中国典型污染区域居民二噁英类膳食暴露研究进展

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摘要 二噁英(PCDD/Fs)和类二噁英多氯联苯(dl-PCBs)统称为二噁英类, 因其对人体健康和环境的危害而受到人们的广泛关注. 二噁英类作为副产物在废弃物焚烧、金属冶炼、非受控燃烧等热过程以及制浆造纸等化工生产中生成, 也存在于含多氯联苯(PCBs)的电力设备中. 释放到环境中的二噁英类能够进入食物链, 并在食物链中蓄积放大, 进而对人体健康造成危害. 对现有文献进行调研发现, 我国电子垃圾拆解地和化工厂作为二噁英类污染源其周边膳食中PCDD/Fs和dl-PCBs含量显著高于对照区域. 基于此, 本文综述了我国电子垃圾拆解地和化工厂周边膳食中PCDD/Fs和dl-PCBs的污染水平, 评估了当地居民二噁英类膳食暴露的风险.

关键词 二噁英, 类二噁英多氯联苯, 污染源, 污染水平, 膳食暴露

多氯代二苯并-对-二噁英(PCDDs)、多氯代二苯并呋喃(PCDFs)和类二噁英多氯联苯(dl-PCBs)因具有相似的结构和毒性特征, 统称为二噁英类. 它们作为持久性有机污染物(POPs), 具有高毒性、长期残留性、半挥发性和高脂溶性的特征, 可以在食物链中富集放大, 并且能够通过多种传输途径在全球迁移分配, 对人体健康和生态环境具有严重的危害^[1,2].

人类的生产活动是PCDD/Fs和dl-PCBs的主要来源. 人类并未有意生产过PCDD/Fs, PCDD/Fs主要作为副产物在多种工业热过程及化工生产中无意生成^[3]. 我国二噁英类的排放源主要涉及钢铁冶炼、再生有色金属生产、废弃物焚烧、火力发电、燃煤和燃油工业锅炉、含氯化学品的生产、制浆造纸、水泥窑共处置固体废物、遗体火化等近60个工业行业, 也有来自露天焚烧秸秆和废物、森林和草原火灾等^[4]. 含多氯联苯(PCBs)电力设施中PCBs的泄露以及对废弃含PCBs电力设施的不当处理是导致dl-PCBs环境污染的重要来源. dl-PCBs也可作为副产物在焚烧等

热过程中随PCDD/Fs无意生成, 并排放到环境中. 但并非所有PCDD/Fs和PCBs的产生都来自人类活动, 一些自然现象如森林火灾也会导致PCDD/Fs和PCBs的生成^[4]. 此外, 高岭土中PCDD/Fs和dl-PCBs含量较高, 可能与火山等地质活动有关^[5,6].

食物链中的PCDD/Fs和dl-PCBs既可来自污染源的直接排放(空气途径), 也可经由受污染的水、土壤、底泥等介质的传输. 由于PCDD/Fs和dl-PCBs难溶于水, 水体中PCDD/Fs和dl-PCBs含量较低; 又由于PCDD/Fs和dl-PCBs较难挥发, 空气中PCDD/Fs和dl-PCBs含量较低, 除非特殊的职业人群, 一般可以忽略通过呼吸途径暴露二噁英类. 正是因为PCDD/Fs和dl-PCBs具有亲脂性的特点, 致使其在脂肪含量较高的动物源性食物中, 如肉类、鱼类、奶制品、蛋类等含量较高^[7].

为了减少人体经膳食对二噁英类的暴露, 许多国家和地区对食物中PCDD/Fs和dl-PCBs的含量(以毒性当量(TEQ)值计算)进行了限定. 1998年, 世界卫

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Dong S J, Liu G R, Zhu Q Q, et al. Dietary intake of dioxins and dioxin-like PCBs by residents at two typical sites in China: A review (in Chinese). Chin Sci Bull, 2016, 61: 1336–1343, doi: 10.1360/N972016-00045

生组织(WHO)提出人体对PCDD/Fs和dl-PCBs的每日容许摄入量(TDI)为 $1\sim 4\text{ pg WHO-TEQ kg}^{-1}\text{ 体重(bw)}$ 每天(d^{-1})^[8]。2001年, 欧盟食品科学委员会(EC SCF)提出人体对PCDD/Fs和dl-PCBs的每周容许摄入量(TWI)为 $14\text{ pg WHO-TEQ kg}^{-1}\text{ bw}$ 每周(w^{-1})(http://europa.eu.int/comm/food/fs/sc/scf/index_en.html)。同年, 联合国粮农组织(FAO)/WHO食品添加剂联合委员会(JECFA)提出PCDD/Fs和dl-PCBs的人体暂定每月容许摄入量(PTMI)为 $70\text{ pg WHO-TEQ kg}^{-1}\text{ bw}$ 每月(m^{-1})(http://www.who.int/foodsafety/areas_work/chemical-risks/jecfa/en/)。2006年, 欧盟(EU)发布法规(No 1881/2006)中规定了多种食物中PCDD/Fs, 以及PCDD/Fs和dl-PCBs的最大允许限量(MLs)(<http://data.europa.eu/eli/reg/2006/1881/oj>)。

国内外研究表明, 一些二噁英类排放源周边环境介质中PCDD/Fs和dl-PCBs具有较高的污染水平^[9~11]。然而, 我国有关二噁英类污染源周边膳食中PCDD/Fs和dl-PCBs含量的研究相对较少。Chan和Wong^[12]与Song和Li^[13]的综述研究表明, 我国电子垃圾拆解地空气、土壤、生物等环境介质中PCDD/Fs等污染物含量高于对照区域, 膳食暴露是当地居民PCDD/Fs等污染物的主要暴露途径。我国废旧的氯碱厂和五氯酚厂等化工厂作为二噁英类排放源, 其周边环境介质中PCDD/Fs和dl-PCBs含量高于对照区域^[14~17]。此外, 20世纪50年代中期, 我国长江流域南部多省为了防止血吸虫病的流行, 广泛使用五氯酚作为杀灭血吸虫宿主钉螺的杀虫剂, 致使这些区域环境介质中PCDD/Fs等污染物含量高于对照区域^[18]。本文以电子垃圾拆解地和化工厂这两类二噁英类污染源为研究对象, 综述了现有文献中关于我国这两类污染源周边膳食中PCDD/Fs和dl-PCBs含量的研究, 并与我国一般人群PCDD/Fs和dl-PCBs膳食暴露水平比较, 评估了当地人群PCDD/Fs和dl-PCBs膳食暴露风险。

1 电子垃圾拆解地居民PCDD/Fs和dl-PCBs膳食暴露水平

我国曾是全球最大的电子垃圾(e-waste)进口国, 曾有大量的国内外电子垃圾集中在浙江省的台州地区、广东省汕头市的贵屿镇和广东省清远市的龙塘镇做简易分选处理^[12,19], 在简易焚烧电子垃圾分选回收金属的同时会有大量PCDD/Fs和dl-PCBs排放到环

境中。20世纪80年代末期浙江省温州还发生因拆解含PCBs电容器而导致PCBs环境污染的严重事件。现有大量研究对台州和贵屿两地多种环境介质中PCDD/Fs, PCBs等POPs的污染水平进行分析测试^[12,20~23]。龙塘环境介质中二噁英类污染水平研究相对较少。路风辉等人^[24]研究发现, 龙塘电子垃圾、残渣和池塘沉积物中PCBs含量高于对照区域2~3个数量级。

Chan等人^[12]归纳总结了现有文献有关台州和贵屿空气、土壤、沉积物、尘土、食物等环境介质中PCDD/Fs污染水平的报道, 发现膳食是台州成人、儿童和婴儿摄入PCDD/Fs的最主要途径, 其次为呼吸摄入。计算得出成人、儿童和婴儿经呼吸、皮肤接触、土壤/尘土以及膳食对PCDD/Fs的总摄入量为 $5.59\sim 105.16\text{ pg WHO-TEQ kg}^{-1}\text{ bw d}^{-1}$, 此数值远高于WHO TDI($1\sim 4\text{ pg WHO-TEQ kg}^{-1}\text{ bw d}^{-1}$)。由于缺少贵屿膳食中PCDD/Fs污染水平的相关研究, 计算中假设贵屿膳食中PCDD/Fs含量与台州相当。

Chan等人^[25]将在浙江省台州市路桥区西北部245 km远的杭州市下辖市临安市作为参照, 以哺乳期女性为研究对象, 对比研究了路桥和临安两地母乳等人体组织样品中PCDD/Fs含量。该研究结果表明, 路桥母乳中PCDD/Fs含量明显高于临安。路桥母乳($n=10$)中PCDD/Fs含量为 $21.02\text{ pg WHO-TEQ/g fat}$, 高于临安($9.35\text{ pg WHO-TEQ/g fat}$)。由母乳中PCDD/Fs含量计算得到路桥地区婴儿经母乳对PCDD/Fs的估算日摄入量(EDI)为 $102.98\text{ pg WHO-TEQ kg}^{-1}\text{ bw d}^{-1}$ 。

Zhao等人^[26]以台州西北部100 km远的平桥镇为参照, 考察了两地母乳和3种膳食(大米、鲫鱼、鸡蛋)中PCBs的含量。研究结果表明, 台州样品中PCBs含量远高于平桥, 其中台州母乳中PCB TEQs为 $25.99\text{ pg WHO-TEQ/g fat}$, 约为平桥母乳中PCBs含量($8.07\text{ pg WHO-TEQ/g fat}$)的3倍, 与Chan等人^[26]研究得到该地母乳中PCDD/F TEQs($21.02\text{ pg WHO-TEQ/g fat}$)相当。计算得出婴儿对dl-PCBs的EDI为 $127.35\text{ pg WHO-TEQ/kg bw/d}$ 。在台州的大米、鲫鱼和鸡蛋样品中, 鲫鱼中PCBs含量最高, 为 $1740\text{ pg WHO-TEQ/g dw}$, 而大米中PCBs含量($3.93\text{ pg WHO-TEQ/g dw}$)最低。

Xing等人^[27]以临安为参照, 对路桥和临安两地淡水鱼、海鱼、甲壳类(虾、蟹、贝等)、肉类、内脏、蛋、大米、蔬菜和水果9类108种食物中PCBs的含量

进行对比研究. 该研究结果表明, 台州动物源性食物中PCBs含量远高于非动物源性食物. 淡水鱼中dl-PCBs含量最高(8.53 pg WHO-TEQ/g fw), 超过了欧盟最大允许限量(EU MLs, 3.0 pg WHO-TEQ/g fw, 以WHO-PCDD/F-PCB-TEQ 减 WHO-PCDD/F-TEQ 得出); 蔬菜中dl-PCBs含量最低, 有些样品中并未检测到dl-PCBs. 计算得出台州居民(60 kg bw)经膳食对dl-PCBs的EDI为9.78 pg WHO-TEQ kg⁻¹ bw d⁻¹, 远高于临安地区(0.73 pg WHO-TEQ kg⁻¹ bw d⁻¹). 动物源性食物是台州和临安两地居民PCDD/Fs和dl-PCBs膳食摄入的主要来源, 分别占dl-PCBs膳食摄入总量的84%和99%. 其中, 淡水鱼(40%)、甲壳类水生生物(24%)、鸭肝(18%)和大米(12%)是台州居民dl-PCBs膳食摄入量的主要贡献者; 临安淡水鱼为当地居民dl-PCBs膳食摄入量的最主要的贡献者, 约占dl-PCBs总膳食摄入量的99%. 由于两地居民水产品消费量较高, 且水产品中dl-PCBs含量较高, 因此两地居民经水产品对dl-PCBs的摄入量较高.

Song等人^[28]以距离台州市路桥区西北部200 km远, 且并未受到电子垃圾污染的杭州市余杭区为参照, 对比研究了路桥和余杭两地的6种膳食(大米、蔬菜、鸡、鸡蛋、鸭和鲫鱼)中PCDD/Fs和dl-PCBs的含量. 研究结果表明, 在路桥区所选膳食中PCDD/Fs和dl-PCBs的含量均远高于余杭区. 在路桥区的膳食中, 鲫鱼鱼肉中PCDD/Fs和dl-PCBs含量(10.87 pg WHO-TEQ/g fw)最高, 超过了EU MLs(8.0 pg WHO-TEQ/g fw), 其次为鸭肉(3.37 pg WHO-TEQ/g fw), 蔬菜中PCDD/Fs和dl-PCBs含量(0.022 pg WHO-TEQ/g fw)最低. 在余杭区, 鸭肉中PCDD/Fs和dl-PCBs含量(0.74 pg WHO-TEQ/g fw)最高, 而大米中含量(0.0002 pg WHO-TEQ/g fw)最低. 估算得出路桥区居民经膳食对于PCDD/Fs和dl-PCBs的EDI为13.42 pg WHO-TEQ bw/d, 高于余杭区(1.24 pg WHO-TEQ kg⁻¹ bw d⁻¹). 路桥区和余杭区居民经动物源性食物PCDD/Fs和dl-PCBs的摄入量分别为95.6%和98.77%, 植物源性食物PCDD/Fs和dl-PCBs摄入量不足5%. 路桥区居民经鲫鱼对PCDD/Fs和dl-PCBs摄入量最高, 约占膳食摄入总量的67.5%, 其次为鸭(11.7%)、蔬菜PCDD/Fs和dl-PCBs摄入量最低(2.8%); 余杭区居民经鲫鱼PCDD/Fs和dl-PCBs摄入量最高, 约占总量的36.6%, 大米PCDD/Fs和dl-PCBs摄入量最低(0.1%).

Labunska等人^[29]考察了台州鱼、虾、鸡肉、鸭肉、

猪肉、鸡肝、鸭肝、鸡蛋和鸭蛋中PCBs含量. 研究结果表明, 除猪肉外的台州样品中PCBs含量均高于对照组. 鱼肉中PCBs含量最高, 其次为鸭肉、鸭蛋和鸡蛋. 鸭肉和鸡肉中PCBs含量分别高于鸭肝和鸡肝. 该研究仅考察了12种dl-PCBs同类物的其中4种(CB 105, 118, 156和167), 其中鱼肉、鸡肉、鸭肉、鸡蛋和鸭蛋中dl-PCBs含量超过了EU MLs. 以WHO 2005-毒性当量因子(TEF)计算得出台州成人经膳食摄入dl-PCBs的EDI为2.83 pg WHO-TEQ kg⁻¹ bw d⁻¹, 儿童(14.65 kg bw)为10.22 pg WHO-TEQ kg⁻¹ bw d⁻¹. 该计算结果低于以WHO 1998-TEF计算结果, 即成人膳食摄入dl-PCBs的EDI为11.07 pg WHO-TEQ kg⁻¹ bw d⁻¹, 儿童为39.9 pg WHO-TEQ kg⁻¹ bw d⁻¹.

目前尚缺少有关广东贵屿膳食中PCDD/Fs污染水平的相关研究. Xing等人^[30]考察了贵屿的淡水鱼($n=7$)和母乳($n=19$)中PCBs的污染水平. 淡水鱼中dl-PCBs含量为0.04~2.02 pg WHO-TEQ/g fw, 母乳中dl-PCBs含量为0.68 pg WHO-TEQ/g fat. 计算得出当地人群经淡水鱼对dl-PCBs的EDI为0.71 pg WHO-TEQ kg⁻¹ bw d⁻¹, 远低于台州地区(9.78 pg WHO-TEQ kg⁻¹ bw d⁻¹)^[27]; 婴儿dl-PCBs母乳摄入量为3.33 pg WHO-TEQ kg⁻¹ bw d⁻¹, 低于台州地区(127.35 pg WHO-TEQ kg⁻¹ bw d⁻¹)^[26].

总而言之, 我国台州电子垃圾拆解地周边膳食中具有较高PCDD/Fs和dl-PCBs污染水平, 当地居民经膳食对PCDD/Fs和dl-PCBs的摄入量明显高于对照区域, 其中鱼类是当地人群PCDD/Fs和dl-PCBs膳食摄入量的主要贡献者. 针对贵屿电子垃圾拆解地周边膳食中PCDD/Fs和dl-PCBs污染水平的研究相对较少, 现有研究表明贵屿地区淡水鱼和母乳中dl-PCBs含量并不高, 当地人群dl-PCBs膳食暴露水平远低于台州地区.

2 化工厂周边居民PCDD/Fs和dl-PCBs膳食暴露水平

我国氯碱工业中曾采用石墨电极法生产氯气, 产生的固体废渣中含有大量PCDD/Fs^[31]. 位于湖北省武汉市东部的鸭耳湖湖畔有一个大型的氯碱工厂, 曾将氯碱废渣排入鸭儿湖中, 造成严重的环境污染. Wu等人^[15-17,32-35]针对鸭耳湖地区的多种环境样品进行了研究, 发现该地区底泥、土壤以及一些生物中含有较高浓度的PCDD/Fs和PCBs.

Wu等人^[16]于1997年采集了鸭耳湖地区的软体动物(螺、虾、蚌)、鱼、鸭蛋、食鱼鸟蛋、肥猪肉,并研究其中PCDD/Fs含量。食鱼鸟蛋、鸭蛋和鱼肝脏中PCDD/Fs含量较高,超过了EU MLs,可能会对对人体造成一定的健康风险;其中一个鱼肉样品中PCDD/Fs含量超过了EU MLs(4.0 pg/g fat),但鱼肉平均值低于EU MLs。肥猪肉中PCDD/Fs含量为0.25 pg/g fat, 低于EU MLs(1.0 pg/g fat)。作者认为肥猪肉中PCDD/Fs含量较低是由于猪的食物主要来自鸭儿湖外的地区,而其他生物样品受鸭儿湖底泥中PCDD/Fs的影响(鸭儿湖底泥中PCDD/Fs含量较高),并通过食物链累积,在食物链营养级较高的食鱼鸟的鸟蛋中含量较高。在鸭儿湖地区,鱼类是当地居民的主要蛋白质来源,当地居民鱼类的平均摄入量为200 g/d,鱼肉中平均脂肪含量为3.02%,PCDD/Fs含量为84.85 pg WHO-TEQ/g fat(以WHO 1998-TEF计算),计算得出鸭耳湖周边居民经鸭儿湖所产鱼类对PCDD/Fs的EDI为9.32 pg WHO-TEQ kg⁻¹ bw d⁻¹。鸭儿湖地区所产鸭蛋中PCDD/Fs含量较高,以蛋类平均摄入量25 g/d计算得出当地居民经鸭蛋对PCDD/Fs的EDI为22.62 pg WHO-TEQ kg⁻¹ bw d⁻¹。

五氯酚及其钠盐的生产被认为是环境中PCDD/Fs的一个重要的历史来源,PCDD/Fs可以作为副产物在五氯酚及其钠盐的生产过程中无意产生^[36]。20世纪50年代中期,我国长江流域南部多省血吸虫病流行,五氯酚及其钠盐被广泛用来杀灭血吸虫的宿主钉螺,致使这些区域环境介质中五氯酚、PCDD/Fs等污染物含量高于对照区域^[18]。虽然我国已禁止五氯酚的生产和使用,但历史遗留的五氯酚及其钠盐生产厂周边或者曾经大量施用五氯酚钠的地区(如洞庭湖)空气、土壤、底泥、水体等环境介质和人体组织中具有较高的PCDD/Fs含量^[14,37~39]。然而,我国关于五氯酚及其钠盐污染区域膳食中PCDD/Fs污染水平的研究较少。Fang等人^[40]研究表明,洞庭湖地区鸟蛋中PCDD/Fs含量低于鸟蛋中PCDD/Fs的毒性阈值标准。Gao等人^[41]研究发现尽管洞庭湖水体中PCDD/Fs含量高于US EPA相关标准,但鱼类中PCDD/Fs含量低于EU限量标准。

以上研究表明,受历史二噁英类排放源氯碱工厂的影响,鸭儿湖底泥中具有较高的二噁英类污染水平,进而影响到鸭儿湖地区膳食中PCDD/Fs具有较高的污染水平,当地人群经鱼类和鸭蛋摄入

PCDD/Fs的暴露水平较高。有关五氯酚及其钠盐污染区域膳食中PCDD/Fs和dl-PCBs污染水平的研究亟待开展。

3 我国典型污染区域居民二噁英类膳食暴露风险

2000, 2007和2011年的中国总膳食研究(CTDS)结果表明,我国大陆地区一般人群PCDD/Fs和dl-PCBs膳食暴露水平分别为0.52, 0.71和0.67 pg WHO-TEQ kg⁻¹ bw d⁻¹, 均低于WHO TDI的最低值(1 pg WHO-TEQ kg⁻¹ bw d⁻¹),说明我国大陆一般人群膳食摄入PCDD/Fs和dl-PCBs的风险较低^[7,42,43]。2011年的香港总膳食研究(FEHD)表明,香港一般人群PCDD/Fs和dl-PCBs膳食摄入量为0.73 pg WHO-TEQ kg⁻¹ bw d⁻¹,与大陆地区一般人群PCDD/Fs和dl-PCBs膳食摄入量相当,低于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹)最低值,说明香港一般人群膳食摄入PCDD/Fs和dl-PCBs的风险较低;香港膳食高消费人群PCDD/Fs和dl-PCBs膳食摄入量为1.99 pg WHO-TEQ kg⁻¹ bw d⁻¹,高于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹)最低值,说明香港膳食高消费人群可能具有PCDD/Fs和dl-PCBs膳食摄入的风险^[44]。2007年,我国大陆地区母乳中PCDD/Fs和dl-PCBs含量调查研究表明,我国一般地区婴儿经母乳对PCDD/Fs和dl-PCBs的摄入量为28.0 pg WHO-TEQ kg⁻¹ bw d⁻¹,低于发达国家婴儿经母乳对PCDD/Fs和dl-PCBs的摄入量^[45]。

台州居民经膳食摄入PCDD/Fs或dl-PCBs的水平均高于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹)的最高值,也高于EC SCF TWI(14 pg WHO-TEQ kg⁻¹ bw d⁻¹)和JECFA PTMI(70 pg WHO-TEQ kg⁻¹ bw m⁻¹),表明当地居民膳食摄入PCDD/Fs和dl-PCBs的健康风险较高(表1)。当地婴儿经母乳对PCDD/Fs和dl-PCBs摄入量约是我国一般婴儿的7倍,远高于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹)的最高值,说明当地婴儿经母乳摄入PCDD/Fs和dl-PCBs可能具有一定的健康风险。

广东贵屿电子垃圾拆解地居民膳食摄入dl-PCBs的水平低于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹),婴儿经母乳对dl-PCBs的摄入量也低于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹)的最低值,说明当地居民膳食摄入dl-PCBs的健康风险较低。然而,由于缺乏

表 1 中国一般人群和受污染区域人群PCDD/Fs和dl-PCBs膳食暴露水平比较^{a)}

Table 1 Comparison on dietary exposure of average consumers and polluted area residents to PCDD/Fs and dl-PCBs

名称	二噁英类 化合物	食物种类	人群	TDI (pg WHO-TEQ kg ⁻¹ bw d ⁻¹)	TWI (pg WHO-TEQ kg ⁻¹ bw w ⁻¹)	PTMI (pg WHO-TEQ kg ⁻¹ bw m ⁻¹)	参考 文献
CTDS 2000	PCDD/Fs 和 dl-PCBs	水产品、肉及肉类制品、蛋及蛋类 制品、原奶及奶制品	成人	0.52	3.64	15.6	[7]
CTDS 2007	PCDD/Fs 和 dl-PCBs	水产品、肉类及肉制品、蛋类及蛋 制品、原奶及奶制品、谷类、豆 类制品、马铃薯、蔬菜	成人 儿童	0.71 1.08	4.97 7.58	21.3 32.5	[42]
CTDS 2011	PCDD/Fs 和 dl-PCBs	水产品、肉类及肉制品、蛋类及蛋 制品、原奶及奶制品、谷类、豆 类制品、马铃薯、蔬菜	成人	0.67	4.69	20.1	[43]
香港 FEHD	PCDD/Fs 和 dl-PCBs	谷物及谷物制品、肉类、家禽和野 味及其制品、蛋及蛋类制品、鱼 类和海产品及其制品、乳类制 品、油脂类、不含酒精饮品、混 合食品、其他	成人(一般 人群) 成人(膳食 高消费人 群)	0.73 1.99	5.11 13.9	21.9 59.6	[44]
中国母乳 中二噁英 类调查 (2007)	PCDD/Fs 和 dl-PCBs	母乳	婴儿	28.0	—	—	[45]
台州	PCDD/Fs dl-PCBs	母乳	婴儿	102.98 127.35	— —	— —	[25] [26]
	dl-PCBs	淡水鱼、海鱼、甲壳类(虾、蟹、 贝等)、肉类、内脏、蛋、大米、 蔬菜、水果	成人	9.78	68.5	293	[27]
	PCDD/Fs 和 dl-PCBs	大米、蔬菜、鸭、鸡、鸡蛋、鲫鱼	成人	13.42	93.74	401.8	[28]
	dl-PCBs	鱼、虾、鸡肉、鸭肉、猪肉、鸡肝、 鸭肝、鸡蛋、鸭蛋	成人 儿童	2.83 10.22	19.8 71.54	84.9 306.6	[29]
贵屿	dl-PCBs	淡水鱼	成人	0.71	4.97	21.3	[30]
		母乳	婴儿	3.33	—	—	
鸭儿湖	PCDD/Fs	鱼	成人	9.32	65.2	280	[15]
国际标准	PCDD/Fs 和 dl-PCBs	—	—	1~4	14	70	[8]

a) 以WHO 1998-TEF计算

贵屿地区膳食中PCDD/Fs含量的相关研究，而PCDD/Fs对总TEQ贡献较大，因此还需要对该地食物中PCDD/Fs含量进行考察，进而评估当地人群二噁英类膳食暴露风险。

鸭儿湖周边居民经鱼类和鸭蛋摄入PCDD/Fs的水平高于WHO TDI(1~4 pg WHO-TEQ kg⁻¹ bw d⁻¹)的最高值，也高于EC SCF TWI(14 pg WHO-TEQ kg⁻¹ bw w⁻¹)和JECFA PTMI(70 pg WHO-TEQ kg⁻¹ bw m⁻¹)，表明当地居民经鸭儿湖所产鱼类和鸭蛋摄入PCDD/Fs而引发的健康风险较高。

总之，我国一般人群二噁英类膳食暴露风险较低，膳食高消费人群可能存在一定的二噁英类膳食

暴露风险，儿童和婴儿二噁英类膳食暴露风险高于成人。台州和鸭儿湖受污染区域居民二噁英类膳食暴露水平显著高于我国一般人群以及相关国际标准，其膳食摄入二噁英类的健康风险较高。

4 小结

目前我国一般地区食物中PCDD/Fs和dl-PCBs含量较低，我国一般人群膳食摄入PCDD/Fs和dl-PCBs的健康风险也较低。电子垃圾拆解地作为二噁英类污染源其周边膳食中PCDD/Fs和dl-PCBs具有较高的污染水平，当地人群二噁英类膳食暴露量超过了国际组织的相关标准，表明可能存在一定的健康风险，

需要给予特别关注。目前尚缺少贵屿地区食物中PCDD/Fs污染水平的相关研究,以及鸭儿湖周边食物中dl-PCBs污染水平的相关数据,且现有研究所考察贵屿地区和鸭儿湖周边的食物种类和数量有限,更

为深入和广泛的研究还有待开展。此外,由于我国二噁英类排放源众多,有必要开展我国主要二噁英类排放源区域识别及其周边膳食中二噁英类污染水平的相关研究,评估当地人群二噁英类膳食暴露风险。

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Dietary intake of dioxins and dioxin-like PCBs by residents at two typical sites in China: A review

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Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (dl-PCBs) are referred to as dioxin-like compounds due to their structural similarity. There have been increasing concerns about dioxin-like compounds because they are highly toxic and persistent compounds that may be harmful to human health and the environment. PCDD/Fs and dl-PCBs can be unintentionally produced as byproducts from certain thermal processes such as waste incineration, metal smelting and open burning as well as from manufacture of certain chemicals and pulp and paper production. They can also be found in electrical equipment containing polychlorinated biphenyls (PCBs). PCDD/Fs and dl-PCBs released in the environment can accumulate in the food chain. Human exposure to PCDD/Fs and dl-PCBs mainly through the dietary intake. This paper presents an overview on the available literatures on PCDD/F and dl-PCB levels in foodstuffs at dioxin-like compound polluted sites in China. Although various dioxin-like compound sources in China have been reported and relatively high levels of PCDD/Fs and dl-PCBs were found in the environmental matrices near dioxin-like compound sources, data on PCDD/F and dl-PCB concentrations in foodstuffs in dioxin-like compound polluted areas in China were relatively few. PCDD/Fs and dl-PCBs were found higher levels in the foodstuffs at E-waste recycling sites such as Taizhou in Zhejiang Province and Guiyu in Guangdong Province than the control areas. Moreover, higher levels of PCDD/Fs were also found in foodstuffs in Ya-Er lake than the control area because the water of Ya-Er lake had been continuously polluted by a chemical factory situated on the bank of the lake. It is estimated that dietary intake of PCDD/Fs and dl-PCBs by the residents at the two typical dioxin-like compound polluted sites exceeded the international limits and were also higher than the average consumer dietary intake of PCDD/Fs and dl-PCBs in China. It indicates that the residents at the two typical dioxin-like compound polluted sites in China may have health risks. Therefore, more attention should be attracted on the human health risks at dioxin-like compound polluted areas in China. Large scale investigation on PCDD/F and dl-PCB levels in foodstuffs in various dioxin-like compound polluted areas in China is needed to be conducted.

PCDD/Fs, dl-PCBs, emission source, concentration, dietary exposure

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