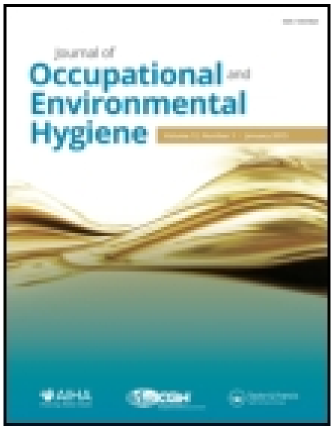
View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Archivio della ricerca - Università degli studi di Napoli Federico II

On: 08 July 2015, At: 01:03
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: 5 Howick Place, London, SW1P 1WG



CrossMark

Click for updates

Journal of Occupational and Environmental Hygiene

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uoeh20

Occupational Exposure to Chromium of Assembly Workers in Aviation Industries

G. Genovese[a], L. Castiglia[a], M. Pieri[ab], C. Novi[c], R. d'Angelo[c], N. Sannolo[a], M. Lamberti[a] & N. Miraglia[a]

[a] Department of Experimental Medicine - Section of Hygiene, Occupational Medicine and Forensic Medicine - Occupational Medicine Area - Second University of Naples, Naples, Italy

[b] Department of Advanced Biomedical Science - Legal Medicine, Histology and Anatomy Section, University "Federico II" of Naples, Naples, Italy

[c] Regional Technical Advisory Department Risk and Prevention Assessment (CONTARP) of Campania, Italian Workers' Compensation Authority (INAIL), Naples, Italy

Accepted author version posted online: 20 Mar 2015.Published online: 07 Jul 2015.

To cite this article: G. Genovese, L. Castiglia, M. Pieri, C. Novi, R. d'Angelo, N. Sannolo, M. Lamberti & N. Miraglia (2015) Occupational Exposure to Chromium of Assembly Workers in Aviation Industries, Journal of Occupational and Environmental Hygiene, 12:8, 518-524, DOI: 10.1080/15459624.2015.1019075

To link to this article: http://dx.doi.org/10.1080/15459624.2015.1019075

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Journal of Occupational and Environmental Hygiene, 12: 518–524
ISSN: 1545-9624 print / 1545-9632 online

DOI: 10.1080/15459624.2015.1019075

Occupational Exposure to Chromium of Assembly Workers in Aviation Industries

G. Genovese,[1] L. Castiglia,[1] M. Pieri,[1,2] C. Novi,[3] R. d'Angelo,[3] N. Sannolo,[1] M. Lamberti,[1] and N. Miraglia[1]

[1]Department of Experimental Medicine – Section of Hygiene, Occupational Medicine and Forensic Medicine – Occupational Medicine Area – Second University of Naples, Naples, Italy
[2]Department of Advanced Biomedical Science – Legal Medicine, Histology and Anatomy Section, University "Federico II" of Naples, Naples, Italy
[3]Italian Workers' Compensation Authority (INAIL) Regional Technical Advisory Department Risk and Prevention Assessment (CONTARP) of Campania, Naples, Italy

Aircraft are constructed by modules that are covered by a "primer" layer, which can often contain hexavalent chromium [Cr(VI)], known carcinogen to humans. While the occupational exposure to Cr(VI) during aircraft painting is ascertained, the exposure assessment of assembly workers (assemblers) requires investigations.

Three biological monitoring campaigns (BM-I,II,III) were performed in an aviation industry, on homogeneous groups of assemblers (N = 43) and controls (N = 23), by measuring chromium concentrations in end-shift urine collected at the end of the working week and the chromium concentration difference between end- and before-shift urines. BM-I was conducted on full-time workers, BM-II was performed on workers after a 3–4 day absence from work, BM-III on workers using ecoprimers with lower Cr(VI) content. Samples were analyzed by atomic absorption spectroscopy and mean values were compared by T-test.

Even if Cr concentrations measured during BM-I were lower than Biological Exposure Indices by ACGIH, statistically significant differences were found between urinary Cr concentrations of workers and controls. Despite 3–4 days of absence from work, urinary chromium concentrations measured during BM-II were still higher than references from nonoccupationally exposed populations. In the BM-III campaign, the obtained preliminary results suggested the efficacy of using ecoprimers.

The healthcare of workers exposed to carcinogenic agents follows the principle of limiting the exposure to "the minimum technically possible". The obtained results evidence that assemblers of aviation industries, whose task does not involve the direct use of primers containing Cr(VI), show an albeit slight occupational exposure to Cr(VI), that must be carefully taken into consideration in planning suitable prevention measures during risk assessment and management processes.

Keywords aviation industries, biological monitoring, chromium, occupational exposure

G. Genovese and L. Castiglia contributed equally to this work.
Address correspondence to: Maria Pieri, Department of Advanced Biomedical Science – Legal Medicine, Histology and Anatomy Section, University "Federico II" of Naples, Via S. Pansini, 5 80131, Naples, Italy; e-mail: maria.pieri@unina.it

INTRODUCTION

Chromium is a transition element occurring in the environment (soil, rocks, plants, dust, and gases), primarily in the elemental, trivalent [Cr(III)], and hexavalent [Cr(VI)] oxidation states. Cr(III) has limited toxicological properties,(1) and is an essential nutrient in humans, as it affects the metabolism of sugars and fats, and is contained in many foods. Cr(VI), despite not playing any role in biological systems, is readily absorbed by the lungs and from the skin. Absorbed chromium distributes to nearly all tissues, with the highest concentrations found in kidney and liver. Bone is also a major depot and may contribute to long-term retention kinetics of chromium. Absorption is also affected by nutritional status, since the absorption fraction is higher when dietary intakes are lower.(2) *In vivo*, Cr(III) and Cr(VI) accumulate in various tissues (lung, liver, kidney, and spleen); in lung, stomach, and intestine, Cr(VI) is reduced to Cr(III) by various cellular components (glutathione, ascorbate, and cysteine), and then is excreted in urine, which lowers the absorbed dose from ingested Cr(VI).(2,3) Cr can also be eliminated by transfer to hair and nails.(2) The health risks associated with exposure to chromium are dependent on the oxidation state. Cr(VI) is known to be toxic, leading to acute effects, such as irritation of skin, eyes, and respiratory tract, and chronic effects, lung, and stomach cancer.(2–5) On the basis of experimental and epidemiological evidence, Cr(VI) was classified by the International Agency for Research on Cancer (IARC) as carcinogen to humans (Group 1).

Cr(VI) compounds are used in several industrial applications (chrome plating, welding inox steel, and other special steels, painting, leather tanning, and wood preserving), and occupational exposure mainly occurs by inhalation, but it may involve the gastrointestinal tract and skin.(5,6)

In the production cycle of the aviation industry, in particular, the modules forming aircrafts are first coated with a layer of primer, then assembled and then coated. The primer is applied to internal and external surfaces of the aircraft to protect them from corrosion and to offer a valid anchor to subsequent organic coatings formed by the paints. Often, the primers used in the aeronautic industry contain Cr(VI) salts as pigments.(7–9)

Workers' healthcare in relation to the exposure to hexavalent chromium may involve both control measures centered on biological monitoring (BM) campaigns, together with the implementation of environmental monitoring campaigns, and preventive measures such as the use of appropriate personal and collective protective equipment (e.g., centralized vacuum systems). In absence of specific legislation as far as regards the biomarkers that should be monitored, to assess the level of occupational exposure to Cr(VI), the total chromium concentrations in end-shift urine collected at the end of the working-week (CrU-es$_{eww}$) or the chromium concentration difference between end- and before-shift urines (ΔCrU) are commonly used as biological indicators. These indicators reflect both the *in vivo* reduction of Cr(VI) to Cr(III) and the tendency of chromium to accumulate in tissues throughout the working week. The American Conference of Governmental Industrial Hygienists (ACGIH) proposed Biological Exposure Index (BEI) of 25 μg/L for the CrU-es$_{eww}$ and 10 μg/L for the ΔCrU.(10)

While the occupational exposure of workers, whose task exactly involves the direct handling of products containing hexavalent chromium (painters), has been documented,(11,12) no information is available about workers engaged in the assembly of aircraft. The task consists first of all in the drilling of the modules forming the aircraft, and then modules are assembled. Weekly, it may happen that the assemblers must proceed with touch-ups on the joints, manipulating small amounts of primers for a short time. The absorption of Cr(VI), therefore, might occur through the inhalation of airborne particles originating from drilling and for direct contact with the primer.

As described, the task of "assembler" in aircraft industry does not imply the direct handling of chemicals or compounds containing hexavalent chromium, hence a low Cr exposure is expected, nevertheless, given Cr(VI) carcinogenic properties, biological monitoring campaigns were performed to assess the levels of chromium found in the urine of workers employed in assembly areas of an aircraft industry, in which products containing calcium chromate (2.5–10%, w/w), strontium chromate (2.5–10% and 10–25%, w/w), and chromium trioxide (2.5–10%, w/w) were used.

MATERIALS AND METHODS

Workers Enrollment and Sample Collection

In the first biological monitoring campaign (BM-I), Similar Exposure Groups (SEGs) were identified. The rationale for identifying SEGs consisted in the identification of parameters able to influence exposure, namely the amount of chromium to which workers were potentially exposed and its distribution within the workplace. As a consequence, SEGs depended on the model and the size of the assembled aircraft (chromium amounts increase when larger planes surfaces are involved), and on the particular hangar (influencing the airborne chromium concentration). Since all workers carried out the same task (assemblers) working in large hangars, the SEGs were defined on the basis of different work programs. In particular, two SEGs—SEG A and SEG B—were defined with respect to (i) the model and size of the assembled aircraft and (ii) the particular hangar.

(i) Model and size of the assembled aircraft: SEG A was composed of assemblers of small size aircrafts, operating both inside and outside of the fuselage (it must be noted that when workers operated inside, the openings were made from nonassembled doors and portholes); SEG B was composed of assemblers of big size aircrafts (e.g., BOEING), operating both inside and outside of the fuselage, on fuselage wings and on the aircraft cabin (not assembled to the fuselage).

(ii) Hangar: Workers of SEG A operated in small hangars, containing 6–7 aircrafts and 15–20 workers/aircraft, where doors were normally opened only to bring aircrafts in and out of the hangar; workers of SEG B operated in big hangars, containing 50–60 aircrafts and 5–6 workers/aircraft, where doors were frequently opened.

Control subjects were taken from administrative employees, whose jobs do not involve the handling of compounds containing hexavalent chromium. Two SEGs, for a total of 43 workers, and 23 control subjects were identified. Biological monitoring was performed on workers of the first turn shift (6.00 a.m.–2.00 p.m.), together with the environmental monitoring (EM) yearly performed by a certified laboratory. Both BM and EM were part of the Health Surveillance Program, in accordance with the provisions of law.

The second BM campaign (BM-II) was performed to determine the chromium urinary concentrations in 19 workers (among those investigated during BM-I) after a brief absence from work. Six not occupationally exposed subjects were enrolled as control group.

During the BM-III, 30 workers, chosen among previously monitored workers, were investigated, and in the sampling day, they handled exclusively a primer with reduced hexavalent chromium content (*ecoprimer*) for 3 hr. The *ecoprimer* was not used for the actual aircraft production, because the employer wanted to verify its effectiveness as safety protection measure before introducing it in the production cycle. Assemblers drill panels for 3 hr in all, and during the rest of their shift, workers normally assemble the aircrafts. Since the drilling activity is expected to be the main cause of exposure to chromium particles, workers involved in BM-III, after having used the *ecoprimer*, assembled aircrafts, so that BM-III investigation reflected the assemblers exposure to chromium.

Before starting with the urine sample collection, all workers were properly informed about the aims of the study, and each worker provided informed consent. It must be underlined that the human subject study approval was given by the investigated firm direction itself, because the study was part of the Prevention Improvement Program required by provisions of law and, in particular, the BM campaigns were included into the Health Surveillance Program defined by the Occupational Physician.

A detailed questionnaire was administered to each enrolled subject in order to investigate the habits of life and work, e.g., tobacco smoking, the use of drugs, and the presence of pathology such as diabetes and kidney or pulmonary diseases.

In both the first and the third investigations, urine specimens were collected before and after the work-shift at the end of the working week (CrU-bs$_{eww}$ and CrU-es$_{eww}$, respectively), for a total of 132 (BM-I) and 60 (BM-III) samples.

In BM-II, only before shift urines at the beginning of the working-week (CrU-bs$_{bww}$), after 3–4 days of absence from work, were collected, for a total of 25 samples.

The value of creatinine concentrations were used to assure the validity of the samples, according to the acceptable range (0.3 g/l $\leq$ creatinine $\leq$ 3.0 g/l) indicated by the World Health Organization.(13) After collection, samples were stored at 4°C and transferred within three days to the laboratory, by using a refrigerated thermal box.

During all BM campaigns, workers used individual protection equipment, as gloves and masks; moreover, drills were provided with exhaust ventilation systems and hangars were provided with centralized vacuum systems, whose effectiveness was periodically verified by the firm.

Chemicals and Apparatus

Urinary Cr quantitative analyses were performed using a Perkin-Elmer (Milan, Italia) dual-beam spectrophotometer, model AAnalyst 800, equipped with Zeeman-effect background correction, graphite furnace tube and automatic sampler. Data were acquired and processed using the WinLab32 for AA program.

A Cr standard solution, 1 mg/mL in 2% HNO_3, was used for both calibrators and quality controls preparation. The Cr standard solution, the matrix modifier ($MgNO_3$) and the chromium hollow-cathode lamp were all from Perkin Elmer Italy. Ultrapure atomic absorption grade water and nitric acid, used during analytical steps, were from Carlo Erba (Milan, Italy).

Instrumental Psarameters

Metal hollow-cathode lamp specific for Cr at wavelengths of 357.9 nm was employed as radiation source. Argon was used as support gas; the spectral resolution (slit) was 0.5. Injection temperature and volumes were 70°C and 20 μL, respectively, and the temperature program shown in Table I was used.

Analysis

Urinary samples were acidified immediately after their arrival in laboratory (22.2 μL of nitric acid added to 10 mL of urine), stored at 4°C and analyzed within three days.

Quantification of chromium levels in urine samples from enrolled workers was performed by using calibration curves obtained through the analysis of standard solutions at decreasing Cr concentrations, prepared by subsequent dilution of the 1 mg/mL standard one (all dilutions were performed with 0.2% HNO_3). Calibration interval ranged from 5.0 to 0.30 μg/L and a linear response was recorded ($y = 0.0154x + 0.0247$, $R^2 = 0.9997$). The quantification of samples from the control group (for which lower Cr concentrations were expected) was based on a lower calibration curve (1.0–0.06 μg/L).

Percentage accuracy (Acc%) and precision (in terms of percentage coefficient of variation, CV%) were determined by the analysis of quality control samples at three concentration levels (4.0, 1.5, and 0.5 μg/L), prepared from independent solutions of chromium, 0.2% HNO_3. For the examined three concentration levels, both accuracy and precision fulfilled recommendations proposed by the Food and Drug Administration for bioanalytical procedures validation (Acc% = 1.5, 6.3, and 15.0%; CV% = 3.8, 8.0, 9.4%, respectively).(14)

Detection and quantification limits were determined through the analysis of six matrix blank samples as the mean Cr concentration plus 3 and 10 times the standard deviation, obtaining values of 0.03 and 0.06 μg/L, respectively. Each urinary sample from enrolled workers was analyzed in triplicate and quality control samples were analyzed every ten unknown samples.

Statistical Analysis

The statistical description of data was carried out by using SPSS software, version 15.0 for Windows (SPSS ITALIA s.r.l., Bologna, Italy). A value of 0 was assigned to samples with undetectable levels of chromium (i.e., to analytical results below the Limit Of Detection, LOD), so as to be included into the statistical analysis.

For each BM campaign, the normality of the distribution functions of CrU-bs$_{eww}$, CrU-es$_{eww}$, ΔCrU, both in workers and controls, was evaluated by the Kolmogorov-Smirnov test if the number of data was higher than 30, otherwise the Shapiro-Wilk test was used. When quantitative data were divided into subgroups (e.g., different SEGs, smokers/nonsmokers), normality tests were applied. Mean values of CrU distributions were compared by using the Student t-test for unpaired data.

RESULTS

Enrollment and Influence of Smoking Habit

Enrolled workers and control groups were all men. Since diabetes is considered a confounding factor,(15) one worker suffering from diabetes was excluded from the study.

TABLE I. Temperature Program

	Step	Temp. (°C)	Ramp time (s)	Hold time (s)	Internal flow (mL/min)
I	evaporation	160	2	20	200
II	incineration	1500	150	20	200
III	atomization	2450	0	3	0
IV	cleaning	2600	0	3	200

The first biomonitoring campaign (BM-I) was performed on workers of two Similar Exposure Groups (SEG A and SEG B) and on a control group. Concentrations lower than LOQ were obtained in 3 (for CrU-bs$_{eww}$) and 5 (for CrU-es$_{eww}$) out of 23 controls (representing 13% and 22% of analyzed samples), while no sample from workers presented CrU concentrations below LOD. In order to establish if a different exposure to Cr(VI) could derive from belonging to different SEGs, t-tests were performed by comparing CrU-bs$_{eww}$, CrU-es$_{eww}$, and ΔCrU average concentrations for workers of SEG A with respect to workers of SEG B (Table II, first and second rows). No statistically significant differences between the mean concentrations of Cr in before shift urine (CrU-bs$_{eww}$) and end shift urine (CrU-es$_{eww}$) were found ($p = 0.052$ and 0.253, respectively), as well as for ΔCrU mean values ($p = 0.727$). These findings showed that in the here reported case, the two considered SEGs involved the same occupational exposure. This evidence was also confirmed by the simultaneous environmental monitoring study commissioned by the investigated firm to another certified laboratory the authors had the opportunity to collaborate with. It must be underlined that the collaboration involved the planning of sampling days (i.e., to perform environmental and biological monitoring during the same days), the possibility of verifying that both sampling and analyses were carried out according to official guidelines and the chance to compare obtained data. Results from environmental monitoring evidenced in all hangars airborne chromate concentrations 1/10 below of the corresponding TLV-TWA (CrVI soluble and insoluble compounds: 50 and 10 μg/m^3, respectively) proposed by ACGIH,(10) confirming the same levels of occupational exposure of the investigated SEGs. As a consequence, during the subsequent biomonitoring campaigns, all workers were grouped in a single SEG (SEG A+B), and data from BM-I (reported below) were discussed considering the enrolled workers *in toto* with no difference with respect to the initially defined SEG.

The influence of tobacco smoking on chromium excretion was evaluated. In the enrolled population, 45.2% of workers and 34.7% of controls were smokers. t-Test was applied to compare CrU-bs$_{eww}$ levels measured in smokers and nonsmokers in workers and it was repeated for controls. Then, the same analysis was applied to evaluate CrU-es$_{eww}$ differences. Obtained results (Table II, third and fourth rows) evidenced no statistically significant differences between CrU-bs$_{eww}$ ($p = 0.542$) and CrU-es$_{eww}$ ($p = 0.609$) mean concentrations of smokers and nonsmokers workers. The same results were also obtained by comparing smokers and nonsmokers among controls (Table II, fifth and sixth rows), ($p = 0.111$ and 0.126, respectively).

The comparison between the CrU-bs$_{eww}$ and CrU-es$_{eww}$ mean concentrations of workers and controls divided in smokers and nonsmokers evidenced statistically significant differences ($p = 0.001$ in both cases), suggesting an occupational exposure to chromium of assemblers.

Occupational Exposure

The occupational exposure of monitored workers was even more evident by considering the CrU-es$_{eww}$ mean concentration values obtained for workers and the control group (Table III, first and second rows, second column), as well as the ΔCrU levels (Table III, first and second rows, third

TABLE II. Mean Values of CrU-bs$_{eww}$, CrU-es$_{eww}$, and ΔCrU ± Standard Deviation (SD), Measured in Workers from Two Different SEGs (SEG A and SEG B), in Smoking and Nonsmoking Workers without SEG Distinction (SEG A + B) and in Smoking and Nonsmoking Control Subjects

	Number of subjects	CrU-bs$_{eww}$ ± SD (μg/L)	CrU-es$_{eww}$ ± SD (μg/L)	ΔCrU± SD (μg/L)
SEG A	15	3.21 ± 1.25	3.47 ± 0.67	0.26 ± 1.92
SEG B	27	2.50 ± 0.66	3.10 ± 0.69	0.60 ± 0.86
SEG A+B, smokers	19	2.47 ± 0.66	3.09 ± 0.63	0.62 ± 0.94
SEG A+ B, nonsmokers	23	2.62 ± 0.83	3.21 ± 0.77	0.59 ± 1.11
Controls, smokers	8	0.10 ± 0.08	0.08 ± 0.03	−0.06 ± 0.11
Controls, nonsmokers	15	0.07 ± 0.02	0.06 ± 0.03	−0.01 ± 0.05

TABLE III. Mean Concentration Values of CrU-bs$_{eww}$, CrU-es$_{eww}$ and ΔCrU ± Standard Deviation (SD), Obtained for Workers During BM-I, BM-II, and BM-III and for Controls During BM-I

	Number of subjects	CrU-bs ± SD (μg/L)	CrU-es$_{eww}$ ± SD (μg/L)	ΔCrU ± SD (μg/L)
BM-I, workers (SEG A+B)[1]	42	2.59 ± 0.77	3.14 ± 0.69	0.55 ± 1.01
BM-I Controls[1]	23	0.08 ± 0.03	0.07 ± 0.03	−0.01 ± 0.07
BM-II, workers[2]	19	0.63 ± 0.33		
BM-III, workers[1]	30	2.60 ± 0.62	2.68 ± 0.46	0.08 ± 0.64

[1] Urine were collected before shift, at the end of the working week, hence CrU-bs = CrU-bs$_{eww.}$

[2] Urine were collected before shift, at the beginning of the working week, hence CrU-bs = CrU-bs$_{bww.}$

column): statistically significant differences were recorded (p = 0.001) in both cases.

Moreover, the t-test performed on CrU-bs$_{eww}$ mean values obtained for all workers and controls (Table III, first and second rows, first column) evidenced a statistically significant difference (p = 0.001) also for before shift data, in line with the tendency of chromium to accumulate in the body.

To further confirm that the task of assemblers involves a low but detectable occupational exposure to Cr(VI), data recorded for workers were compared with Reference Values (0.05–0.35 μg/L), proposed for the general population by the Italian Reference Value Society.(16) Extremely low CrU-bs$_{eww}$ and CrU-es$_{eww}$ mean values were obtained for the control group (Table III, second row, first and second columns), and, as expected, data were superimposable to SIVR's ones. On the contrary, CrU-bs$_{eww}$ and CrU-es$_{eww}$ mean values of workers were about one order higher with respect to reference values for general nonexposed population (Table III, first row, first and second columns).

Extraprofessional Exposure

As reported previously, results of BM-I obtained for workers evidenced chromium concentrations in urinary samples collected at the end of working week higher than reference values, both for end shift and before shift samples. In order to highlight the source of chromium exposure (professional or extraprofessional), chromium levels were quantified in before shift samples collected at the beginning of the working week (CrU-bs$_{bww}$), by repeating the monitoring campaign on some of the initially enrolled workers, after a brief period of absence from the work (BM-II). Obtained urinary concentrations, schematically reported in Table III (first column, third row), resulted significantly lower (p = 0.001) with respect to before shift levels recorded during BM-I (Table III, first column, first row), thus showing that: (i) few days of absence from work are sufficient for lowering chromium excretion levels; and (ii) no relevant extraprofessional exposure to Cr is present. CrU values obtained after some days of absence from work were, in fact, in line with SIVR reference values.

Preventive Measures

Since BM-I and BM-II results suggested the existence of an albeit slight occupational exposure to chromium of assemblers, ordinary primers were substituted with an *ecoprimer*, presenting a lower Cr(VI) content, and a third biomonitoring campaign (BM-III) was performed on some of the workers initially enrolled, in order to verify the potential efficacy of the *ecoprimer* adoption as prevention measure. Workers monitored during BM-III were asked to handle exclusively the *ecoprimer* for three hours. Data were interpreted by comparing CrU-bs$_{eww}$ values obtained in BM-I and BM-III (Table III, first column, first and fourth rows), in order to verify if basal CrU levels were equal. Since superimposable excretion levels (p = 0.943) were obtained in before shift samples collected during BM-I and BM-III, the difference in CrU concentrations in end shift samples could be attributed to the chromium absorbed during the daily working activity. A statistically significant difference (p = 0.001) was found between CrU-es$_{eww}$ mean concentration values of BM-I and BM-III (Table III, second column, first and fourth rows).

DISCUSSION

The case study reported in the present article was aimed to evaluate the occupational exposure level to Cr(VI) of assemblers in the aircraft industry.

With this aim, a biological monitoring campaign (BM-I) was performed, allowing the evaluation of urinary chromium levels in workers employed as assemblers in the monitored aircraft plant, where compounds containing strontium and calcium chromate and chromium trioxide were used.

Since no BEI are reported for chromium insoluble compounds, as a preliminary/indicative evaluation, results were evaluated with respect to both ACGIH 2013 BEI for soluble compounds, as well as with the Reference Values for nonexposed population proposed by the Italian SIVR. Actually, the question about the modality of performing biological monitoring investigations aimed to evaluate, in particular, the exposure to insoluble chromium compounds is still under debate.(17–19) Nevertheless, here the reported results show a detectable occupational exposure to chromium; as a consequence, preventive measure should be taken in order to reduce exposure levels.

In fact, even if the levels of biological indices measured during BM-I at the end of working week (CrU-es$_{eww}$ and ΔCrU) were lower than occupational exposure limits, they were higher than Reference Values, thus suggesting a low but detectable occupational exposure to Cr(VI) for the task taken into consideration. In order to verify if tobacco smoking, proposed by Petrilli as a possible confounding factor,(20) could have any influence on urinary chromium excretion, CrU-bs$_{eww}$ and CrU-es$_{eww}$ measured for workers and controls were compared, by distinguishing smokers and nonsmokers. On the basis of BM-I results, tobacco smoking does not affect the urinary chromium excretion at the levels of exposure encountered in this study.

Since not only end-shift levels but also urinary chromium concentrations measured at the beginning of working shifts were higher than SIVR Reference Values, a second monitoring campaign (BM-II) after 3–4 days of absence from work, was planned, aimed to discriminate between professional and extraprofessional exposure. Despite the absence from work, chromium urinary concentrations were still slightly higher than Reference Values. Such results can be ascribed to the tendency of chromium to accumulate within the organism, together with the urinary excretion kinetics, which differs for each subject. In particular, Cr excretion follows triphasic kinetics, with a 7-hr long first phase, a second of 20–27 days, and a third of 129.(21,22) Nevertheless, the CrU-bs$_{bww}$ concentrations measured after the absence from work were actually lower than the ones obtained during BM-I, thus suggesting that measured CrU levels essentially derive from the working activity. Since the second and third Cr excretion kinetics are longer than the period of absence from work, it seems reasonably that the first Cr half-life (about 7 hr) was sufficient to determine the measured differences. Summarizing, CrU levels lowered as a consequence of the absence from work, but they were still higher than Reference Values because the absence was only 3–4 days long due to production cycle exigency.

Several solutions can be adopted to reduce health risks deriving from the exposure to a chemical, such as the modification of working procedures, the adoption of adequate personal and collective protection equipment, as well as performing education courses aimed to increase risks' perception and to give workers indications on the correct use of personal protection equipment:(23–26) in this reported case study, the adoption of an *ecoprimer* with lower Cr(VI) content was tested as improving action. As a pilot study, a third biological monitoring campaign (BM-III) was performed and workers (presenting homogeneous basal CrU levels) were asked to use only the *ecoprimer* during the whole sampling day for at least 3 hr. Even if workers used the *ecoprimer* for a short period, the obtained results highlighted lower-end shift CrU concentrations, demonstrating a decrement of the chromium absorbed dose. Nevertheless, despite positive, the measured Cr concentration difference was comparable to the standard deviations of both investigated workers groups (see Table III), as a consequence such results can be merely considered as preliminary results, and should be verified by repeating the biological monitoring on a larger workers' group and by considering the normal working conditions, in regards to time and as a way of using the primer.

CONCLUSIONS

The risk of developing cancer has a stochastic nature; as a consequence, in the Italian legislation no limit value is defined and the principle of limiting the exposure to "the minimum technically possible" is stressed.

The reported case study here evidences that assemblers of aviation industries, whose task does not involve the direct use of primers containing Cr(VI), show an albeit slight occupational exposure that has to be properly taken into consideration during risk assessment and management.

REFERENCES

1. **De Flora, S., M. Bagnasco, D. Serra, and P. Zanacchi**: Genotoxicity of chromium compounds. A review. *Mutat. Res. 238*:99–172 (1990).
2. **U.S. Department of Health and Human Services. Public Health Service Agency for Toxic Substances and Disease Registry**: *Toxicological Profile for Chromium*. 2012. ATSDR, Atlanta (US). Available at http://www.atsdr.cdc.gov/ToxProfiles/tp7.pdf. (accessed November 12, 2014)
3. **Environmental Protection Agency**: *Toxicological Review of Hexavalent Chromium*. 1998. Available at http://www.epa.gov/iris/toxreviews/0144tr.pdf. (accessed November 12, 2014)
4. **De Flora, S.**: Threshold mechanisms and site specificity in chromium (VI) carcinogenesis. *Carcinogenesis 21*:533–541 (2000).
5. **Beaumont, J.J., R.M. Sedman, S.D. Reynolds, et al.**: Cancer mortality in a Chinese population exposed to hexavalent chromium in drinking water. *Epidemiology 19*:12–23 (2008).
6. **Gatto, N.M., M.A. Kelsh, D.H. Mai, M. Suh, and D.M. Proctor**: Occupational exposure to hexavalent chromium and cancers of the gastrointestinal tract: a meta-analysis. *Cancer Epidemiol. 34*:388–399 (2010).
7. **LaPuma, P.T., J.M. Fox, and E.C. Kimmel**: Chromate concentration bias in primer paint particles. *Reg. Tox. Pharm. 33*:343–349 (2001).
8. **LaPuma, P.T., and B.S. Rhodes**: Chromate content versus particle size for aircraft. *Reg. Tox. Pharm. 36*:318–324 (2002).
9. **Carlton, G.N**: Hexavalent chromium exposures during full-aircraft corrosion control. *AIHA J. 64*:668–672 (2003).
10. **American Conference of Governmental Industrial Hygienists**: Threshold limit value and biological exposure index. *It. J. Occup. Environ. Hyg. 4*(*Suppl. 2*) (2013).
11. **Gherardi, M., M.P. Gatto, A. Gordiani, E. Paci, and A. Proietto**: Occupational exposure to hexavalent chromium during aircraft painting. *G. Ital. Med. Lav. Erg. 29*:553–555 (2007).
12. **Nolli, F., P.E. Cirla, A.M. Firmi, et al.**: Esposizione a cromo: i risultati dello studio PPTP – Verniciatura. [Exposure to chromium: results of the PPTP study – Painting]. Acts of the conference *"Attività di verniciatura: salute e sicurezza"* [Painting: safety and security]; Cimal (ed.). Milan, Italy.: 2009. pp. 87–96. [Italian]
13. **World Health Organization**: *Biological Monitoring of Chemical Exposure in the Workplace. Guidelines*. Vol. 1. Geneva, Switzerland, 1996.
14. **Department of Health and Human Services, Food and Drug Administration**: *Guidance for Industry – Bioanalytical Method Validation*. 2001. Available at http://www.fda.gov/downloads/Drugs/Guidances/ucm070107.pdf (accessed November 12, 2014).
15. **Afridi, H.I., T.G. Kazi, N. Kazi, et al.**: Status of essential trace metals in biological samples of diabetic mother and their neonates. *Arch. Gynecol. Obstet. 280*:415–423 (2009).

16. **SIVR. Italian Reference Values Society**: *Third List of Reference Values for Elements, Organic Compounds and Their Metabolites*. (2001) Available at http://www.valoridiriferimento.it. (accessed June 10, 2014).
17. **Lovreglio, P.**, **M.N. D'Errico**, **A. Basso**, **et al.**: A pilot risk assessment study of strontium chromate among painters in the aeronautical industry. *Med. Lav. 104*:448–459 (2013).
18. **International Agency for Research on Cancer**: *Monograph 100C. Chromium VI compounds* (2012). Available at: http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-9.pdf (accessed November 12, 2014).
19. **Workplace Health and Safety Queensland, Department of Justice and Attorney**: *General Chromium health monitoring*. PN10450 Version 2. Last updated June 2012. Available at: http://www.deir.qld.gov.au/workplace/resources/pdfs/ddp-chromiumguide.pdf (accessed November 12, 2014).
20. **Petrilli, F.L.**, **G.A. Rossi**, **A. Camoirano**, **et al.**: Metabolic reduction of chromium by alveolar macrophages and its relationships to cigarette smoke. *J. Clin. Invest. 77*:1917–1924 (1986).
21. **Welinder, H.**, **M. Littorin**, **B. Gullberg**, **and S. Skerfving**: Elimination of chromium in urine after stainless steel welding. *Scand. J. Work Environ. Health 9*:397–403 (1983).
22. **Petersen, R.**, **J.F. Thomsen**, **N.K. Jørgensen**, **and S. Mikkelsen**: Half life of chromium in serum and urine in a former plasma cutter of stainless steel. *Occup. Environ. Med. 57*:140–142 (2000).
23. **Hatzistavrou, D.**, **P. Ponirou**, **M. Charalampidou**, **and M. Diomidous**: Health and Safety Modelling processes at work for the support of the Epidemiological Surveillance. *Stud. Health Technol. Inform. 190*:255–257 (2013).
24. **Hinkin, J.**, **J. Gammon**, **and J. Cutter**: Review of personal protection equipment used in practice. *Br. J. Commun. Nurs. 13*:14–19 (2008).
25. **Roelofs, C.R.**, **E.M. Barbeau**, **M.J. Ellenbecker**, **and R. Moure-Eraso**: Prevention strategies in industrial hygiene: a critical literature review. *AIHA J. 64*:62–67 (2003).
26. **Ghittori, S.**, **M. Ferrari**, **S. Negri**, **et al.**: Recent prevention strategies and occupational risk analysis: Control banding and Soban. *G. Ital. Med. Lav. Ergon. 28*:30–43 (2006).