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Human Exposure to Dioxins and Other Contaminants Following an Accidental Fire at the Fiumicino Airport (Italy): A Public Health Response

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Abstract: In May 2015, a fire occurred at Terminal 3 of the Rome–Fiumicino International Airport. To respond to the health concern associated with the resulting emissions of combustion products, Pier D of Terminal 3 underwent a pre-emptive sequestration. The Italian National Institute of Health was asked to carry out environmental monitoring of the affected areas, and to evaluate the related risk for health. Polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) were measured in air samples in the pre- and post-remediation phases. Results showed a decrease of 44% of the cumulative concentrations at Pier D after the remediation operations compared to those detected before. The human exposure assessment carried out after the remediation operations confirmed that there were no risks for people in the Terminal which was then reopened. Due to the lack of quality limit values or Italian national guidelines for indoor air, WHO air quality guidelines or legislative/guidance documents of other European countries were considered for the air quality assessment.

Keywords: airport; indoor air; fire; dioxins; PCBs; PAHs; environmental monitoring; health risk assessment

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1. Introduction

Unintentional fires can lead to emissions of persistent organic pollutants (POPs), such as polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs), as a result of uncontrolled combustion depending on the involved materials, the nature of the fire and the environmental conditions [1,2]. Such pollutants are associated with several adverse health effects [3,4] and are classified as known human carcinogens (Group 1) by the International Agency for Research on Cancer (IARC) [5–7].

When accidental fires involve public buildings, risks for people associated with the possible exposure to such contaminants should be properly assessed and remediation actions carried out before reopening the buildings to the public. In 1979, a fire occurred in an office building in Washington DC involving a basement transformer with the consequent releasing of PCDDs, PCDFs and PCBs. Before the building could be reoccupied, appropriate cleanup actions and analytical measurements of dioxin contamination were provided in order to guarantee no risks for public health [8]. In many countries, appropriate guidelines are provided in order to assist the public health response in case of major fires. In New Zealand, the Public Health Unit has prepared specific guidelines focused on industrial and forest fires, providing an overview of the types of contaminants released during fires and information on sampling, analysis of air samples and interpreting the sampling results by comparison against ambient air quality guidelines or national environmental standards [9]. In the United Kingdom, an environmental monitoring of air quality following the Grenfell

Tower fire was assigned to the UK Health Security Agency (UKHSA) (formerly Public Health England), which compared the results for PCDDs, PCDFs, DL-PCBs and PAHs to background levels for London to understand if there is a risk to public health [10].

A proper indoor and outdoor air monitoring strategy involves the study and development of a number of aspects, such as operating modes, methods and protocols agreed upon internationally by ISO (International Organization for Standardization) and CEN (European Committee for Standardization). With regard to indoor air monitoring, ISO 16000 describes sampling and analysis techniques for the determination of the concentration levels of PM_{10} and $PM_{2.5}$ and their PCDDs/Fs, PCBs and PAHs content [11,12].

To our knowledge, few studies consider the concentrations of PCDDs, PCDFs, PCBs and PAHs in indoor environments after accidental fires. Moreover, few papers are available describing such emergencies in airports and dealing with analysis of causes, action taken and prevention [13]. In addition, none of them analyzed the trends over time of the concentrations of priority combustion products after an accidental fire in an airport terminal.

In this paper we report the case study of an accidental fire occurred in the Rome–Fiumicino International Airport "Leonardo da Vinci" (FCO). This is the main Italian airport in terms of passenger traffic, and one of the busiest airports in Europe, with over 43.5 million passengers served in 2019 [14], located along the coast, 35 km west of the center of Rome. On 7 May 2015, around midnight, a major fire broke out in one of the Airport terminals, Terminal 3, as a result of a short circuit in an electrical cabin and caused serious damages to the transit hall. This Terminal, which operates the highest number of flights, is the largest in the Airport, and hosts over 200 check-in desks, shops, moneychanger stations and passport control booths. To extinguish the fire, seventeen firefighter teams worked the entire night. Although a limited number of people were present when the fire broke out, mostly airport personnel, some people were hospitalized as a consequence of the smoke release, three of whom reported quite serious problems. After an initial closure of several hours, in the following days the airport gradually reopened to air traffic, although with a reduced capacity. Following the preliminary clean-up and recovery operations, and based on the monitoring activities commissioned by the company that manages Aeroporti di Roma (ADR) to assess the air quality in the areas affected by the fire, on 25 May accesses to Terminal 3 were completely reopened. At the same time, the regional Public Health Authority (Azienda Sanitaria Locale Roma D) was called in to carry out environmental monitoring with the support of the regional environmental agency (ARPA) in order to verify air quality in the Terminal affected by the fire. As a result of the detection of high concentrations of PCDDs, PCDFs and PAHs, on 26 May, the Public Prosecutor's Office of Civitavecchia, taking into account the concern expressed by the airport staff, issued the pre-emptive sequestration of Pier D and asked the Public Health Authority to assess whether there was a possible risk to human health from toxic pollutants in the areas under sequestration. To this aim, the Italian National Institute of Health (Istituto Superiore di Sanità- ISS) Units of Air Hygiene and Toxicological Chemistry were specifically appointed.

The environmental monitoring carried out by ISS, differently from other experiences previously reported [9,10], was especially focused on indoor areas of the airport station as, due to the ventilation system still in operation during the fire event, they were mostly interested in the smoke produced by the combustion spread. The ISS monitoring campaign started on 5 June with the sampling of PM_{10} in five indoor and one outdoor sites in the Terminal and continued after completion of the remediation interventions in order to verify the remediation's effectiveness, as issued by the Public Health Authority. Sampling and analysis focused on PCDDs, PCDFs and PCBs, comprising the two groups of congeners with dioxin-like activity (DL-PCBs) and non-dioxin-like activity (NDL-PCBs) and PAHs. Measurements were repeated on different days in order to derive a temporal trend of concentrations of the various pollutants and assess when the Terminal could be reopened to workers and passengers.

Assessment of risk for human health correlated with exposure to these pollutants was conducted with reference to the different groups of people potentially present in the area, such as airport ground personnel with different functions (travelers' ticket sales, travelers' ticket control, travelers' security, travelers' information, commercial and duty-free areas) and travelers (including vulnerable groups such as children). For the purposes of risk assessment, monitored areas were considered indoor living environments. Different from what concerns industrial sites, to date in Italy, there are still no limits or national guidelines related to PCDDs, PCDFs, PCBs and PAHs values in indoor air [15]. Therefore, the main information on reference values to be used for comparison are those that can be found in the scientific literature, in air quality guidelines developed by the World Health Organization (WHO) or in use in other European countries.

Specifically, WHO has developed the "Guidelines for indoor air quality" for different pollutants as benzene, nitrogen dioxide, formaldehyde, PAHs (with a specific focus on benzo[*a*]pyrene—B[a]P), carbon monoxide, naphthalene, radon, trichlorethylene and tetrachlorethylene [16]. For the sum of PCDDs, PCDFs and DL-PCBs, several European Union (EU) countries have set indoor reference/guide values with a legal validity in the evaluation of hygienic–sanitary parameters. Among these, with the Bericht des Länderausschusses für Immissionsschutz (LAI), Germany proposed a long-term target value of 150 fg WHO_{98}-TE/m^3 (annual average) [17]. Already in the late 1980s, WHO indicated, in the air quality guidelines, a concentration reference value in ambient air of 100 fg WHO_{98}-TE/m^3, emphasizing how air represents only a minor contribution to human exposure [18]. In Directive 2004/107/EC, EU set a target value of 1 ng/m^3 for B[a]P, used as a marker for PAHs, in order to protect human health [19]. This value coincides with that established by Legislative Decree 155/2010, in force in Italy for ambient air [20].

Our study therefore aims primarily to provide an example response to indoor environmental emergencies to protect public health, but also to contribute in part to fill the data gap on dioxin emissions following accidental fires inside public buildings. Moreover, given the absence of reference values for the assessment of air quality in a non-industrial site, such as an air terminal, the values of contaminants measured in this study in the post-reclamation phase, can be considered an appropriate reference value for future risk assessment evaluations. In the following paragraphs we illustrate the sampling plan of the air samples, the methodology of the chemical analysis, the related risk assessment and report the results of our study.

2. Materials and Methods

2.1. Study Area and Air Sampling

The airport has an area of 29 km^2 and includes four terminals and three runways with a capacity of 90 aircraft movements per hour, including takeoffs and landings. The fire event occurred inside Terminal 3 at 00:05 a.m. on 7 May 2015 between the air conditioner and the electrical grid, developing flames. This resulted in smoke escaping, which caused severe structural damage and affected dedicated dining and shopping areas. The ventilation system (heating, ventilation and air conditioning—HVAC) that remained in operation caused the spread of smoke produced by combustion to areas adjacent to Pier D, and to areas far from the point of ignition. The severity of the fire event was also a consequence of the impossibility of immediate access by the Fire Department to the fire site. Air samples were collected in established workstations from 7 June (one month after the fire accident) to 18 July (Figure 1, Table 1).

All the workstations were placed at street level, on the floor of the departure entrance area (Figure 2).

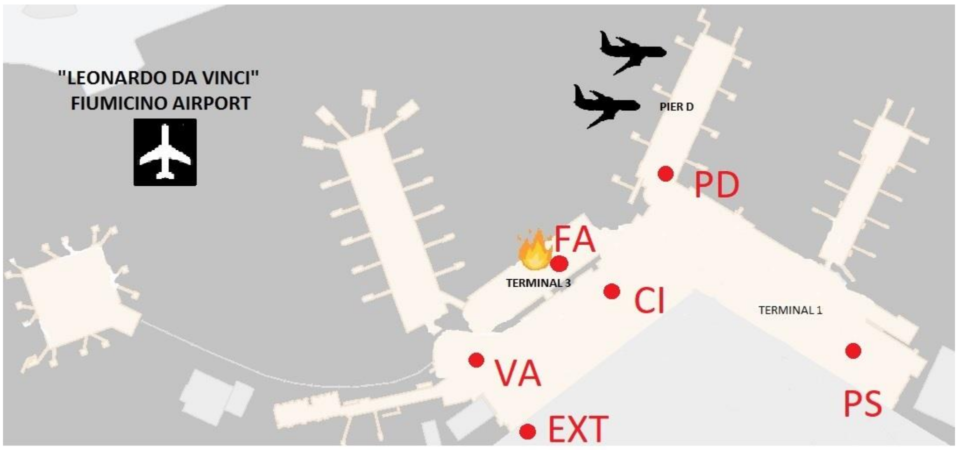

Figure 1. Air sampling sites at Rome–Fiumicino International Airport "Leonardo Da Vinci" (FCO) after the fire occurred on 7 May 2015 (VA = Varco Auriemma, FA = fire area, CI = check-in area, PS = police station, PD = Pier D).

Table 1. Monitoring scheme.

Sampling Sites	Sampling Days	
	June 2015	July 2015
Pier D	10, 13, 16, 19	**15 ***, **18 ***
Check-in area (T3)	7, 10,13, 16, 19	**18 ***
Fire area	7, 10	-
Police station (T1)	13, 16, 25	6
Varco Auriemma	7, 10,13, 16, 25	**18 ***
External (T3)	13, 16, 22	6, **18 ***

* Days in bold refer to post-remediation sampling. T1 = Terminal 1, T3 = Terminal 3.

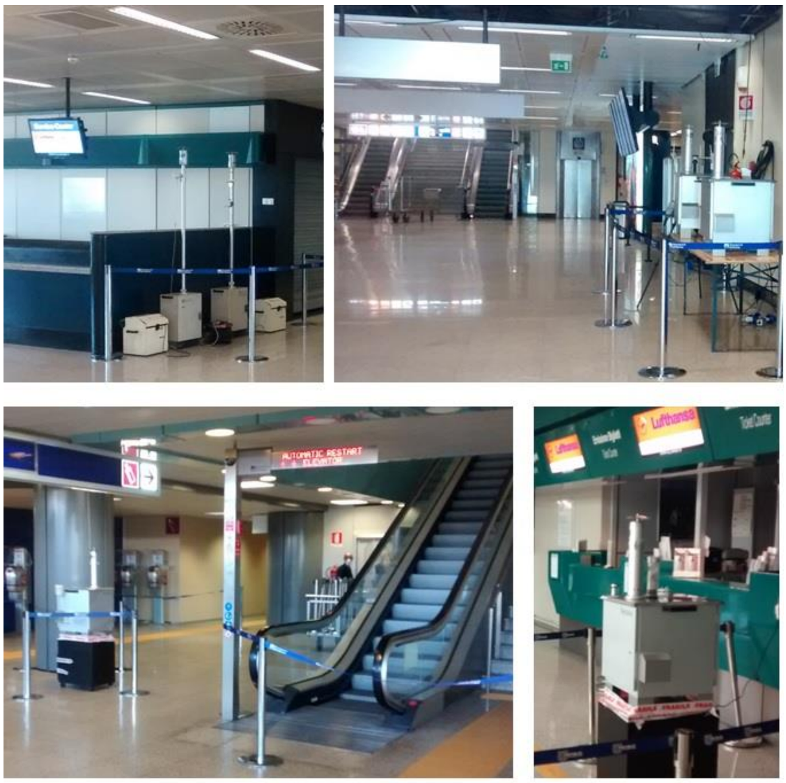

Figure 2. Air sampling workstations at the monitoring sites inside the Fiumicino Airport.

The Varco Auriemma station was positioned at the gate Auriemma, near a security check; the check-in station was near the escalators in the check-in area; the police station site was in the area just outside the police station door, not frequented by passengers; the external station was immediately outside the area leading to the Auriemma gate. During the sampling period some workstations were moved to allow remediation operations and then repositioned to evaluate the operations' effectiveness. The ventilation system (HVAC) was stopped during the environmental monitoring because it was likely the main source of contamination of the areas adjacent to the fire area due to its remaining on during the spread of fumes produced by the fire. The monitoring timeline was divided into two sections considering the cleaning and remediation operations of Pier D: a pre-remediation period (until 11 July) and a post-remediation period (starting from 15 July). Reclaiming of the entire Pier D was completed on 11 July with the encapsulation of the fire area, which represented a potential source of contaminant emission that was still active. On 15 July, ISS positioned samplers in the reclaimed areas of Pier D (in the same position where they had been placed before reclaiming). ISS carried out the analysis of PCDDs, PCDFs and PCBs in samples collected in the pre-remediation and in the post-remediation period, and the analysis of PAHs in samples collected in the pre-remediation period. The sampling procedure followed the requirements of ISO 16000-1:2004, ISO 16000-13:2008 and UNI EN 12341:2014, which prescribe the use of low-volume samplers set to supply sampled quartz fiber filters [11,12,21]. Sampling lasted for approximately 24 h. Air volumes of 54–55 m^3 were collected every three days for almost all the sampling sites.

2.2. Chemical Analysis

The analysis protocol was based on US EPA Methods 1613B (1994) and 1668C (2010) for PCDDs, PCDFs and PCBs, while an in-house method was used for PAHs [22,23]. Briefly, the quartz fiber filter, removed after the end of sampling, was added with ^{13}C-labeled PCDDs, PCDFs and PCBs used as internal standards (Wellington Laboratories Inc., Guelph, ON, Canada). The spiked sample underwent a triple instrument-aided extraction by accelerated solvent extraction (ASE) carried out with dichloromethane at a temperature of 100 °C and a pressure of 138 atm. A minor fraction of the extract (5%) was used to analyze PAHs; the remaining portion underwent cleanup by elution with *n*-hexane through a column filled with Extrelut impregnated with sulfuric acid. The eluate was concentrated under a gentle nitrogen stream to undergo an additional cleanup step with an automatic DEXTech™ System (LCTech GmbH, Obertaufkirchen, Germany) equipped with three different pre-packed columns (acid silica, Florisil, and activated carbon). PCDDs, PCDFs and non-ortho DL-PCBs were determined by high resolution gas-chromatography coupled with high resolution mass-spectrometry (HRGC-HRMS). A Thermo-DFS (Thermo Fisher Scientific Inc., Waltham, MA, USA) was used, operating in selected ion monitoring mode (SIM) through electron impact ionization. Analyte separation was performed on an Agilent J&W DB-5MS UI column (length, 60 m; inner diameter, 0.25 mm; film thickness, 0.25 µm). Mono-*ortho* DL-PCBs and NDL-PCBs were analyzed by HRGC coupled with tandem mass-spectrometry (HRGC-MS/MS), performed by a Thermo-TSQ Quantum GC (Thermo Fisher Scientific Inc., Waltham, MA, USA) operating in MS/MS mode, using electron impact ionization. Analyte separation was performed on a SGETM HT8-PCB column (length, 60 m; inner diameter, 0.25-mm; film thickness, 0.25 µm). Cumulative concentrations of PCDDs, PCDFs and DL-PCBs were expressed as fg WHO_{98}-TE/m^3 [24], applying the most conservative upper bound (UB) approach. Limits of quantifications (LOQs) were in the range of 3–10 fg WHO_{98}-TE/m^3 for most PCDDs and PCDFs, in the range of 10–100 fg WHO_{98}-TE/m^3 for DL-PCBs and in the range of 0.1–0.5 pg/m^3 for NDL-PCBs.

For PAH analysis, the 5% portion was concentrated, ^{13}C-labeled PAHs were added and 10 g of 10% deactivated silica gel were transferred onto a glass column. Elution was carried out with *n*-hexane (Fraction 1), *n*-hexane/dichloromethane (90:10) (Fraction 2) and dichloromethane (Fraction 3). The second eluted fraction was reduced and injection standards were added just prior to instrumental analysis. Quantification of PAHs was carried out on a Thermo-DFS (Thermo Fisher Scientific Inc., Waltham, MA, USA) operating in selected ion monitoring mode (SIM), using electron impact ionization. Analyte separation was performed on an Agilent J&W DB-EUPAH column (length, 20 m; inner diameter, 0.18-mm; film thickness, 0.15 µm). Cumulative concentrations of PAHs, as a sum of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, benzo[*j*]fluoranthene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*e*]pyrene, benzo[*a*]pyrene, perylene, indeno [1,2,3-[*cd*]pyrene, benzo[*ghi*]perylene, dibenz[*a,h*]anthracene, dibenzo[*a,l*]pyrene, dibenzo[*a,e*]pyrene, dibenzo[*a,i*]pyrene and dibenzo[*a,h*]pyrene were expressed as ng/m^3, applying the most conservative UB approach. LOQs were in the range of 1–5 pg/m^3.

For internal quality control purposes, a procedural blank sample (a clean quartz filter) was processed with real samples in the same batch run. Internal standard (IS) recovery rates were considered to be acceptable when in the 40–130% range. Accuracy of the analytical procedure was controlled by the regular participation of the laboratory in international proficiency tests, under accreditation conditions.

2.3. Approach to Human Health Risk Assessment

On the basis of the first results of the post-remediation monitoring of Pier D, a preliminary estimate of human exposure to contaminants of priority health interest was carried out, and health risks for workers and children were evaluated.

For PCDDs, PCDFs and DL-PCBs, the two main exposure pathways for the general population were considered: air inhalation and food intake. In this regard, it is worth emphasizing that dietary exposure is normally responsible for more than 90% of total exposure to dioxins and PCBs [25]. In the period when the risk assessment was carried out, the tolerable weekly intake (TWI) adopted by the European Commission Scientific Committee of Food (EC SCF) was 14 pg WHO_{98}-TE/kg of body weight (bw), with a tolerable daily intake (TDI) of 2 pg WHO_{98}-TE/kg bw [26]. In 2018, the European Food Safety Authority (EFSA) lowered the TWI to 2 pg TE/kg bw [27]. In the evaluation of the contribution of the inhalation pathway, the most conservative case was taken into account, considering absence of personal protective equipment, 100% bioavailability of pollutants adsorbed to PM_{10}, 8-h working shifts, inhalation volume of 1.7 m^3/h (conservative estimate referred to an average heavy working activity) and body weight of 60 kg. Exposure scenarios for workers of 4–8 h/day was hypothesized and, as a precautionary measure, a two-hour exposure was estimated for children who could pass, as passengers, inside Pier D.

2.4. Statistical Analysis

Statistical analysis was performed using SPSS 28 (IBM Statistics, IBM Corp.: Armonk, NY, USA). The non-parametric Wilcoxon test was used to compare measurements obtained in the sampling sites under study before and after the cleaning and remediation operations of Pier D. A p value equal or lower than 0.1 was considered statistically significant.

3. Results and Discussion

3.1. Environmental Concentrations of Target Pollutants

Fire events are not comparable to each to the other because of differences in the material composition, quantity and conditions of the environment where the fire occurred [2]. In this specific study, the results of the monitoring of pollutants after the fire accident at Fiumicino Airport were aimed at protecting health, and, in particular, at verifying the decrease in concentrations of the contaminants in order to make the banned areas active again (with special attention to Pier D). Because of the absence of limits values for the monitored pollutants in indoor air and of the paucity of existing literature on similar studies, the reference values adopted for comparison are 100–150 fg WHO_{98}- TE/m^3 set by WHO and Germany for the sum of PCDDs, PCDFs and DL-PCBs in ambient air [17,18] and 1 ng/m^3 for B[a]P, a target value used as a marker for PAHs, established by EU and Italian legislation for ambient air [19,20].

Levels of PCDDs, PCDFs, PCBs and PAHs analyzed in air samples are reported for pre- and post-remediation sampling periods and are summarized in Table 2.

Table 2. Upper bound (UB) concentrations of contaminants under study in air samples collected after the fire occurred at the Fiumicino Airport.

Sampling Sites	Sampling Days	TE_{TOT} [1] fgWHO$_{98}$-TE/m^3	PCDDs + PCDFs fgWHO$_{98}$-TE/m^3	DL-PCBs fgWHO$_{98}$-TE/m^3	Σ_{30}NDL-PCBs [2] pg/m^3	Σ_6NDL-PCBs [3] pg/m^3	Σ_{17}PAHs [4] ng/m^3	B(a)P ng/m^3
Pier D	10 June 2015	1916	1842	75	881	312	3.48	0.08
	13 June 2015	2503	2405	98	966	341	3.93	0.10
	16 June 2015	3091	2990	101	753	283	—	—
	19 June 2015	2237	2160	78	785	291	2.26	0.04
	15 July 2015	1263	1204	59	685	264	—	—
	18 July 2015	986	939	46	509	192	—	—
Check-in area (T3)	7 June 2015	680	620	60	514	201	1.03	0.01
	10 June 2015	973	899	74	659	249	1.66	0.03
	13 June 2015	1083	1002	81	553	211	1.67	0.03
	16 June 2015	936	879	57	378	143	—	—
	19 June 2015	965	904	61	530	202	1.08	0.02
	18 July 2015	344	322	22	214	86	—	—
Fire area	7 June 2015	512	478	34	279	111	128	0.34
	10 June 2015	674	630	44	479	166	2.80	0.10
Police station (T1)	13 June 2015	620	579	41	188	71	2.05	0.07
	16 June 2015	343	324	19	64	25	—	—
	25 June 2015	24	23	1	36	12	0.26	0.01
	06 July 2015	90	87	3	18	6	—	—
Varco Auriemma	7 June 2015	285	266	19	186	74	0.80	0.03
	10 June 2015	229	213	16	162	62	0.66	0.02
	13 June 2015	488	460	28	258	97	1.32	0.04
	16 June 2015	323	308	15	131	52	—	—
	25 June 2015	199	184	14	157	60	0.60	0.02
	18 July 2015	149	135	14	147	57	—	—
External (T3)	13 June 2015	17	16	1	34	11	0.49	0.02
	16 June 2015	19	18	1	15	5	—	—
	22 June 2015	40	38	2	27	10	0.10	0.01
	6 July 2015	24	23	1	31	11	—	—
	18 July 2015	44	41	3	27	9	—	—

[1] PCDDs + PCDFs + DL-PCBs. [2] Sum of NDL-PCBs 18, 28, 31, 33, 49, 52, 66, 70, 74, 91, 95, 99, 101, 110, 128, 138, 141, 146, 149, 151, 153, 170, 174, 177, 180, 183, 187, 194, 196, 203 [3] Sum of NDL-PCBs 28, 52, 101, 138, 153, 180 [4] Sum of FLU, PYR, B[a]A, CRY, B[b]F, B[k]F, B[j]F, B[e]P, B[a]P, PER, I[cd]P, B[ghi]P, D[ah]A, D[al]P, D[ae]P, D[ai]P, D[ah]P. The upper bound (UB) approach requires using the limit of quantification for the contribution of each non-quantified congener to the cumulative concentrations.

3.2. PCDDs, PCDFs, PCBs, PAHs—Pre-Remediation Levels

The first, measurements carried out after one month from the accidental fire at the Fiumicino Airport showed the persistence of a source of contamination that was still active, affecting the areas outside the burned area. In particular, Pier D presented the highest cumulative levels of PCDDs, PCDFs and DL-PCBs (TE_{TOT}), about 20–30 times higher than the concentration level of 100 fg WHO$_{98}$- TE/m^3 recommended by WHO for ambient air [18]. In the period considered, the marked fluctuations in cumulative concentrations of PCDDs, PCDFs and PCBs assessed at the different workstations did not permit identification of a decreasing trend in contamination (Figure 3).

Cumulative TE_{TOT} concentrations found in samples collected at Pier D on 10, 13 and 16 June (respectively, 1916, 2503 and 3091 fg WHO$_{98}$-TE/m^3) show an increasing trend in contamination (Table 2, Figure 3). A downward trend is observed only starting from 19 June (Table 2, Figure 3). In the check-in area, an increase in concentration is observed in the sample of 10 June compared to the sample of 7 June (973 vs. 680 fg WHO$_{98}$-TE/m^3). This increase is confirmed in the samples of 13, 16 and 19 June (1083, 936, 965 fg WHO$_{98}$-TE/m^3). In the fire area, a moderate increase in concentration can be observed in the sample of 10 June compared to 7 June (674 vs. 512 fg WHO$_{98}$-TE/m^3). Samples collected at the police station in Terminal 1 halved cumulative levels starting from the second sampling (343 vs. 620 fg WHO$_{98}$-TE/m^3) until reaching values below 100 fg WHO$_{98}$-TE/m^3 in the last measurements (Table 2). Samples collected at external workstations in Terminal 3 show values below 50 fg WHO_{98}-TE/m^3 in each sampling date (Table 2). Additionally, for NDL-PCBs, the highest cumulative concentrations observed are those detected at Pier D (Table 2). At a temporal level, fluctuations in concentrations are observed at the other workstations (Table 2).

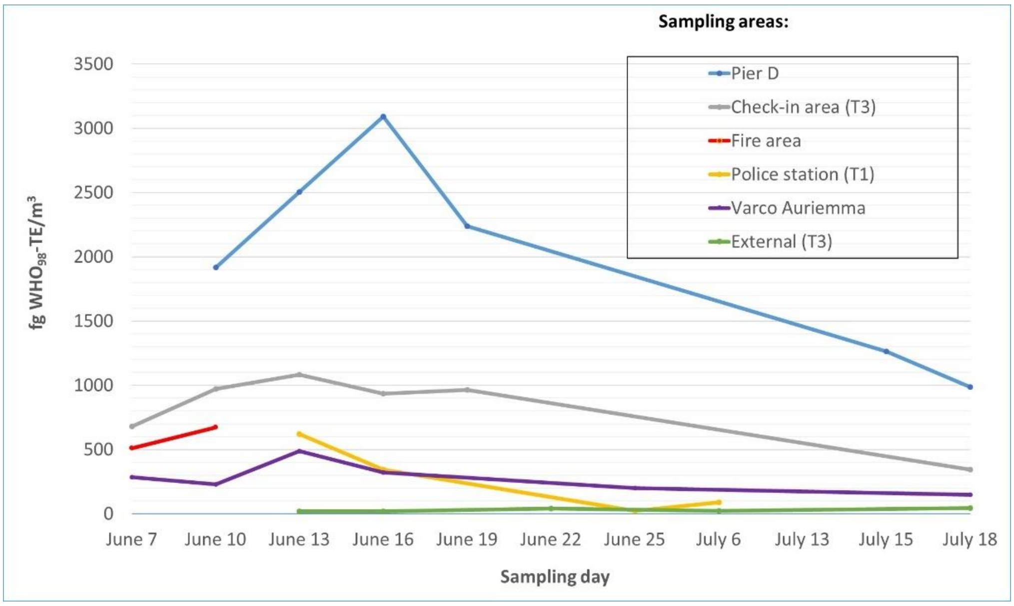

Figure 3. Temporal trend of the cumulative concentrations of PCDDs, PCDFs and DL-PCBs in air samples collected in the monitoring period in each sampling area.

The cumulative concentrations of PAHs ($\sum_{17}$PAHs) measured at the Fiumicino airport in the pre-remediation period ranged from 0.26 ng/m^3 (police station) to 128 ng/m^3 (fire area). In the same period, PAH concentrations quantified in the external area were in the range 0.103−0.50 ng/m^3. Compared to 7 June, after three days, the concentration of PAHs in the fire area decreased by nearly two orders of magnitude (from 128 to 2.80 ng/m^3, respectively). Additionally, for PAHs, excluding the fire area, the highest cumulative concentration was observed at Pier D. Concentrations of PAHs detected in air samples from the monitored indoor spaces in the airport were higher compared with the concentrations measured in hospitals, libraries and coffee shops (0.4–0.6 ng/m^3) in the United States [28], while they were within the range of 2.1–18.2 ng/m^3 measured inside Czech kindergartens [29]. In all the sampling days, the concentrations of PAHs detected at Pier D exceed the range of 1.2–1.4 ng/m^3 found in food courts and shopping malls in the United States [28]. The concentration of B[a]P was below the regulatory limit of 1 ng/m^3 [20] in all the sampling days, and in all the monitored areas.

3.3. PCDDs, PCDFs, PCBs—Post-Remediation Levels

Statistical analysis shows that cumulative concentrations quantified in the sampling sites after the cleaning and remediation operations of Pier D were significantly lower compared to those quantified before such operations (Wilcoxon test, $p < 0.068$). Specifically, comparison of data related to pre- (19 June) and post-remediation (15 July) shows a decrease in cumulative TE_{TOT} concentrations of about 44% at the sampling station at Pier D (Figure 3, Table 2). A further decrease of about 22% is observed in the following sampling (18 July). Similarly, for $\sum_{30}$PCB, a decrease of about 9% is observed comparing the data of 19 June with those of 15 July. Such a reduction further increases in samples collected on 18 July (27%) (Table 2). Concerning the other sampling sites, a reduction in the concentration of cumulative PCDDs, PCDFs and DL-PCBs of about 25% with respect to values measured on 25 June is observed for the Varco Auriemma area. In the check-in area, a decrease of approximately 64% compared to the previous sampling (19 June) is detected. Additionally, for $\sum_{30}$PCB, a decrease in environmental contamination is observed: about 6% and 57% at the Varco Auriemma and the check-in area, respectively.

The main limitations of our study are related to the small number of data over time in the post-remediation period. This is not a longitudinal study, as the study was commissioned to ISS in response to the prosecutor's request to provide an immediate opinion on the usability of Pier D in terms of public health protection.

3.4. Human Health Risk Assessment

After Pier D remediation, concentrations of PCDDs, PCDFs and DL-PCBs, despite showing a decreasing trend, remained above the reference values set by WHO [18] and Germany [17], adopted by ISS (100–150 fg WHO_{98}-TE/m^3). Taking into account the worst-case scenario, exposure to PCDDs, PCDFs and DL-PCBs for workers and for children passing Pier D was estimated considering the parameters reported in Tables 3 and 4.

Table 3. Estimation of workers' exposure trough inhalation and via food intake.

Subject	Inhalation Rate m^3/h	Body Weight kg	Working Time h/Day	Concentration fg WHO_{98}TE/m^3	Inhalation Intake pg/kg bw/day	Average Food Intake pg/kg bw/Day	Total Daily Intake pg/kg bw/Day
Adult	1.7	60	8	1250	0.28	1.21	1.49
Adult	1.7	60	4	1250	0.14	1.21	1.35

Table 4. Estimation of children's (0–10 years old) inhalation exposure.

Subject	Inhalation Rate m^3/h	Body Weight kg	Time Spent h/Day	Concentration fg WHO_{98}TE/m^3	Total Inhalation Dose pg/kg bw/Day
Children (0–1 year old)	0.25	7	2	1250	0.09
Children (1–5 years old)	0.35	15	2	1250	0.06
Children (5–10 years old)	0.38	28	2	1250	0.03

At a concentration of 1250 fg WHO_{98}-TE/m^3, the contribution of the estimated inhalation exposure for workers was 0.28 and 0.14 pg WHO_{98}-TE/kg bw, respectively, for 8 and 4 h of exposure. The inhalation dose was added to the average daily food intake for an Italian adult subject, reported to be approximately 1.21 pg WHO_{98}-TE/kg bw [30]. Total daily intake was estimated to be 1.49–1.35 pg WHO_{98}-TE/kg bw, for 8 and 4 h/day workers, respectively, below the TDI of 2 pg WHO_{98}-TE/kg bw adopted by the EC SCF [26] and within the TDI range (1–4 pg WHO_{98}-TE/kg bw) adopted by WHO for dietary exposure to dioxins [31]. For children aged 0–10 years, the inhalation exposure considered (two hours) represented a negligible increase in exposure compared to the exposure via food estimated for these age classes [27]. Such an estimate was precautionary since, as a consequence of the Public Health Authority prescription, workers had to undertake precautionary measures, such as the use of personal protective equipment and reduction of working hours. Assuming the above exposure concentrations to protract for a few weeks, no significant increase in risk associated with current exposure to PCDDs PCDFs and DL-PCBs was likely to occur. As to this specific point, it worthwhile to recall that WHO highlighted that the TDI represents a tolerable intake for the duration of an average life, and that occasional exceedances of the same do not have health consequences as long as that there are no exceedances of the average long-term intake [31]. It should be noted, however, that the substances in question are undesirable pollutants in the environment due to their high toxicity, and that this makes it necessary to adopt all necessary measures to reduce exposure. Moreover, WHO highlights that subtle effects can occur in some groups of the population even at the current levels of intake [31].

4. Conclusions

The paper reports the results of a study commissioned to ISS in response to the prosecutor's request to provide an immediate opinion on the usability of Pier D in terms of public health protection after the accidental fire occurred at the Fiumicino Airport. An extensive contamination occurred in large indoor areas adjacent the fire area, due to the spread of fumes through the ventilation system (HVAC), which remained on during fire. An environmental monitoring of such areas with particular regard to Pier D started one month after the accidental event and continued after the cleaning and remediation operations in order to verify the effectiveness of the interventions carried out. Preliminary results showed an increasing trend in the concentrations of the monitored pollutants with a marked variability among different areas. Pier D showed higher concentration values for cumulative PCDDs, PCDFs, PCBs (TE_{TOT} from 1916 to 3091 fg WHO_{98}-TE/m^3) and PAHs (from 2.26 to 3.48 ng/m^3). This confirmed the persistence of a source of contamination still in action. Only after the remediation operations was a decreasing trend observed. In particular, Pier D showed a decrease in cumulative TE_{TOT} concentrations of about 44%. Despite this, the concentrations detected remained above the reference values set by WHO [18] and Germany [17], adopted by ISS (100–150 fg WHO_{98}-TE/m^3). Once the assessment of exposure to PCDDs, PCDFs and PCBs in the days immediately after the remediation operations revealed that there were no particular health risks for passengers and staff, Pier D was reopened on 18 July with subsequent resumption of the airport's activities. ISS is the technical–scientific body of the Italian National Ministry of Health. Its role in the accident and post-accident management fell within the ISS institutional tasks. All the information derived from this study represents a scheme of intervention with a specific focus on human risk assessment to be considered by health authorities in case of similar accidents.

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