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The Changing Profile of Human Exposure to Persistent Organic Chemicals

Stuart Harrad

BACKGROUND

- Silent Spring focused on organochlorine pesticides such as DDT, dieldrin, and chlordane (also organophosphates like malathion and parathion)
- Recognised the potential for occupational exposure for those applying DDT
- Described bioaccumulation (due to hydrophobicity & persistence) leading to ***dietary*** exposure being the principal human exposure pathway
- Highlighted also exposure of the foetus and of neonates
- Important to note the primarily ***outdoor*** use of DDT and related OC pesticides

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BACKGROUND

- The dietary exposure paradigm persisted & in the mid-1990s thought exposure to persistent organochlorine chemicals like dioxins and PCBs occurred primarily through diet
- True for dioxins, but on-going presence of PCBs in ***indoor environments*** shown to lead to high indoor air concentrations that in the UK contribute substantially to overall human exposure (on average 25%)

Currado and Harrad (1998), EST, 32, 3043-3047

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INDOOR PCB CONTAMINATION ELSEWHERE

- UK not a special case…
- Elevated indoor concentrations found for example in:
- Germany
- Switzerland
- Sweden
- USA (up to ~3 μg m^{-3})
- Canada

Fluorescent light ballast

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BACKGROUND

- As well as the shift towards indoor exposures (in addition to diet), another big change
- Rise in use of & exposure to other organo***halogens***
- Organofluorines – such as perfluoro octane sulfonate used as surfactants in fire-fighting foams (Buncefield), and indoors in stain-proofing products for fabrics and even as pesticides
- Also organobromines – as flame retardants
- This shift in exposure emphasis exemplified by inverse temporal trend for OCPs & PBDEs

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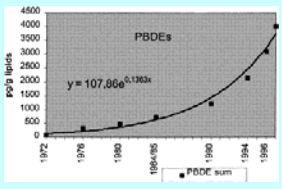
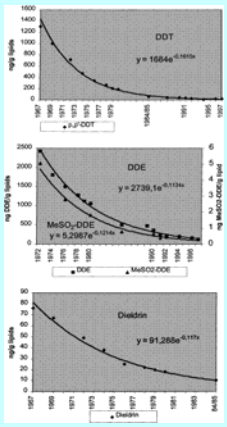
BACKGROUND

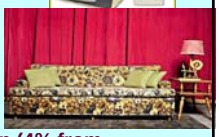




Noren & Meironyté, *Chemosphere*, (2000), 40, 1111-1123

PBDE EXPOSURE ASSESSMENT

- Physicochemical properties of PBDEs are ***broadly*** similar to those of PCBs
- Also extensive indoor use – primarily as Penta-BDE and Deca-BDE (also Octa-BDE)
- Combined, these led early research (2004) to investigate both diet and indoor air inhalation as exposure pathways
- UK study attributed 93% of Penta-BDE congener exposure to arise from diet; 7% from indoor air
- Similar findings for Canadian population (4% from indoor air)



Harrad et al EST (2004) 38, 2345-2350.
Wilford et al EST (2004) 38, 5312-5318.

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PBDE EXPOSURE ASSESSMENT

- This early work did not consider exposure via indoor (***settled***) dust
- This of importance due to the lower vapour pressures of PBDEs c.f. PCBs
- Seminal papers emerged that considered the importance of dust ingestion to ALL PBDEs (including Deca-BDE)
- Also highlighted the potential for especially elevated exposure of young children (dust representing 80-90% of overall exposure)
- Dust likely the most important exposure pathway for Deca-BDE in the UK

Hazrati et al, EST (2006) 40, 4633-4638
Harrad et al, Environ Int (2008) 34, 1170-1175
Harrad et al, Environ Int (2008) 34, 232-238
Jones-Otazo et al, EST (2005) 39, 5121-5130
Stapleton et al, EST (2005) 39, 925-931
Wilford et al, EST (2005) 39, 7027-7035

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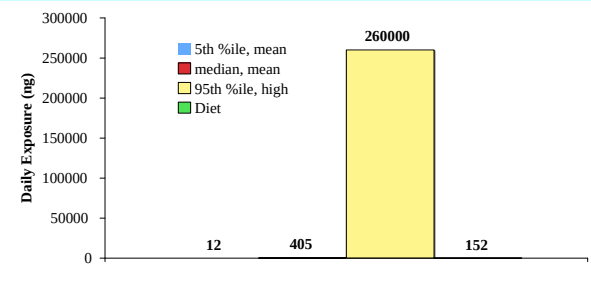
ESTIMATED UK TODDLER EXPOSURE (NG/DAY)TO DECA-BDE VIA DUST INGESTION & DIET



- Mean dust ingestion 50 mg/d;
- High dust ingestion 200 mg/d

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NOT "JUST" PBDEs

- Burgeoning evidence of PBDEs in dust turned attention to other high volume BFRs
- In Europe, Hexabromocyclododecane (HBCD) used substantially
- Concentrations in UK dust in line with those in North America
- In UK, HBCD<10xDeca-BDE and 10-50x>Penta-BDE
- Dust thus an important exposure pathway of exposure to HBCD

Abdallah et al, EST (2008) 42, 459-464

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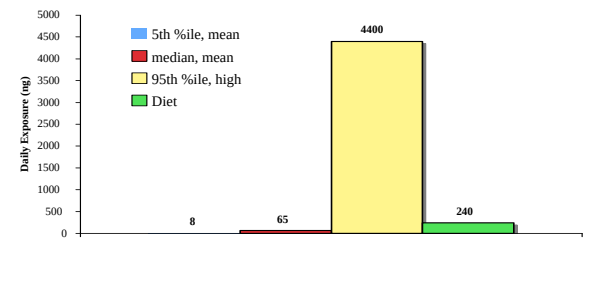
ESTIMATED UK TODDLER EXPOSURE (NG/DAY)TO ΣHBCD VIA DUST INGESTION & DIET



Mean dust ingestion 50 mg/d;
High dust ingestion 200 mg/d

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WHAT EXPOSURE PATHWAYS INFLUENCE BODY BURDENS?

- Clearly, BFRs in dust constitute an exposure hazard, but how does it translate into body burdens?
- While correlation NOT reported in some studies, several studies have shown positive correlation between PentaBDE (n=4) and HBCD (n=1) in indoor dust and in human tissues of dust donors
- Until very recently, no such correlation reported for Deca-BDE – only detected in ~20% of humans; points to low bioavailability and short half-life. BUT, a significant correlation observed between dust and human milk in a NZ cohort
- Important to bear in mind that dietary exposure is also substantial (in some studies correlates with body burden)

Coakley et al, Dioxin 2012
Johnson et al, EST (2010) 44, 5627-5632
Roosens et al, EHP (2009) 117, 1707-1712
Stapleton et al, Dioxin 2011
Vorkamp et al, Environ Int (2011) 37, 1-10
Wu et al, EST (2007), 41, 1584-1589

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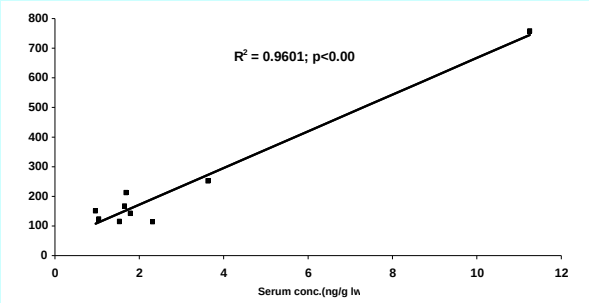
CORRELATION BETWEEN ΣHBCDs IN DUST AND BLOOD SERUM



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CAN WE EXPLAIN PBDE DISTRIBUTION IN HUMAN POPULATIONS?

- Biomonitoring of human populations suggests a highly positively skewed distribution of Penta-BDE concentrations; with 5-10% of individuals substantially more contaminated than the rest
- This consistent with the distribution in dust, less so for diet
- Simple, one-compartment steady-state pharmacokinetic models that attempt to relate external and internal exposures, suggest dust ingestion to be the major exposure pathway of Americans to PBDEs and to contribute ~25% of UK adult body burdens of HBCDs

Abdallah and Harrad, Environ Int (2011) 37, 443-448
Lorber, J Exp Sci Environ Epi (2008) 18, 2-19
Sjödin et al, EST (2008) 42, 1377–1384
van Bavel et al Organohalogen Compd. 2002, 58, 161-164.

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HOW DO BFRs IN DUST TRANSFER TO HUMANS?

- Current thinking suggests it occurs via contact with dust, with exposure occurring via incidental ingestion, or via dermal absorption from dust; or direct contact with FR-treated items
- Frequent hand washing (>4 times/day) appears to reduce exposure - Penta-BDE in serum of frequent handwashers 3x less
- Intuitively, observation suggests young children indulge more frequently in hand-to-mouth behaviour than adults
- And (admittedly VERY uncertain) figures used for dust ingestion imply greater dust ingestion by toddlers than adults
- NO dust-serum correlation for office workers, but YES for kids

Stapleton et al, EST (2008) 42, 3329-3334
Watkins et al, EHP in press
Stapleton et al Dioxin 2011

EXPOSURE OF CHILDREN – BODY BURDEN PICTURE

- FRs in dust transfer to hands and children indulge in more frequent hand-to-mouth behaviour, but what are implications for body burdens?
- Limited data available are consistent with higher exposures of young children
- Higher Penta-BDE in 0-4 year olds than adults in Norway
- Highest Penta-BDE in 2.6-3 year olds in Australian population
- Californian children have three times higher Penta-BDE than their mothers & levels of BDE 47 peak in US 4-6 year olds
- Evidence suggests that elevated exposure is post natal

Thomsen et al, J. Chrom. B (2007) 846, 252–263.
Toms et al, EHP (2009) 117, 1461–1465.
Eskenazi et al EHP (in press)
Sjödin et al, Dx2011
Webster et al, Dx2011

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HOW, WHEN & WHERE ARE CHILDREN EXPOSED?

- *Via* breast milk
- *In utero* – reports of PBDEs in human cord blood, placenta & fetal liver
- Via diet – note that children ingest more food than adults normalised to body weight
- Via inhalation (primarily of indoor air)
- Via contact with indoor dust
- Indoor exposures shown to occur in homes, cars, and schools/nurseries

Harrad et al EST (2010) 44, 4198-4202
Rawn et al, Dioxin 2011

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SHOULD WE BE CONCERNED?

- For HBCD - recent EFSA statement concluded "that current dietary exposure in the EU does not raise a health concern. Also additional exposure, particularly of young children, from house dust is unlikely to raise a health concern." *Degradation products??*
- For BDE-99, high-end exposure estimate for UK children exceeds 10-fold a recently published HBLV of 0.23-0.30 ng/kg bw/d (impaired spermatogenesis). "Typical" exposure estimate is 20-25% of the HBLV. *North American exposure?*
- For BDE-209, high-end exposure estimate for UK children is double USEPA RfD of 7 µg/kg bw/d (neurotoxicity).

Bakker et al Mol. Nutr. Food Res. 2008, 52, 204–216.
Harrad et al EST (2010) 44, 4198-4202
www.efsa.europa.eu/en/efsajournal/pub/2296.htm?WT.mc_id=EFSAHL01&emt=1
USEPA cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid)190307

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FUTURE EXPOSURE ARISING FROM INDOOR CONTAMINATION

- In addition to *direct* exposure, current indoor reservoir of BFRs like PBDEs has implications for future exposure
- This via releases during both use ***and disposal***
- Currently, around 20 million t e-waste generated annually

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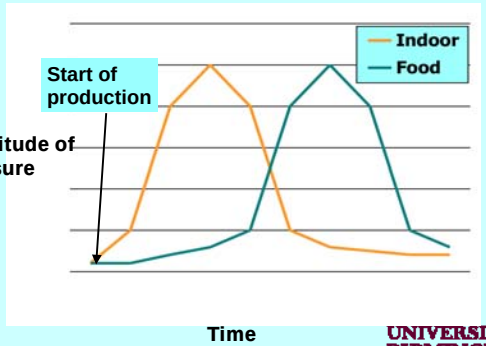
FUTURE EXPOSURE SCENARIO FOR POPs WITH INDOOR APPLICATIONS



Harrad & Diamond (2006) *Atmos Environ*, 40: 1187-1188

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CONCLUSION

- While the exposure pathways (dietary etc) identified by Carson remain relevant & progress made (Stockholm Convention), contemporary picture is more complex
- Real challenges ahead in controlling exposure arising from legacy of BFRs remaining in use and from those in waste stream
- Also exposure to replacements of PBDEs & HBCDs – NBFRs & OPFRs (chlorinated organophosphates like tris-(1,3-dichloro-2-propyl) phosphate & tris-(1-chloro-2-propyl) phosphate – present at high μg g^{-1} levels in house dust)
- WATCH THIS SPACE!

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