Spectrometer (Model 5975C) system (Agilent Technologies, Santa

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Clara, CA, USA) in electron ionization mode (GC/EI–MS) and an Agilent Gas Chromatograph (Model 6890N)–Mass Spectrometer (Model 5975) system (Agilent Technologies, Santa Clara, CA, USA) in negative chemical ionization mode (GC/ECNI–MS). The resulting chromatograms were inspected manually, and significant peaks in the chromatograms were compared with both in-house and NIST mass spectral libraries. Positive detections were identified when there was >80% probability match. Detections of 2,4,6-tribromophenol (2,4,6 TBP) were further confirmed using an Agilent Liquid Chromatograph (Model 1260) Tandem Mass Spectrometer (Model 6460) in negative electrospray ionization mode (LC/ESI–MS). Extracts were blown to dryness on an N-evap and solvent-exchanged to methanol before analyzing via LC–MS. See Table S3 for a full list of targeted analytes in foam, including CAS numbers.

Quality Assurance/Quality Control. Field blanks (n = 5 winter, n = 5 summer) consisted of sampling kits, which were mailed to study collaborators in California, but not opened or deployed. These blank samplers were processed alongside participant samples to detect background contamination from the mailing and laboratory processes. These blanks were also used to calculate method detection limits (MDLs).[33] If a target compound was detected in 3 or more field blanks, MDLs were calculated as 3 times the standard deviation of the blanks. If a compound was detected in only 2 blanks, MDLs were calculated as 2 times the average of the blanks. If a compound was detected in only 1, or no blanks, 1/2 the lowest concentration visible in the calibration curve was used as the MDL. MDLs for all compounds, normalized to the average mass of silicone samplers extracted (~0.7 g), can be found in Table S2. All compounds were blank-corrected by subtracting their average concentration in field blanks from the raw measurements. Recovery averages of isotopically labeled internal standards ranged from 79 to 119% (Table S1).

Statistical Analysis. Statistical analyses were performed using JMP Pro 17 and SAS 9.4 (SAS Institute, Cary, NC, USA). Statistical analyses were only performed on compounds with greater than 60% detection in silicone samplers in both the winter and summer collection periods. Data are reported in units of mass of FR per mass of silicone sampler (e.g., ng/g). For compounds with >60% detection, concentrations below the MDL were imputed with MDL divided by the square root of two, adjusted based on the mass of the sampler extracted.

Nonparametric statistical tests were used because Shapiro-Wilk normality tests revealed that FR concentrations in silicone samplers were not normally distributed. To assess whether concentrations were different between the winter and summer collection periods, we used both Wilcoxon Rank Sum (Mann–Whitney) and Wilcoxon Signed Rank (paired) tests. A Wilcoxon Rank Sum Test was used to compare concentrations based on FR presence in paired foam samples. To assess differences in concentration between multiple groups, such as vehicle engine type, we first used a Kruskal–Wallis Test and then performed posthoc testing with the Wilcoxon Each Pair Method. We used linear mixed effect models (accounting for repeated measures) to determine whether there was a statistically significant correlation between FR concentrations in silicone samplers and ambient temperature. Concentration values were $\log_{10}$-transformed prior to running the regression to improve normality. Statistical significance was considered when $p < 0.05$.

RESULTS AND DISCUSSION

Study Population. Vehicles in this study were primarily manufactured between 2015 and 2022, reflecting our interest in understanding FRs in recently manufactured vehicles. Vehicles were from locations across 30 different states, with the largest number located in California (Figure S1 and Table S4). Because of this wide geographic distribution and the sampling of a subset of vehicles in both winter and summer, we were able to study vehicles exposed to average ambient temperatures ranging from approximately −5 to 30 °C. More details on the specific vehicles included in this study are found in Table 1.

Table 1. Summary Statistics for Winter (n = 101) and Summer (n = 54) Collection Periods[a]

	deployment period	
	winter	summer
total vehicles, n	101	54
engine type, n (%)		
electric	26 (26)	14 (26)
gas	49 (49)	25 (46)
hybrid	26 (26)	15 (28)
year of manufacture, n (%)		
2013	1 (1.0)	1 (1.9)
2014	1 (1.0)	0 (0.0)
2015	14 (14)	11 (20)
2016	8 (7.9)	2 (3.7)
2017	17 (17)	6 (11)
2018	15 (15)	8 (15)
2019	13 (13)	6 (11)
2020	13 (13)	10 (19)
2021	16 (16)	7 (13)
2022	3 (3.0)	3 (5.6)
country of manufacture, n (%)		
United States	39 (39)	21 (39)
Japan	24 (24)	12 (22)
Mexico	8 (7.9)	3 (5.6)
Germany	7 (6.9)	6 (11)
South Korea	5 (5.0)	3 (5.6)
Canada	4 (4.0)	2 (3.7)
other[b]	6 (5.9)	4 (7.4)
unknown	8 (7.9)	3 (5.6)
average temperatures		
Celsius (°C)	8.7	21.9

[a]Values in parentheses are percentages of total participants for a given deployment period. [b]Countries of manufacture reported as "other" only appeared once and include Austria, Belgium, England, France, Slovakia, and Sweden (Winter) and Belgium, England, Slovakia, and Sweden (Summer).

OPE Measurements in Silicone Samplers. We targeted 49 BFRs and OPEs that are commonly detected in the environment. A total of 17 different FRs were identified in at least one silicone sampler (Table S2), suggesting that a wide range of FRs are present in vehicle cabin air. Six types of brominated flame retardant (BFRs) were detected. Among these, 2,4,6-tribromophenol (2,4,6-TBP) was the most detected, in 22% of winter samples and 43% of summer samples. Most detections were organophosphate esters (OPEs), with 12 OPE compounds detected in at least one sampler. Four OPEs were detected in >60% of silicone samplers during both the winter and summer collection

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Table 2. Summary Statistics for the Most Frequently Detected Compounds in Silicone Samplers from Winter (n = 101) and Summer (n = 54) Sampling[a]

	detection frequency (%)		range (ng/g)		median (ng/g)	
compound	winter	summer	winter	summer	winter	summer
TEP	85	96	<3.53–21,000	<5.07–18,300	13.6	26.9
TIBP	63	100	<0.71–316	0.39–524	1.36	5.62
TNBP	73	100	<0.71–286	0.94–807	2.64	9.87
TCIPP	99	98	<0.19–5100	<4.29–11,600	62.9	231
TDCIPP	23	59	<7.07–640	<3.53–909	n/a	8.82
TPHP	0	65	n/a	<2.01–151	n/a	2.79

[a]For a full list of analytes, see Table S2. n/a indicates not calculated due to low detection frequency.

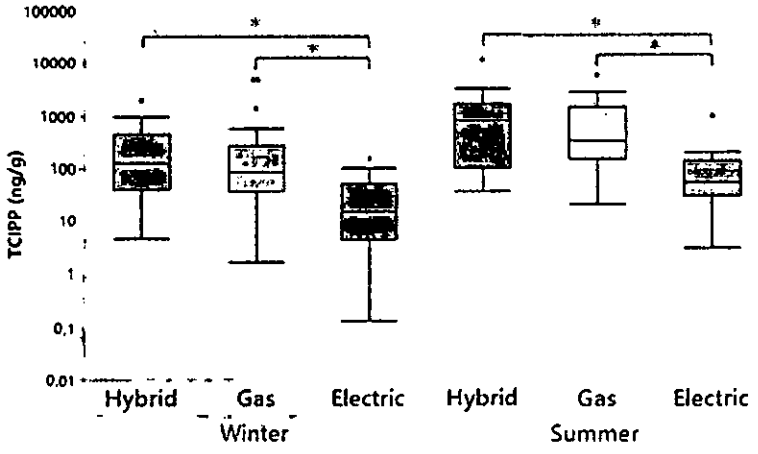

Figure 1. Comparison of TCIPP levels (ng/g) among the three vehicle engine types (hybrid, gas, and electric) in both winter (n = 101) and summer (n = 54) silicone samplers. TCIPP levels are graphed on a logarithmic scale. A Kruskal–Wallis ($p < 0.05$) global test indicated significant differences by engine type. Statistical significance ($p < 0.05$) in post hoc nonparametric Wilcoxon Each Pairs Test indicated by orange bars with asterisk.

periods, triethyl phosphate (TEP), triisobutyl phosphate (TIBP), tri-n-butyl phosphate (TNBP), and tris(1-chloro-2-propyl) phosphate (TCIPP). TCIPP concentrations are reported as a sum of the three major isomers. Among these highly detected compounds, all four are known to be used as FRs. However, TEP, TIBP, and TNBP also have known uses as plasticizers[34−37] and TNBP may be used in automotive fluids.[38] Two additional OPEs were detected in greater than 58% of silicone samplers only during the summer collection: tris(1,3-dichloro-2-propyl) phosphate (TDCIPP) and triphenyl phosphate (TPHP). Concentration ranges and medians for these compounds are listed in Table 2.

Trends by Vehicle Engine Type. Utilizing data on participants' vehicles, the relationship between vehicle characteristics and FR concentrations was first considered. FR levels were not significantly different based on vehicle make, model, year, or country of manufacture. However, we found that TCIPP (Figure 1) and TNBP (Figure S2) concentrations were significantly lower in vehicles with all-electric engines compared to those with gasoline engines. During both winter and summer, TCIPP concentrations were ~6 times lower, and TNBP concentrations ~3 times lower in electric vehicles than in gasoline vehicles. TCIPP concentrations also differed between electric and hybrid vehicles (Figure 1). In winter and summer, respectively, TCIPP concentrations were ~8 and ~14 times lower in electric vehicles than in hybrids.

It is worth noting that the observed trends by engine type may be confounded by vehicle make/brand. Of the vehicles included in this study, certain brands are overrepresented for a given engine type. For example, eight brands are included in the electric vehicles category (n = 26), but among these, 53% are exclusively one brand. This is also true of the hybrid category (n = 26), where nine brands are included, and 50% of these vehicles are exclusively one brand. Therefore, it is difficult to determine if this trend is driven by engine type or another factor associated with manufacturers/brands.

Comparison of Summer and Winter Concentrations. We compared FR levels in samplers from vehicles that were sampled both in summer and winter (n = 54). Summer concentrations of TEP, TIBP, TNBP, and TCIPP were significantly higher than winter concentrations according to both a Wilcoxon Rank Sum (Mann–Whitney) Test (performed on all data) and the Wilcoxon Signed Rank Test (performed on only paired data). Figure 2 depicts the distribution of concentrations for participants whose vehicles were sampled twice (n = 54). Among these paired samples, the median TCIPP concentration was 56 ng/g in the winter, which increased ~4-fold to 231 ng/g in the summer. Similar increases from winter to summer were observed for TEP, TIBP, and TNBP, with median summer concentrations being 1.6, 4.9, and 5.3 fold higher, respectively. Average exterior temperatures experienced by these twice-sampled vehicles increased from 7.4 to 21.9 °C between the two seasons.

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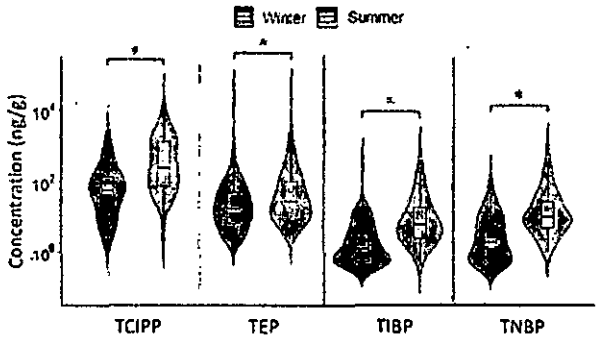

Figure 2. Concentrations (graphed on a log scale) of the four most abundant (>60% detection) OPEs detected in both winter and summer sampling periods, restricted to vehicles sampled during both seasons (n = 54). Box plots inside violin plots depict the 25th percentiles, medians, and 75th percentiles. Orange bars with an asterisk represent a significant difference ($p < 0.001$) between summer and winter values by Wilcoxon Signed Rank (paired) Test.

The increase in the median concentrations from winter to summer is consistent with the temperature-dependent release of FRs from materials. Our data show that when semivolatile OPEs are used within vehicles, notably TEP, TIBP, TNBP, and TCIPP, they can be released into the cabin air, especially during warmer periods of the year.

Temperature and FR Concentrations in Silicone Samplers. To further examine the influence of temperature, we assessed the relationship between the average ambient temperature of the vehicle's environment and FR concentrations in silicone samplers. This was done for the four most frequently detected FRs (TEP, TIBP, TNBP, and TCIPP) using linear mixed effect models, which incorporated the data collected from all silicone samplers (n = 101 winter, n = 54 summer). For all four FRs, there was a significant ($p < 0.0001$) positive relationship between temperature and concentration (Figure 3). Exponentiated beta coefficients and confidence intervals are listed in Table S5. The strongest associations were found for TNBP and TCIPP. Every 1 °C increase in ambient temperature was associated with a 12% increase in the concentration of TNBP and TCIPP in the silicone sampler on average. TIBP was predicted to increase by 10% on average for every one-degree Celsius increase in temperature. TEP showed the weakest association, with a 4% increase in TEP concentration on average for every one-degree increase in ambient temperature.

These data clearly demonstrate empirically that temperature plays an important role in the extent to which FR chemicals are

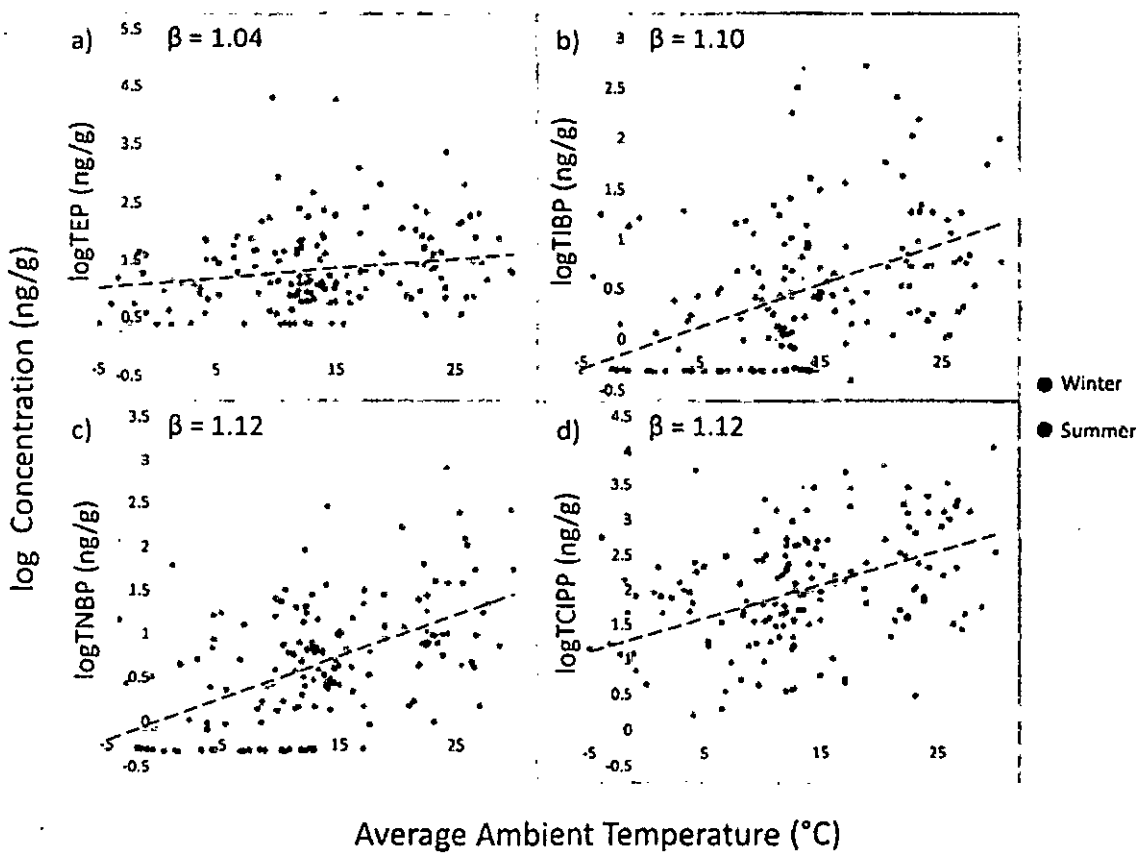

Figure 3. Plots of average ambient temperature (°C) vs log silicone sampler concentration (ng/g) for the four most detected compounds (a) TEP, (b) TIBP, (c) TNBP, and (d) TCIPP. Concentrations are $\log_{10}$ transformed to better show the spread in the data and allow for overlay of linear model results. All data are displayed including winter (blue) and summer (orange) time points and imputed values for detections < MDL. β = exponentiated fixed effect coefficient generated from the mixed effect model (see Table S5). A significant relationship ($p < 0.0001$) between temperature and concentration was found for all four compounds, represented by the dashed lines.

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released from materials inside a vehicle cabin. The internal temperature of a parked vehicle can become significantly higher than the ambient air temperature, exacerbating this effect during warmer months. For example, Diaz et al. found that a vehicle parked in direct sun during the summer was on average 20 °C hotter than the outside temperature, with peak internal temperatures reaching as high as 68.8 °C.[39] The observed relationship between higher temperatures and higher FR levels in cabin air becomes increasingly important to consider during these summer months, as passengers entering a hot vehicle may be exposed to higher concentrations.

Vehicle Seat Foam Analyses. Because furniture foam has been shown to be a source of FRs in homes,[6] we were interested in whether seat foam is a source of FRs in personal vehicles. Of the foam samples analyzed (n = 52), FRs were detected in 33 samples (Table S3). The most commonly detected compounds were OPEs, including TCIPP (n = 23) and TDCIPP (n = 5). Other infrequently detected FRs included V6 (BCMP-BCEP) or Thermolin 101, 2,4,6-tribromophenol (2,4,6-TBP), tris(2-chloroethyl) phosphate (TCEP), and decabromodiphenyl ether (BDE 209).

To examine the likelihood that FRs in foam act as a source to the cabin air, we conducted statistical analyses on the silicone sampler data stratified by whether TCIPP was detected in foam or not. Only TCIPP was examined in these analyses due to the lower detection frequency for other FRs in the foam. We observed significantly higher levels of TCIPP in samplers when it was detected in paired foam (Figure 4).

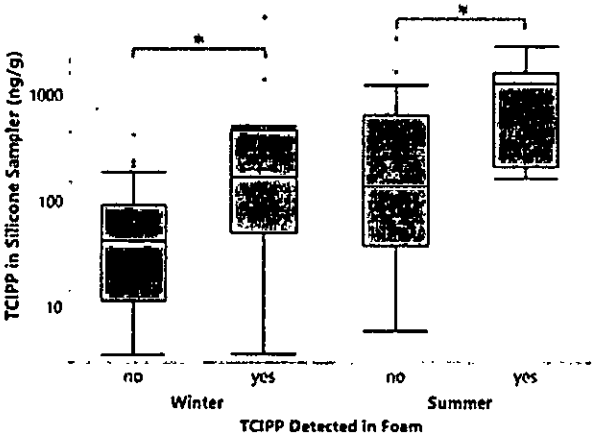

Figure 4. TCIPP concentrations in silicone samplers (ng/g) in both winter (n = 51) and summer (n = 28) sampling periods from vehicles where a foam sample was provided. TCIPP concentrations are graphed on a logarithmic scale for clarity. Statistical significance (p < 0.05) in nonparametric Wilcoxon Rank Sum Test indicated by orange bars with asterisk.

During the winter collection period, the median TCIPP concentration in samplers from vehicles without TCIPP in their foam was 42 ng/g. If a vehicle had TCIPP in its foam sample, this median concentration increased to 166 ng/g, approximately 4 times higher. This relationship was even more striking during the summer sampling period, when the median TCIPP concentration was 134 ng/g for vehicles without TCIPP in foam and approximately 9-fold higher (1250 ng/g) for vehicles with TCIPP in foam.

To assess whether differences in TCIPP concentrations by vehicle type were driven by the presence in seat foam, we assessed the relationship between silicone sampler concentrations (winter) and TCIPP detections in foam, stratified by vehicle type. Stratification reduces sample sizes for statistical analysis, but visual inspection of the data suggests that regardless of engine type, TCIPP levels are higher in samplers when TCIPP was detected in paired foam (Figure S3). Detection in foam does not seem to explain the lower levels of TCIPP observed in electric vehicles compared to those in gas and hybrid vehicles, again suggesting that this trend is likely driven by another characteristic.

To examine the influence of both TCIPP in foam and temperature, we again used a repeated measures linear mixed effect model (Figure S4). This model assessed the relationship between TCIPP concentrations (ng/g) and temperature for the subset of participants with foam samples (n = 51). Figure S4 illustrates that TCIPP concentrations increased with increasing ambient temperature and that the presence of TCIPP in paired foam samples shifts concentrations higher, suggesting foam is a source of TCIPP. Additionally, the model provided a similar slope (Figure S4) regardless of whether TCIPP was detected in paired foam, suggesting that there were additional sources of TCIPP in the cabin, and FR release from these materials is similarly influenced by temperature.

Together, these results suggest that the presence of TCIPP in vehicle seat foam contributes to higher levels of TCIPP in cabin air. Seat foam appears to be a source of this compound in cabin air, though not the only source, as vehicles without TCIPP in their foams still consistently contained TCIPP in their silicone samplers. The presence of other sources is also indicated by the detection of other FRs, such as TEP, TNBP, and TIBP in vehicles without detectable FRs in their seat foam. Other possible sources of FRs include other foam-containing components (headrests, ceiling headliner, interior padding, expanded polystyrene foam components, etc.) or other interior materials. These results are not surprising, as FRs are used in many components of vehicles in addition to polyurethane foam seating.[40] Though updated flammability standards have led to the reduced use of FRs in many products with foam, such as furniture and baby products, FR-treated foam continues to be used in vehicles.

Predicting Cabin Air Concentrations of TCIPP. Since TCIPP was the primary FR detected in the seat foam, we contextualized our results by predicting TCIPP air concentrations in the vehicle interior. To do this, we used air sampling rates derived from indoor calibration studies with silicone wristbands[41] to estimate vehicle cabin air concentrations.

Okeme et al.[41] derived a generic OPE sampling rate for stationary silicone wristbands of 1.5 $m^3/day/dm^2$, after compiling sampling rates from several indoor calibration studies. Using this sampling rate, we estimated a TCIPP air concentration (ng/m^3) for each silicone sampler, accounting for the deployment period in the vehicle. Details of these calculations are reported in Table S6. Given the generic sampling rate of 1.5 $m^3/day/dm^2$, we estimated that the median air concentration for TCIPP in vehicles would be 56 ng/m^3 in the winter and 180 ng/m^3 in the summer. Estimated air concentrations in individual vehicles ranged from 0.12 to 4200 ng/m^3 in the winter and 2.3 to 9000 ng/m^3 in the summer. This generic sampling rate likely provides a reasonable estimate of air concentrations; however, the actual sampling rate will vary based on temperature, humidity, and air

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flow.[42,43] Estimated air concentrations derived from the generic sampling rate, as well as the lower and upper bound sampling rates reported in Okeme et al., can be found in Table S7.

Estimated air concentrations of TCIPP in vehicles were comparable to those reported in the literature for indoor air. Schreder et al.[44] reported TCIPP air concentrations from 10 adults equipped with personal active air samplers. Concentrations ranged from 16 to 1180 ng/m^3, with median air concentrations of 262 ng/m^3. Similar levels have been detected with passive samplers, such as polyurethane foam discs deployed by Vykoukalova et al., who reported median air concentrations in homes from three countries to be 26.3 (USA), 73.6 (Canada), and 16.4 ng/m^3 (Czech Republic).[45] Additionally, maximum estimated air concentrations from summer sampling were as high as 9000 ng/m^3, above typical maxima reported in indoor air (e.g.: 3300 in bedrooms[46] and 4190 ng/m^3 in homes[45]).

Similar air concentrations between this study and those focused on the indoor environment highlight that personal vehicles could be an important microenvironment to consider when assessing human exposure to FRs. Inhalation is estimated as a major route of TCIPP exposure in indoor environments, predicted as 85% of total exposure in a recent study of UK homes.[46] Other potential routes of exposure in vehicles, which were not estimated in this study but would contribute to overall exposure, include dermal uptake from air[47] or treated materials[48] and inadvertent dust ingestion.[44]

The strong relationship between temperature and FR concentration in vehicle cabin air makes the vehicle microenvironment especially important to consider, particularly as temperatures increase due to climate change. Vehicles have the potential to provide a much greater exposure to FRs than other sources, such as homes and office buildings, especially during the summertime, when commuters may be climbing into a hot vehicle with little airflow. It is likely that an individual entering a hot car would open their windows and/or turn on the air conditioning, which would reduce exposure; however, this will lead to the FRs being flushed into the external environment, and thus, cars are likely a source to outdoor air as well. It is also possible that changes in temperature between winter and summer could influence the relative partitioning of these OPEs between phases (source materials, gas phase, and particle phase). This change in partitioning could influence the total amount of OPEs in the cabin air and should be explored further in future studies to assess how inhalation exposure is impacted by this difference in partitioning.

Study Limitations. Our results should be interpreted in the context of several limitations. Our sample size, of 101 in the winter and 54 in the summer, constrained the number of variables we could examine to explain differences in cabin air concentrations. The recruitment of more vehicles may have allowed us to elucidate any differences between the year and location of manufacture, which was not possible due to our sample size.

Temperatures reported in this study were estimated based on ambient air data from the region where each vehicle was stored and were not actual interior cabin air temperatures. It is likely that summertime interior temperatures could be much higher than our estimates, especially if participants parked in direct sun. We also did not consider participants' use of climate control or whether they drove or parked with their vehicle windows down. While this ensures that vehicles were used in a regular manner while sampling, those behaviors would influence temperature and ventilation and could thus influence air concentrations and sampler uptake.

Seat foam was collected wherever participants could access it, which could also contribute to some uncertainty in our measurements. There are other foams in the vehicle that we did not test, such as roof headliners, wall padding, and other seat components. We also did not test other materials, such as plastics and textiles, which are likely additional sources of FRs to the cabin air.

Finally, although our estimated cabin air concentrations are useful when considering FR exposure in vehicles, it is important to note that FRs are present in both gas and particle phases (where the particle phase is poorly captured by stationary silicone samplers) which may be inhaled[44] or contribute to other exposure routes. Vehicle dust has also been shown to contain FRs,[49] and dust ingestion could serve as another source of human exposure.

Study Implications. The results of this study suggest that personal vehicles are an important microenvironment to consider for understanding human exposure to FRs. In particular, the results showed the extensive use of organophosphate esters (OPEs) by the vehicle industry today. TCIPP was detectable in 99% of vehicles, and vehicle foam was identified as a source of this compound. To the authors' knowledge, this is the first study to explore the potential associations between FR applications in car seat foam and indoor air levels. The frequent detection of TCIPP in vehicles is particularly concerning given that a 2023 United States National Toxicology Report found evidence of carcinogenic activity in male and female rats and mice exposed to TCIPP,[50] with observed increases in liver adenomas, liver carcinomas, and uterine adenomas or adenocarcinomas. Carcinogenic potential of other OPEs has led to restrictions on their use, such as TDCIPP, which was added to the California Proposition 65 (Prop 65) List in 2011[19] and has been banned from certain products such as children's pajamas and mattresses.[51] Our study was limited to vehicles manufactured from 2013 to 2022, after TDCIPP was listed on Prop 65. Our data suggest that this listing has resulted in a substitution of TCIPP in place of TDCIPP, which would explain the high detections of TCIPP in vehicles as well as lower TDCIPP detections compared to previous vehicle studies.[26,27,52] This substitution is concerning given the higher vapor pressure of TCIPP (1.35×10^{-3} mmHg)[53] compared to TDCIPP (7.22×10^{-6} mmHg),[54] making TCIPP more likely to be released from foams and other sources into vehicle cabin air. Growing evidence on the negative health effects of TCIPP, and the increased potential for airborne exposure to this compound, suggests yet another case of regrettable substitution.

Our identification of vehicle foam as a source of exposure to FRs is similar to the results of previous studies, where FR detection in furniture foam was associated with higher levels in indoor dust and human serum.[6] However, home air temperatures are relatively stable, while vehicle temperatures can vary greatly. Our data confirming the temperature-dependent release of FRs suggest that vehicle exposure is particularly influenced by the cabin conditions.

These findings highlight that commuters are likely to be exposed to FRs, especially those with longer commutes or those who drive vehicles full time as part of their employment. In addition, children, who breathe a greater amount of air per kg body weight compared to adults,[55] would also be at risk of

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greater exposures for equivalent commuting times. People living in warmer climates may also have higher exposure to FRs and other semivolatile chemicals used in vehicles, though further research on human exposure patterns is warranted, since exposures will be influenced by personal behaviors such as rolling down windows or utilizing climate control. Vehicle users may be able to reduce FR concentrations in their cabin air by controlling their vehicle's cabin temperature. Parking in a garage or shade instead of full sun may reduce the cabin temperature and limit the extent of FR release. Increasing ventilation by opening vehicle windows and avoiding recirculating interior cabin air may also reduce exposures. However, the greatest reduction in exposure from vehicle air would come from significantly reducing the amount of FRs added to personal vehicles.

Given that FMVSS 302 continues to drive the use of FRs in vehicles, more information is needed to understand the true risks and benefits of their use. Similar considerations have been conducted for other industries, such as the 2013 update to California's TB 117 flammability standard for upholstered furniture. This change provided options to achieve fire safety without the use of FR chemicals, and studies have indicated that this change has reduced the levels of FRs in home furnishings.[56] This study indicates that vehicles are likely important sources of human exposure to potentially harmful FRs. Coupled with the uncertain fire safety benefits of adding FRs to personal vehicle interiors, these results suggest that FMVSS 302 should be reevaluated.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.3c10440.

Summary of chemical standards, the full panel of target analytes, further details on the study population, details on the estimation of air concentrations, and results of additional temperature, seat foam, and vehicle type analyses (PDF)

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The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

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Notes

The authors declare no competing financial interest.

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■ ABBREVIATIONS

FR, flame retardant; TCIPP, tris(1-chloro-isopropyl) phosphate; OPE, organophosphate ester; PBDE, polybrominated diphenyl ether; BFR, brominated flame retardant; TDCIPP, tris(1,3-dichlorop-2-propyl) phosphate; GC−MS, gas chromatography−mass spectrometry; LC−MS, liquid chromatography−mass spectrometry; N-evap, nitrogen evaporator; NIST, National Institute of Standards and Technology; TEP, triethyl phosphate; TIBP, triisobutyl phosphate; TNBP, tri-*n*-butyl phosphate

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ANNEXURE R-4

22

Agents Classified by the IARC Monographs, Volumes 1–136

CAS No.	Agent	Group	Volume	Volume publication year	Evaluation year	Additional information
	Aloe vera, whole leaf extract	2B	108	2016	2013	
	Clonorchis sinensis (infection with)	1	61, 100B	2012	2009	
	Fusarium graminearum, F. culmorum, and F. crookwellense, toxins derived from (zearalenone, deoxynivalenol, nivalenol, and fusarenone X)	3	Sup 7, 56	1993	1992	
	Fusarium sporotrichioides, toxins derived from (T-2 toxin)	3	56	1993	1992	
	Helicobacter pylori (infection with)	1	61, 100B	2012	2009	
	Microcystis extracts	3	94	2010	2006	
	Opisthorchis felineus (infection with)	3	61	1994	1994	
	Opisthorchis viverrini (infection with)	1	61, 100B	2012	2009	
	Schistosoma haematobium (infection with)	1	61, 100B	2012	2009	
	Schistosoma japonicum (infection with)	2B	61	1994	1994	
	Schistosoma mansoni (infection with)	3	61	1994	1994	
	Acheson process, occupational exposure associated with	1	111	2017	2014	
	Acid mists, strong inorganic	1	54, 100F	2012	2009	
	Acrylic fibres	3	19, Sup 7	1987	1987	
	Acrylonitrile-butadiene-styrene copolymers	3	19, Sup 7	1987	1987	
	Alcoholic beverages	1	44, 96, 100E	2012	2009	
	Alpha particles (see Radionuclides)					
	Aluminium production	1	34, Sup 7, 92, 100F	2012	2009	
	Anaesthetics, volatile	3	11, Sup 7	1987	1987	
	Androgenic (anabolic) steroids	2A	Sup 7	1987	1987	
	Areca nut	1	85, 100E	2012	2009	
	Arecoline	2B	128	2021 online	2020	
	Art glass, glass containers and pressed ware (manufacture of)	2A	58	1993	1993	
	Auramine production	1	Sup 7, 99, 100F	2012	2009	
	BK polyomavirus (BKV)	2B	104	2014	2012	
	Benzidine, dyes metabolized to	1	99, 100F	2012	2009	NB Overall evaluation

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CAS No.	Agent	Group	Volume	Volume publication year	Evaluation year	Additional information
111-44-4	Bis(2-chloroethyl)ether	3	9, Sup 7, 71	1999	1998	
111-76-2	2-Butoxyethanol	3	88	2006	2004	
111025-46-8	Pioglitazone	2A	108	2016	2013	
111189-32-3	Naphtho[1,2-b]fluoranthene	3	92	2010	2005	
1116-54-7	N-Nitrosodiethanolamine	2B	17, Sup 7, 77	2000	2000	
1120-71-4	1,3-Propane sultone	2A	4, Sup 7, 71, 110	2017	2014	NB Overall evaluation upgraded to Group 2A with supporting evidence from other relevant data
1143-38-0	Dithranol	3	13, Sup 7	1987	1987	
115-02-6	Azaserine	2B	10, Sup 7	1987	1987	
115-07-1	Propylene	3	Sup 7, 60	1994	1994	
115-28-6	Chlorendic acid	2B	48	1990	1989	
115-32-2	Dicofol	3	30, Sup 7	1987	1987	
115-96-8	Tris(2-chloroethyl) phosphate	3	48, 71	1999	1998	
116-06-3	Aldicarb	3	53	1991	1990	
116-14-3	Tetrafluoroethylene	2A	19, Sup 7, 71, 110	2017	2014	NB Overall evaluation upgraded to Group 2A on the basis of sufficient evidence in experimental animals with a striking and atypical pattern of tumours
1163-19-5	Decabromodiphenyl oxide	3	48, 71	1999	1998	
116355-83-0	Fusarium moniliforme, toxins derived from (fumonisin B1, fumonisin B2, and fusarin C)	2B	56	1993	1992	
116355-83-0	Fumonisin B1	2B	82	2002	2002	
117-10-2	Dantron (Chrysazin; 1,8-Dihydroxyanthraquinone)	2B	50	1990	1989	
117-39-5	Quercetin	3	Sup 7, 73	1999	1998	
117-79-3	2-Aminoanthraquinone	3	27, Sup 7	1987	1987	
117-81-7	Bis(2-ethylhexyl) phthalate (see Di(2-ethylhexyl) phthalate)					
117-81-7	Di(2-ethylhexyl)phthalate	2B	Sup 7, 77, 101	2013	2011	

True Copy

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BEFORE THE NATIONAL GREEN TRIBUNAL

PRINCIPAL BENCH AT NEW DELHI

24

OA NO. 717 OF 2024

IN THE MATTER OF:

NEWS ITEM TITLED "PEOPLE ARE BREATHING IN CANCER-CAUSING CHEMICALS IN THEIR CARS STUDY FIND" APPEARING IN NDTV. COM DATED 08.05.2024 ..... SUO-MOTO

VERSUS

UNION OF INDIA & ORS. ..... RESPONDENTS

KNOW ALL to whom these present shall come that I, Dr. R. Lakshminarayanan, working as Deputy Director General (Admn.) with Indian Council of Medical Research the above named Respondents do hereby

SIKRI & CO. Advocates

(i)	MS. EKTA SIKRI (D/564/05)	(v)	SHRI JASBIR BIDHURI (D-1973/2015)
(ii)	SHRI VIKALP MUDGAL (D-2113/2013)	(v)	SH. ARUN SANWAL (D-1719/2017)
(iii)	SHRI AJAY PAL SINGH (D-1280/2013)	(vi)	SHRI SHASHWAT SHARMA (D-2187/2018)
		(vii)	SH. AKSHIT GUPTA (D-4668/2019).

(herein after called the Advocates)

to be my / our Advocates in the above case and authorize them:

To act, appear and plead in the above-noted case in this Court or in any other Court in which the same may be tried or heard and also in the appellate Courts.

To sign, file, verify and present pleadings, appeals, cross objections or petitions f revision, restoration, withdrawl, compromise or other petitions, replies, objection or affidavits o may be deemed necessary or proper, for the prosecution of the said case in all stages.

To file and take back documents.

To withdraw or compromise the said case or submit arbitration any differences, dis touching or in any manner relating to the said case.

To take out execution proceedings.

To deposit, draw and receive money, cheques and grant receipts therefore, and t things which may be necessary to be done for the progress and in the course of the prosecutio

To appoint instruct any other legal Practitioner authorizing him to exercise the powe conferred upon the Advocates whenever they may think fit to do so and to sign the power of acts, as if done by me/us to all intents and purposes.

And I/we undertake that I/we or my/our authorized agent would appear in Court on all he the advocates for appearance, when the case is called.

And I/we the undersigned do hereby agree not to hold the advocates or their substitute (result of the said case inconsequence of this absence from the Court when the said case is cal for any negligence of the Advocates or their Substitute (s).

And I/we undersigned do hereby agree that in the event of the whole or any part of the fee agreed by me/us to be paid to the Advocates remaining unpaid, he shall be entitled to withdraw from the prosecution of said case until the same is paid up. If any costs are allowed for adjournment in Advocates would do the same.

IN WITNESS WHEREOF I/we do here upto set my/our hand to these presents the contents of which have been understood by me/us this 10th day of September, 2024

Accepted

I Identify the Client who has Signed in my presence

(EKTA SIKRI) (VIKALP MUDGAL) (AJAY PAL SINGH)

(AKSHIT GUPTA) (ARUN SANWAL) (JASBIR BIDHURI) (SHASHWAT SHARMA)

Advocates

Client

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भारतीय आयुर्विज्ञान अनुसंधान परिषद
Indian Council of Medical Research
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