

上海市大气颗粒物污染防治
重点实验室

——2022——
年度报告

一、重点实验室介绍

上海市大气颗粒物污染防治重点实验室于 2012 年 10 月获得上海市科学技术委员会批准筹建，于 2014 年 12 月通过市科委验收。重点实验室由复旦大学和上海市环境科学研究院以“校地联合”模式建设，推动基础研究与环境管理的有效衔接。实验室整合上海大气环境领域的主体研究力量，借助完备的仪器设备和先进的大气物理化学研究手段，紧密围绕“大气颗粒物污染防治”的措施与技术，系统深入的开展大气颗粒态污染物形成机制研究，研发先进的大气颗粒污染物监测仪器，探索大气颗粒物污染与人体健康的关系，为上海市大气颗粒污染防治及空气质量管理提供有效的技术支撑和决策依据，并在全国 $\text{PM}_{2.5}$ 污染防控中起到引领和示范作用。

重点实验室现拥有 64 名固定科研人员，其中正高研究人员 39 名，包括中科院院士 2 人，国家自然科学基金委杰出青年 2 人，教育部长江学者 3 人，国家自然科学基金委优秀青年 3 人，国家青年千人 5 人，教育部新世纪人才 7 人，上海市优秀学术带头人 3 人，上海东方学者 3 人，上海浦江学者 6 人。重点实验室现拥有实验室面积 5500 平米，大型先进科学仪器总价值 4000 余万元。重点实验室已在 *Science*、*Chemical Reviews* 等期刊发表 SCI 论文 580 篇。重点实验室每年资助 5~8 项开放课题，连续举办三届“中欧大气化学暑期学校”，重视与国内外科科研单位的学术合作、交流及人才联合培养。

郝吉明院士为重点实验室学术委员会主任，陈建民教授为重点实验室主任。

二、主要研究方向

I. 大气颗粒物污染形成的关键过程

主要利用多种实验分析技术手段，解析大气颗粒物的化学组分、混合态及光学性质，研究大气颗粒物的生成、增长、老化以及灰霾污染形成机制。研究重点：(1)新颗粒物的形成和生长机制，尤其是中国高颗粒物浓度下频繁的新粒子生成机制；(2)气溶胶微物理与化学过程；(3)颗粒物及其前体物的排放清单，向政府提供大气污染防治政策建议。该研究方向的学术带头人为王琳教授。

II. 大气污染物分布、传输与空气质量

通过多个监测点长期外场观测(包括地面观测、高山云雾观测和铁塔观测)，结合激光雷达、卫星遥感资料，并进行实验室数值模拟，对大气污染物的时间空间分布和物理化学性质进行系统研究，从宏观角度了解污染物的分布、传输以及大气气溶胶对空气质量和全球变化的影响。研究重点：(1)大气污染物的化学组成、来源、示踪及环境影响；(2)大气污染与城市边界层；(3)大气污染的传输模拟。该研究方向的学术带头人为陈莹教授。

III. 大气污染对人体健康的影响

结合外场观测、实验模拟和流行病学调查，针对大气污染物的时空演变与疾病发生率的关系等进行研究，深入认识大气颗粒物污染对我国居民健康的影响，揭示出对健康影响最大的颗粒物的物理化学特征；研发日常应用预报方法，进行人体健康适度的预报，提出基于健康的环境政策管理建议。研究重点：(1)大气污染物源解析与居民健康效应的耦合研究；(2)大气污染对我国居民心肺疾病死亡和发病的人群流行病学研究。该研究方向的学术带头人为阚海东教授。

IV. 大气污染探测及仪器研发与应用

对尖端大气污染探测仪器设备进行改进和开发应用，并探索基于物理、化学、生物等交叉学科技术的大气环境测量的新原理、新方法，旨在实现对大气气溶胶及污染物的实时、在线测量。主要开发的仪器有：(1)气溶胶烟雾舱；(2)差分光学吸收光谱仪 DOAS；(3)大气颗粒物毒性在线分析仪；(4)串联电迁移率差分扫描仪 TDMA；(5)光腔衰荡光谱测量仪 CRDS；(6)污染气体等离子体去除仪。该研究方向的学术带头人为周斌教授。

三、2022 年度典型案例

典型案例 1： 人才培养重要进展

本年度，重点实验室在人才培养方面获得重要进展，不仅通过海外人才引进和固有科研人员培养提升了四个研究领域的实力，还加强了对研究生和博士后的培养。

在科研骨干队伍建设上，2022 年度，重点实验室分别从芬兰赫尔辛基大学和新加坡南洋理工大学引进了青年研究员姚磊和方明亮教授。姚磊博士是重点实验室 2018 年培养的博士以及重点实验室首篇 *Science* 论文的第一作者，主要从事城市大气二次污染物形成机制、污染环境大气新粒子形成等研究，现为 *Frontiers in Environmental Science* 特刊编辑。方明亮教授主要研究化学品暴露以及环境健康，注重“暴露组学”方法开发，同时利用高分辨质谱代谢组学等系统生物学方法研究污染物毒性机理和蛋白靶点，现为 *Environmental Pollution* 副主编。重点实验室主任陈建民教授和学术带头人阚海东教授均入选了科睿唯安 2022 年度全球“高被引科学家”名单（交叉学科）。科研骨干宋卫华教授当选为英国皇家化学学会会士，也是重点实验室的第二位皇家化学学会会士。科研骨干王梓萌研究员获得了 James J. Morgan Early Career Award，该奖是国际环境科学与工程学界重要的青年科学家荣誉之一。

在博士后及研究生培养上，本年度，吴葑博士后入选了 2022 年度“博士后创新人才支持计划”；两位博士后邢晓帆和钱云坤荣获 2022 年上海市“超级博士后”激励计划资助；陈斌博士后成功入选中国生态学学会青年人才托举工程项目（2022-2024 年）资助人选；博士后黄小娟获批博士后面基金一等资助，也是大气科学学科唯一一等资助获得者，姜鸿兴、毛敬波和史志坚获批博士后面基金二等资助；博士研究生解伟入选了国家自然科学基金委员会与国际应用系统分析学会 2022 年度暑期青年科学家项目（IIASA-YSSP），于 2022 年 6 月-8 月赴奥地利维也纳开展合作研究。



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Article

Delayed use of bioenergy crops might threaten climate and food security

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Toxic potency-adjusted control of air pollution for solid fuel combustion

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The combustion of solid fuels, including coal and biomass, is a main anthropogenic source of atmospheric particulate matter (PM). The hidden costs have been underestimated due to lack of consideration of the toxicity of PM. Here we report the unequal contribution of solid fuels to PM emissions and PM-related toxicity. The toxicity of PM is determined by the combustion of solid fuels in household stoves generates much higher concentrations of carcinogenic matter, resulting in more than 100-fold higher PM-related toxicity than that of coal-fired power plants. The evidence further demonstrates that controlling only a tenth of toxic fuels in mainland China in 2017, but it contributed about 200-fold higher of the population-weighted toxicity reduction, compared with controlling 50% of total PM emissions. Our results suggest that PM emission control strategies, and incomplete combustion strategies should receive more policy attention to reduce respiratory and cardiovascular diseases.

The combustion of solid fuels has been recognized as the main anthropogenic emission source of particulate matter (PM) that elicits adverse effects on air quality and human health^{1–3}. Solid fuels, including coal and biomass, are the main source of direct energy used in industrial and residential sectors worldwide^{4–6}. In addition to PM emissions, PM-related toxicity is also a particularly cool-fired power plants (CFPPs) have received far less attention. PM emissions from CFPPs have greatly decreased in the past few decades in many regions due to phasing out of old units^{7–9}. However, PM control technology and strengthening policies enforcement^{10–12}. In contrast, the residential sector (including household coal and biomass combustion), as the largest source carrier of global PM, has been neglected for a long time. Residential solid fuel combustion has caused severe air pollution, which has contributed to 35% of the total premature deaths worldwide and can be the even worse in developing countries^{13–15}.

PM emissions from solid fuels combustion are much more toxic or particulate samples to reach the same level of effect on a population^{16–18}. The assessment of sources of PM emissions is an important metric because with mass emission in weighing the exposure risks between emission sources¹⁹. PM (PM₁₀) with aerodynamic diameter less than 2.5 μm) emitted in industrial sectors is much less toxic than PM emitted in residential sectors, even in the same amount^{20–22}. The toxicity of PM is determined by the combustion of solid fuels in household stoves generates much higher concentrations of carcinogenic matter, resulting in more than 100-fold higher PM-related toxicity than that of coal-fired power plants. The evidence further demonstrates that controlling only a tenth of toxic fuels in mainland China in 2017, but it contributed about 200-fold higher of the population-weighted toxicity reduction, compared with controlling 50% of total PM emissions. Our results suggest that PM emission control strategies, and incomplete combustion strategies should receive more policy attention to reduce respiratory and cardiovascular diseases.

current understanding of PM exposure and the devising of air pollution control policies.

This study proposes toxicity-adjusted control of air pollution, by considering the toxicity of source-oriented PM, using solid fuel combustion in the residential and power plant sectors as the example. The toxicity of PM is determined by the combustion of solid fuels in household stoves generates much higher concentrations of carcinogenic matter, resulting in more than 100-fold higher PM-related toxicity than that of coal-fired power plants. The evidence further demonstrates that controlling only a tenth of toxic fuels in mainland China in 2017, but it contributed about 200-fold higher of the population-weighted toxicity reduction, compared with controlling 50% of total PM emissions. Our results suggest that PM emission control strategies, and incomplete combustion strategies should receive more policy attention to reduce respiratory and cardiovascular diseases.

Results and discussion

Real-world PM₁₀ emission profiles. The emission factors (EFs) (the quantity of pollutants released to the ambient air per unit of fuel consumed) are the most commonly used parameters to estimate real-world PM emissions^{23–25}. The EFs of PM₁₀ from coal-fired power plants range from 24 to 324 kg tonnes higher than those from CFPPs that meet the stricter industrial emission (ULI) standards in China (Fig. 1a). The EFs of PM₁₀ from coal-fired power plants are estimated with weighting factors for coal consumption (Supplementary Note 7). The EFs of PM₁₀ from coal-fired power plants are estimated with weighting factors for coal consumption (Supplementary Note 7). The EFs of PM₁₀ from coal-fired power plants are estimated with weighting factors for coal consumption (Supplementary Note 7). The EFs of PM₁₀ from coal-fired power plants are estimated with weighting factors for coal consumption (Supplementary Note 7).

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Significantly accelerated photochemical and photocatalytic reactions in microdroplets

Bulk phase

Microdroplet

Li et al. study photochemistry and photocatalysis in microdroplets using micro-Raman spectroscopy. The photooxidation of organic compounds exponentially increases with decreasing microdroplet diameter, which is attributed to the special air-water interface properties of the microdroplets, including O_2 accessibility enhancement, pH alteration, and species interfacial enrichment.

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Highlights

Photochemistry and photocatalysis are studied in microdroplets of varying diameters

Organic degradation exponentially increases with decreasing the microdroplet size

O_2 availability is improved in microdroplets

pH alteration and species interfacial enrichment are observed via SRS chemical imaging

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四、2022 年度代表性论文

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以上论文的通讯作者均有本重点实验室固定研究人员，且均标注了重点实验室。

五、2022 年度年终总结

研究成果

2022 年，重点实验室在从气溶胶微观理化性质研究，到气溶胶健康效应及风险暴露研究，到能源与气候变化研究，在大气环境相关的各个前沿学术领域均取得了高质量的研究成果，高水平学术论文产出方面创下新高，共正式发表学术论文 210 篇，其中 SCI 论文 193 篇（包括 *Nature* 正刊论文 1 篇、*PNAS* 论文 2 篇、*PNAS* 评论性短文 1 篇、*Nature Energy* 论文 1 篇、*Nature Communications* 论文 2 篇、*Cell Reports Physical Science* 论文 1 篇等）。在气溶胶微观理化性质研究方面，主要是探索了海洋飞沫气溶胶的气泡破裂的膜滴产生机理，发现了微液滴中的光化学反应加速机制等；在气溶胶健康效应及风险暴露研究方面，主要融合源排放 $\text{PM}_{2.5}$ 毒理参数、排放清单和人口权重，提出以气溶胶毒理效应为指标的精准控制理念；在能源与气候变化研究方面，发现了未来气候变暖可影响城市整体经济发展，揭示了全球未来能源、技术、气候、农业的相互作用和反馈机制。此外，除了学术论文外，重点实验室在本年度还有 3 项发明专利获得了授权。

队伍建设与人才培养

2022 年重点实验室在各个研究方向上的优秀骨干人才和研究生及博士后人才培养上均积极发展。具体地，主任陈建民教授和学术带头人阚海东教授均入选科睿唯安 2022 年度全球“高被引科学家”名单（交叉学科）。科研骨干宋卫华教授当选为英国皇家化学学会会士，也是重点实验室第二位皇家化学学会会士。科研骨干王梓萌研究员获得了 James J. Morgan Early Career Award。又分别从芬兰赫尔辛基大学和新加坡南洋理工大学引进了青年研究员姚磊（青年长江）和方明亮教授（青年千人），增强了科研团队的实力。在研究生培养方面，2022 年重点实验室毕业博士生 25 人，硕士生 20 人，在读博士研究生解伟入选了国家自然科学基金委员会与国际应用系统分析学会 2022 年度暑期青年科学家项目。本年度重点实验室在博士后培养方面也取得突破性进展，37 位在站博士后中，1 人入选 2022 年度博士后创新人才支持计划，2 人荣获 2022 年上海市超级博士后激励计划资助，1 人成功入选中国生态学学会青年人才托举工程项目资助人选；1 人获

批博士后面基金一等资助，也是今年大气科学学科唯一一等资助获得者，另有 3 人获批博士后面基金二等资助。

开放交流与运行管理

在开放交流方面，在研和结题的开放课题在 2022 年发表了相关的学术论文 27 篇，创历年最多，其中 SCI 论文 21 篇，包括了多篇在 EP、JGR:Atmosphere 等一区期刊上发表的论文。重点实验室注重社会服务，与山东省泰安市生态环境局组建的“一市一策”驻点跟踪研究工作组，在保障泰安市细颗粒物与臭氧污染协同防治跟踪研究工作中取得了优异的成绩，2022 年，泰安市的空气质量改善排名在全国 168 个重点城市中列第 8 位。在学术交流方面，重点实验室在本年度加强了与上海大学有机复合污染控制工程教育部重点实验室、上海市环科院国家环境保护城市大气复合污染成因与防治重点实验室、江苏省大气环境监测与污染控制高技术研究重点实验室等长三角地区兄弟平台的紧密合作。联合主办了 International Workshop on Air Pollution and Climate Change 和学术委员会联席会议。运行管理方面，重点实验室严格依循实验室各项管理制度，针对由大气超级站、中国大气颗粒物样品库、地面气象站、室外动物暴露舱以及野外观测站等共同组成的平台组合，完善平台仪器使用管理的新的规章制度。

依托单位支撑和保障情况

依托单位复旦大学持续在建设运行经费、实验室场地、人才引进及团队建设等多方面给予大力支持，保障实验室的顺利运行。