

ATTITUDE TOWARDS PERSONAL PROTECTIVE EQUIPMENT IN THE FRENCH NUCLEAR FUEL INDUSTRY

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This descriptive cross-sectional study examines the compliance of workers from the European Gaseous Diffusion Uranium Enrichment Consortium (EURODIF) with personal protection equipment (PPE) in view of the various hazards in the nuclear fuel industry. The PPE inventory was drawn up by an industrial hygienist in charge of the PPE at EURODIF. Two hundred and twenty seven (10 %) randomly selected, active and retired, EURODIF workers filled in a questionnaire on their attitudes towards PPE. Exposure data from the EURODIF job exposure matrix were used to examine whether PPE usage varies according to exposure level. The study suggests a PPE usage profile that varies depending on the hazards present and PPE available. Anti-uranium PPE and gloves were among the best rated, while anti-spray goggles were the least used. We found that, for most hazards known to cause cancer or irreversible health damage, PPE usage varied according to exposure (homogeneity test, $p < 0.05$; trend test, $p < 0.05$). The continuous use of PPE among workers should be encouraged through improvements to the PPE management system. A precise model of individual exposure can only be designed if the use and efficiency of PPE are taken into consideration.

KEY WORDS: *epidemiology, nuclear workers, uranium*

In order to study the health effects of internal irradiation from inhaling uraniferous compounds, an exposure assessment survey was conducted in several French nuclear industry plants (1). Specific job exposure matrices (JEMs) covering the different hazards present in the industry [uraniferous compounds, potentially carcinogenic, mutagen or reprotoxic chemicals (CMR) (2), noise, metal dusts, electromagnetic fields, and heat] were built for the AREVA-NC Pierrelatte (3) and European Gaseous Diffusion Uranium Enrichment (EURODIF) (4) companies. These JEMs enabled the calculation of individual cumulative exposure scores for each hazard.

However, to correctly model the internal exposure dose, we took into account the personal protection equipment (PPE) use and efficiency. This study was aimed at describing the attitudes of workers in the nuclear fuel industry towards PPE for further epidemiological investigation.

MATERIALS AND METHODS

The study was conducted at EURODIF, which produces uranium hexafluoride enriched to 3 % to 5 % in ²³⁵U, between July and October 2010. Apart from

the four gaseous diffusion plants, EURODIF includes a uranium treatment annex, auxiliary fluid utilities, the Reception-Shipping-Control Department, repair workshops, and a physical-chemical analysis laboratory.

This descriptive study used a cross-sectional design to examine the workers' compliance with PPE in view of various hazards present in the nuclear fuel industry. It was based on an inventory of currently available PPE, the assessment of its adequacy and availability, and a self-administered questionnaire on its usage and reasons to neglect it despite recommendations.

Inventory of provided PPE and performance

The levels of exposure to different hazards were assessed retrospectively for the period between 1978 and 2010, based on a EURODIF-specific JEM (4). In this JEM, exposure was assessed without taking into account PPE described in previous studies (3, 5, 6). In order to account for the effect of PPE on the workers' individual exposure, an inventory of the currently used PPE and associated collective protection measures was performed for different hazards by an industrial hygienist at EURODIF. Archived documents were inspected to complete the inventory with previously used PPE. The adequacy and performance of the available PPE were assessed by considering the compliance with PPE management system procedures for all categories of hazards. These procedures were retrieved from the EURODIF occupational safety and occupational medicine departments. Temporal changes in the PPE management system application were identified during interviews with the industrial hygienist.

Questionnaire

The inventory helped create the questionnaire on the workers' attitudes regarding PPE at each workstation and listed the existing PPE for each type of hazard by their generic names: goggles, overalls or work clothes, gloves, breathing protection, earplugs, and earmuffs. Beside each PPE were checkboxes for answers to the following three questions: (1) Was the PPE available? (yes/no); (2) Was the PPE used when its use was recommended? [Never/Occasionally (in the event of an incident or inspection)/Systematically]; (3) Why was PPE not used when recommended? (Did

not feel the need/ A hindrance or uncomfortable/ Misplaced or disappeared).

The survey

The questionnaire was distributed to workers who represented the 101 EURODIF workstations defined in the JEM during a previous exposure assessment survey (4). For each workstation, 5 to 10 active workers with a seniority of more than five years at the same workstation were selected randomly by automatic procedure. They were contacted via safety correspondents, and those consenting to participate ($n=300$) received the assessment documents. After having completed the questionnaire, the evaluators used a prepaid envelope addressed to the study manager at the IRSN, remaining anonymous. Retired evaluators were contacted by mail and their contact details were obtained from the EURODIF Human Resources Department. The assessment document was sent to all non-administrative retired staff younger than 85 years of age ($n=370$).

Treatment and analysis of the collected data

The answers were computerized and analysed at the IRSN using the Stata version 11 software. Each evaluator was asked to answer depending on his/her knowledge about the exposures, working conditions, and professional attitudes for one or more workstations. The answers were examined according to the procedure derived from the Delphi method (4) in order to yield a uniform answer for each workstation. This answer should represent the attitude of all workers assigned to a workstation.

The EURODIF PPE usage database was merged with the EURODIF JEM database according to the workstation number and title in order to input data on the amount of exposure for further analysis. The amount of exposure was categorized using a four-point scale, from 0 (no exposure) to 3 (high exposure). The PPE compliance across exposure amount categories was compared using the Pearson Chi-squared test. The null hypothesis was that the percentage of systematic uses, occasional uses, and failures to use the PPEs was the same regardless of the amount of exposure to a hazard. Furthermore, a linear trend test was performed to examine whether the percentage of systematic PPE use increases with exposure.

External validation of study findings

Since no data was available on subjects from other nuclear plants or facilities, the reliability of the results was assessed by external expertise. An independent experienced industrial hygienist and ergonomist with a 30-year long seniority at the French Atomic Energy Commissariat (CEA) and AREVA NC nuclear plants was enrolled to examine: (1) the completeness of the PPE inventory, (2) the PPE appropriateness for effective protection against hazards, (3) the temporal

changes in the PPE management system within the CEA/AREVA group, and (4) the consistency of the observed results with those at other CEA/AREVA plants.

RESULTS

Table 1 summarises the PPE and collective protection measures implemented within EURODIF for different types of hazards between 1978 and 2010.

Table 1 Personal and collective protection equipment used depending on the hazards at EURODIF (1978-2010)

Hazard		Personal protection equipment		Associated collective protection
	Type	Detail		Type
Uraniferous products	Work clothes	Emmanuelle suit (airtight vinyl overalls), MURUROA suit (Vinyl, airtight and ventilated) since 2001; ULM suit (intervention suit sealed from gas and liquids) since 2003. Tyveck suit (water repellent paper, sealed from dust) Cotton suit (coveralls, hood, boot covers)	Information/Zoning	
	Breathing protection	Complete mask + A2B2P3 cartridge up to 2003, then A2B2E2K2 Hg P3 or A2B2P3 with air supply	Markers/alarm	
	Gloves	MAPA GANTEX 540 gloves	Ventilation	
Emissions from chemical products	Breathing protection	Complete mask + cartridge A2B2P3 until 2003 then A2B2E2K2 Hg P3 or A3P3 or A2B2P3, air supply	Product substitution	
	Gloves	10 references of chemical gloves (PCB, solvents, acids, CIF3, oils, etc.)	Capture at the source (cabin, hob)	
	Goggles	Eye mask	Ventilation	
Metal dust	Work clothes	Emmanuelle suit, Pierrelatte (airtight vinyl suit), MURUROA suit (Vinyl, airtight and ventilated) from 2001, Leather CIF3 suit, Tyveck suit (water repellent paper sealed from dust), Anti-acid apron, ULM suit (intervention suit sealed from gases and liquids) since 2003	Information	
	Breathing protection	Complete mask above, or P3 half mask	Humidifiers	
	Breathing protection	Complete mask + cartridge A2B2P3 until 2003, then A2B2E2K2 Hg P3	Information	
Asbestos fibres	Work clothes	Tyveck suit (water repellent paper and sealed from dust)		
	Earmuff	OPTAC	Separation/ sound insulation	
	Ear plugs	EAR CLASSIC SNR=28 dB and moulded plugs	Covering	
Noise	Work clothes	MATISEC heavy temperature suit (airtight and ventilated suit)	Air conditioned area, Ventilation	
	Work clothes	MATISEC light temperature suit (2 piece suit worn with integrated breathing equipment)		

Major changes in the PPE management system date from the late 1990s to 2003, when national and European standards regarding non-radiological exposure management began being applied. During the first decade of operation (1978 to 1987), radiation (uranium) exposure prevention was emphasized, as heritage from the CEA pilot uranium enrichment facilities. The PPE introduced and tested there was distributed to the EURODIF workforce composed of young, massively recruited individuals who were mainly without the military discipline and radiological risk awareness for which the CEA workforce was well-known. In view of the extent of industrial activity, as well as the width of the staff, it is difficult to determine the effectiveness of PPE usage trainings and supervision during that period. The second decade (1988 to 1997) was characterized by cost reductions including cutting costs on PPE. The aptness of certain pieces of PPE was sometimes deemed questionable by the safety engineers and industrial hygienist, and the potentially exposed staff sometimes refused to use them. Management of PPE was then entrusted to the activity managers. This resulted in heterogeneity of choice, quality, appropriateness, and maintenance of the PPE, before it could be reorganized according to the ISO recommendations implemented within the Quality Management System in the late 1990s.

The questionnaire on PPE usage was completed by 107 active and 127 retired workers with a participation rate of 32 % and 36 %, respectively. For each workstation, four answers were received on average, making it possible to compare them and derive the most uniform answer. Among the three questions for each type of hazard, only question (1) on PPE availability was answered 100 % of the time,

with 100 % affirmative answers. The completeness of the answers to questions (2) and (3) varied depending on the hazard type and PPE (Table 2), with a non-reply rate ranging between 12 % and 60 %.

The PPE used systematically in the majority of workstations (≥ 70 %) were gloves for chemical products, overalls and breathing mask for uranium, and hear protective equipment. Uranium was the only hazard for which PPE was used at all the workstations for which its use was recommended. The anti-heat PPE and anti-spray goggles were the least used pieces of PPE. The reasons for not using PPE depended on the PPE. The anti-heat overalls, earmuffs, and chemical product gloves were considered a hindrance or uncomfortable, whereas the anti-spray goggles were mostly not used because they had been misplaced or perceived unnecessary. The results on the compliance with PPE use recommendation are presented in Table 3. For most hazards, especially those known to cause cancer or irreversible health damage (exposure to uranium, noise, asbestos, welding, trichloroethylene), when PPE usage varied according to the amount of exposure (homogeneity test, $p < 0.05$), a positive tendency (i.e., more systematic PPE use) was observed as exposure increased. The only exception to this tendency was observed for gloves usage while handling chlorinated products (including perchloroethylene and ClF_3), and gloves and work clothes usage while handling hydrocarbon fuels.

DISCUSSION

Although the present study is descriptive in nature, it yields data on PPE usage, reasons for incompliance

Table 2 Characteristics of the use of personal protection equipment (PPE) depending on the type of hazard

PPE use	Noise		Heat	Uranium		Chemical products			Fibres/ Dust	
	Earmuff	Ear plugs	Work clothes	Mask	Work clothes	Mask	Gloves	Goggles	Work clothes	Mask
Never / %	6	6	5	0	0	3	2	6	5	5
Occasional / %	11	9	26	16	15	23	17	20	20	12
Systematic / %	71	65	34	68	70	51	72	41	50	24
Unknown / %	12	20	36	16	15	23	19	33	25	60
Main reason for not using*	2	1	2	N/A	N/A	1	2	1, 3	1	1

*1=did not feel the need; 2=a hindrance, uncomfortable; 3=misplaced
N/A - not applicable

with PPE use recommendations, and its dependence on the nature of the hazard and level of exposure. To the knowledge of the authors, this kind of study on nuclear industry workers and limited to specific PPE has not yet been conducted (7-13). This study shows a PPE usage profile that varies depending on the hazard, but also on the proposed PPE. The rate of positive answers concerning PPE availability was extremely high (100 %). According to the statement of the industrial hygienist and the independent expertise of PPE management and application, all of the provided PPE met the adequacy criteria regarding the tasks and hazards, and was regularly inspected.

Limitations

This study is limited by its objective and design. The global participation rate was 34 %. According to Morton et al. (14), even in well-designed case-control studies, response rates of approximately 50 % are not uncommon. Sneyd and Cox (15) stated that a poor

response rate can provide more opportunity for bias to occur but does not create a selection bias on its own, any more than a high response rate guarantees an unbiased estimate. A selection bias develops if the selection probabilities are different for cases and controls based on their exposure status (15). As in the exposure assessment study (4), the workers were selected randomly. Their participation corresponds to 10 % of the EURODIF workforce for the period from 1978 to 2010, which is similar to our previous study (3, 5). Moreover, the analysis of the responses to exposure frequency and intensity showed reliable results, in agreement with other unbiased sources of exposure data such as industrial measurement data (4). We believe that a selection bias is not likely to be present in this study.

The representativeness of the answers can seem questionable considering the subjectivity related to risk. Having examined several of the uniform answers per workstation, we must admit that they can be a fairly

Table 3 Personal protection equipment use compliance across levels of exposure amount for the most prevalent exposure hazards: Homogeneity χ^2 and linear trend test p-values

Hazard type	Breathing protection		Work clothes		Gloves		Goggles		Earmuffs		Ear plugs	
	p hom	p trend	p hom	p trend	p hom	p trend	p hom	p trend	p hom	p trend	p hom	p trend
<i>Radiological</i>												
Enriched uranium	0.02	<0.01	0.02	<0.01	0.37	0.23	N/A	N/A	N/A	N/A	N/A	N/A
Natural uranium	0.13	0.03	0.17	0.04	0.41	0.52	N/A	N/A	N/A	N/A	N/A	N/A
<i>Chemical</i>												
TCE	<0.01	0.06	<0.01	<0.01	0.11	0.27	0.13	0.20	N/A	N/A	N/A	N/A
Chlorinated products	0.06	0.33	<0.01	0.02	<0.01	0.73	0.10	0.20	N/A	N/A	N/A	N/A
Fluorinated products	0.19	0.28	0.32	0.59	0.78	0.52	0.12	0.94	N/A	N/A	N/A	N/A
Aromatic solvents	0.09	0.49	0.09	0.38	0.37	0.20	0.17	0.61	N/A	N/A	N/A	N/A
Hydrocarbon fuels	0.07	0.56	<0.01	0.62	0.02	0.78	0.14	0.89	N/A	N/A	N/A	N/A
Hydrazine	0.91	0.20	0.54	0.71	0.97	0.34	0.70	0.09	N/A	N/A	N/A	N/A
<i>Physical & fibres</i>												
Noise	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.01	<0.01	<0.01	<0.01
Heat	N/A	N/A	0.95	0.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
<i>Metal dusts/ fibres</i>												
Welding fumes	<0.01	0.03	<0.01	<0.01	0.21	0.02	N/A	N/A	N/A	N/A	N/A	N/A
Asbestos	0.03	0.03	<0.01	0.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Glass/rock wool	<0.01	0.09	0.07	0.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A: not applicable

accurate reflection of the general behaviour of workers, but one which does not allow the characterisation of individual behaviour (16). Furthermore, this cross-sectional study did not allow an analysis of the workers attitudes towards different pieces of PPE over time. The state of wear and the performance of the PPE could not be assessed experimentally in the frame of this study, but were assumed effective based on the tests and in-field studies performed by the company's hygienists and safety engineers. Despite these limitations, the observed results seem coherent and consistent with the previously collected data from the CEA/AREVA group.

Attitude towards personal protective equipment

We observed a lack of information on the exposure to metal dusts and fibres, which had the highest no-answer rate (60 %). The risk related to the presence of asbestos fibres is relatively recent; the first ever asbestos inventory made for the nuclear industry dates back to 1997 (4, 5), and this had perhaps caused a lack of awareness among the retired evaluators. The reasons for not using PPE seem to be in agreement with the data in the literature: earmuffs are reputedly less comfortable than earplugs (9, 17, 18); heat protection overalls are known to be a hindrance (11, 19-21).

A more systematic use of PPE in highly exposed situations is particularly true for exposure to hazardous factors such as noise, TCE, uranium, and asbestos, and less evident for other chemical hazards. Heat is an exception to this observation, accounting for only 34 % of the systematic use of anti-heat equipment, regardless of the amount of exposure. Uranium is the only hazard with a zero refusal of PPE usage, reflecting the workers' awareness about radiation-related risks specific to the nuclear industry, as well as about the potentially irreversible and dangerous health consequences. Heat and noise were the two main exposures due to the number of workstations involved and the amount of exposure. The attitude to heat appears significantly different from other hazards, with a low acceptance of wearing anti-heat coveralls for reasons of discomfort or hindrance. The discomfort of anti-heat clothes is largely discussed in the literature (11, 20-22) and was studied at EURODIF and other CEA/AREVA facilities. Finally, the preventive solution found for heat-related disorders was to reduce the exposure duration based on a model of heat stress and cardiac strain regulation (22-24) and provide

rigorous medical monitoring, micro-breaks of 2 minutes, and intensive hydration.

The chemical risk was third in terms of protection, although the exposure to trichloroethylene and other halogenated solvents was higher than the exposure to certain uraniferous compounds. Furthermore, many of the chemicals used are classified as CMR (2), while uranium is not (2, 25, 26). This confirms the difference in the perceptions and prioritizations of risks in the nuclear industry.

Among chemical hazard PPE, usage of anti-spray goggles was the least frequent. According to the results, misplacing the goggles was the main obstacle for their use. This was affirmed by the industrial hygienist at EURODIF and other AREVA companies, as well as by data from the literature (7, 27, 28). The solution might be to provide the workers with a case, which would preclude this from occurring (7). Another case are workers wearing prescriptive glasses, who in a previous study neglected goggles due to a lesser risk perception (28).

Apart from the usefulness of these data for industrial safety and hygiene practices, we expect the results of this study to be of use in epidemiology and risk analysis. Using the data on individual and collective protection measurements and the attitude of EURODIF workers towards personal protective equipment, a model of individual exposure could be made, which would help estimate the internal radiation dose resulting from uranium exposure. The results of a previous work show that a combination of the JEM and internal dosimetry method allows for a more accurate estimation of the dose (6). The EURODIF JEM (4) was created as a basis for such an estimation, taking into consideration both radiation and non-radiation hazards.

CONCLUSION

The results from this study suggest that, in spite of the predominance of non-radiological physical and chemical exposure, EURODIF workers are more concerned about the radiation-related risks. This concern seems to be shared throughout the French nuclear industry. Regulations on chemical risk prevention are relatively recent, but their application should be supported by improvements to the PPE management system, effective communication from managers and supervisors, and encouraging the continuous use of PPE.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Sažetak

ODNOS PREMA OSOBNOJ ZAŠTITNOJ OPREMI U FRANCUSKOJ INDUSTRIJI NUKLEARNOGA GORIVA

Ovo opisno presječno istraživanje ispituje usklađenost radnika s opremom u pogledu mnogobrojnih rizika u industriji nuklearnoga goriva. Inventar opreme izradio je stručnjak iz područja higijene rada, zadužen za zaštitnu opremu pri francuskoj tvornici za obogaćivanje urana EURODIF. Upitnik o svome odnosu prema zaštitnoj opremi ispunilo je 227 (10 %) nasumično odabranih zaposlenih i umirovljenih radnika te tvornice. Podaci o izloženosti iz matrice profesionalne izloženosti u tvornici EURODIF upotrijebljeni su kako bi se utvrdilo ovisi li korištenje opreme o stupnju izloženosti. U istraživanju se izlaže model korištenja zaštitne opreme, koji ovisi o rizicima i dostupnoj opremi. Oprema za zaštitu od urana i rukavice među najbolje su ocijenjenima, a zaštitne naočale među najgorima. Ustanovili smo da, za većinu rizika za koje je poznato da mogu uzrokovati rak ili trajnu zdravstvenu štetu, povremena i sustavna uporaba opreme ovisi o stupnju izloženosti (test homogenosti, $p < 0,05$; test trenda, $p < 0,05$). Među radnicima je nužno poticati kontinuiranu uporabu opreme dugoročnim unaprjeđenjima sustava upravljanja i učinkovitom komunikacijom njihove uprave i nadzornika. Za kreiranje preciznog modela pojedinačne izloženosti nužno je razmotriti korištenje i učinkovitost osobne zaštitne opreme.

KLJUČNE RIJEČI: *epidemiologija, radnici u nuklearnoj industriji, uran*

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