

TIME-PERIOD MORTALITY PATTERNS IN A GASEOUS DIFFUSION PLANT WORKFORCE

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Abstract

Background: We sub-divided a cohort of 6820 workers at the Paducah (KY) Gaseous Diffusion Plant (PGDP) which was traced from 1953 to 2003. The subdivisions were made to assess the mortality risks in a sub-group of workers employed solely during the plant's refit period, a time of suspected higher exposure to metal dusts (nickel, arsenic, chromium and uranium) and trichloroethylene. **Methods:** This article describes a comparison of exposures and causes of death for 754 workers employed exclusively during the period of 1975–1979, with 1554 workers who worked in this period as well as other years. This interval was when the gaseous diffusion cascade facilities were re-fit. The workers employed 'only' during this period have a variety of deterministic factors (age-at-hire, duration of employment) that distinguish this sub-group of employees from the 'long-term' workforce. **Results:** The 'only 1975–1979' workers had a larger fraction of minorities and female workers. This 'only' sub-group was disproportionately employed in unskilled labor positions. The 'only' workers were younger than the referent group, and a 14-year earlier mean age at death. The all-cause mortality standardized rate ratio [SRR] was 1.58 [95% CI: 0.97–2.42]. The 'only' group was significantly different from the 'ever' workers with respect to suicides, SRR = 3.74 [95% CI: 1.86–6.69], and for homicides, SRR = 11.71 [95% CI: 3.20–30.03]. **Conclusions:** These elevated mortality risks do not seem to be due to PGDP employment exposures to metal dusts or trichloroethylene. Socio-economic factors may be a determinant for the patterns of suicides and murders described for this sub-group of employees. These findings provide guidance for communities with a dominant local employer. Persons who experience short-term hiring may warrant public health services to mitigate their risk of tragic deaths. A case-control study of these deaths is recommended to clarify individual risk behaviors.

Key words:

Occupational cohort, Suicide, Period effect, Epidemiology

INTRODUCTION

Epidemiologic research often seeks for association along the lines of person, place, and time variables [1]. On the other hand, one of the peculiar epidemiological approaches that is seen rather infrequently is the 'period' study [2]. In epidemiological jargon, a 'period' refers to a span of time when a particular risk factor has changed some way for a defined time interval. Then the population's health varies from that period onwards as a function of age (simply disease processes are often associated

with older age, e.g. cancer), or cohort effects (e.g. disease latency as a function of age at exposure) [3]. Examples of the 'period' studies in the occupational health literature refer to before-and-after the advent of a new technology or a protective measure [4–9].

Two previous papers from the NIOSH study on workers at the Paducah Gaseous Diffusion Plant (PGDP) in Western Kentucky led to this specific analysis.

First, the study of all workers described an overall reduced standardized mortality ratio (SMR) for all causes of death,

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and for the major causes of death, e.g. heart disease and cancer. However, that paper identified a perplexing suicide pattern. Significant excess mortality was observed for suicides (SMR = 2.19, $p < 0.05$) for the years 1970–1979 and for the ages 40–44 years (SMR = 8.12, $p < 0.05$). Non-significant elevations of suicide risk were noted for the ages 35–54 years in each of the five-year increments for the study period [10]. Then, an in-depth examination of the workers' mortality from the 1975–1979 period (an interval of heightened hiring at the plant) identified a standardized rate ratio (SRR) of 8.13 for workers employed solely during the 1975–1979 period [11].

This report is an assessment of the mortality risk among workers employed exclusively during this period of unusual exposures due to the dismantling of diffusion centrifuge. This dismantling process was suspected of producing heavier-than-usual metal dusts (e.g. nickel, uranium, arsenic, chromium) as well as cleaning chemicals (trichloroethylene) at PGDP. This U.S. Department of Energy (DOE) owned, contractor-operated uranium enrichment facility was commissioned in 1952 as a part of a U.S. government program to produce enriched uranium for military reactors and nuclear weapons [12,13].

In the mid-1960s, the Paducah plant's mission changed from enriching uranium for nuclear weapons to one focused on enriching uranium for use to generate electricity [12,13].

PGDP "fed" enriched uranium to plants in Oak Ridge, TN, and Piketon, OH, where it was further processed for use by commercial nuclear reactors. Today, PGDP is the only gaseous diffusion plant operating in the U.S. to serve domestic and foreign electric power reactors [12–14].

In the early 1971, the passage of the Occupational Safety and Health Act prompted many companies to begin revising their operating procedures to reduce hazardous settings, and many workplaces began exposure monitoring to anticipate the closer regulation directed by the federal government. Concomitant with these 'process' changes, came the modification of PGDP from producing uranium enrichment to a level of 2% U-235 up to 5.5% U-235 [14]. During the period of 1975–1979, PGDP employment rose precipitously, then declined just as sharply (see Figure 1).

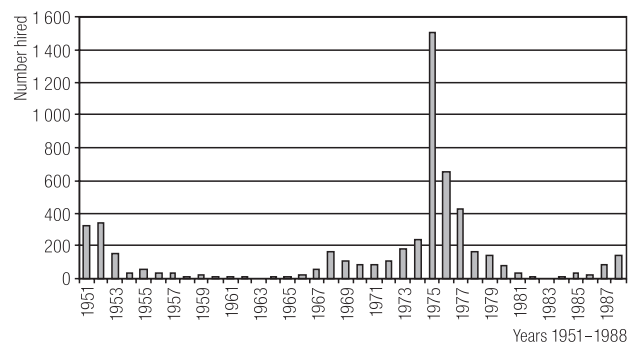


Fig. 1. Distribution of PGDP hiring dates.

The workers who were employed exclusively during this 'refit' period pose a peculiar cohort. They potentially experienced a change in their disease risk, owing to employment during this unusual period.

METHODS

This retrospective cohort mortality study consisted of eligible PGDP workers enumerated from employee records. Demographic, work history, and vital status data for 6820 workers were collected. Inclusion criteria required workers to have been employed at the PGDP for at least 30 days from the start of plant operations, September 1952 through December 2003. These PGDP cohort members workers experienced 1672 deaths. At the time of this publication, a 97.8% follow-up for vital status and cause of death was accomplished. The checking of mortality certificates from federal and state agencies was the most prominent aspect of the workers follow-up [15].

For the preliminary evaluation of specific causes of death, Standard Mortality Ratios (SMR) were used to select elevated mortality risks for direct in-depth analyses. This began with comparisons of two groups that were 'internal' to the cohort; the Standardized Rate Ratios (SRRs) were calculated for those in-depth analyses. [16]. The focal group of employees were 754 workers employed exclusively during the 1975–1979 'refit' period — these workers are referred to as the 'only' group. The principal comparison for the mortality experience of these 'only' workers are the 'ever' exposed group comprising 1554 workers who were employed before or after the 1975–1979 period as well as during some portion

of the 1975–1979 period. Finally, there was a balance of the cohort of workers designated as ‘never’; these workers were employed in the time periods exclusive of the 1975–1979 period of research interest. To analyze the mortality experience of these workers, we used the Life Table Analysis System (LTAS) developed by NIOSH during the 1970’s and up-dated in 2005. LTAS was created to analyze cohorts defined by occupational exposures. The program compares the observed rate for the cohort with comparison rates for several referent populations. Stratified by age, race, sex, calendar time, duration of exposure and time of employment, LTAS calculates person-years at risk for the cohort under study [17,18].

Statistical significance testing consisted of two-sided p-values with 95% confidence intervals for SMRs and was performed by comparing observed with expected numbers of deaths, assuming a Poisson distribution [19]. Confidence intervals and two-sided p-values were calculated when the number of observed deaths was at least three, under the assumption that the observed deaths were random events with a Poisson distribution. LTAS uses an extrapolation technique for greater numbers of observed deaths [19].

A Job Exposure Matrix was developed by Moser [20] under the guidance of the senior industrial hygienist for the project. The increments of exposure likelihood were based on discussions with current and past employees at the plant. Each job title was ranked by classifying the likelihood of a short-term exposure to a specific chemical agent (e.g. TCE) or metal (e.g. nickel) from zero, denoting no possibility of exposure, through 5, standing for the highest probability of exposure. These exposure levels are qualitative only, and as such, have no mathematical relationship — an exposure of 4 is not twice the exposure of 2.

RESULTS

The majority of the PDGP cohort was composed of white males (89%) who were employed at the PGDP plant for 1–5 years (35.5%). The ‘all-cause’ mortality and ‘all-cancer’ mortality experience of the PGDP cohort

was significantly lower than that of the U.S. population. The all-cause SMR was 0.73 (95% CI: 0.6988–0.7696), based on 1654 observed deaths versus 2276 expected. The all-cancer SMR was 0.77 (95% CI: 0.6999–0.8423). This pattern epitomizes the conventional ‘Healthy Worker Effect’ (HWE) [21,22].

The period of 1975–1979 was a time-period that witnessed a hiring ‘spike’ which resulted from the gaseous diffusion cascade being disassembled and re-fit for improved production and to achieve greater enrichment levels. In this period, 1514 ‘new’ hires were made to the PGDP workforce. These workers joined a group of 1554 ‘continuing’ workers. Of the 1514 ‘new’ employees, 760 continued to work at the PGDP after 1979. A group of 754 workers were employees ‘only’ during this five year period.

Figure 2 describes the race and gender aspects of the ‘period’ workforce. These workers were predominantly Caucasian men; however, the proportion of women (17%) within the ‘only’ 1975–1979 group is similar to the entire cohort (18%) and different from the ‘ever’ working in 1975–1979 (12%). By racial composition, the ‘only’ group held 17% minority races (98% African-American). This is dissimilar to both the ‘ever’ working in 1975–1979 group and the entire PGDP cohort that held 11% minorities. When combined, the women and minorities comprised nearly one-quarter (24%) of the workers who were employed ‘only’ in 1975–1979.

As indicated in Figure 3, the age-at-hire was much younger for the ‘only 1975–1979’ workers, compared to the

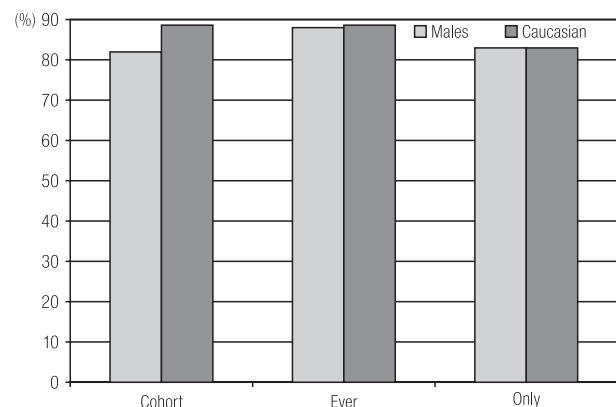


Fig. 2. Race and gender of persons hired, the entire cohort [1951–2002], and by the two comparison groups.

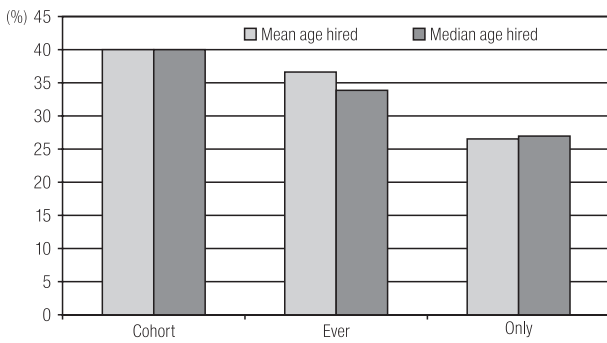


Fig. 3. Mean and median age-at-hire at PGDP, by sub-group analysis.

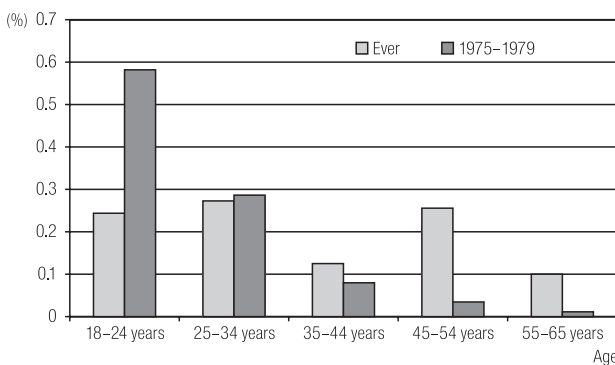


Fig. 4. Distribution of workers at PGDP by age-at-hire groups. Comparison of those employed exclusively in 1975–1979 with those who were ever employed during the 1975–1979 period as well as in other time periods.

‘ever’ hires (see Figure 4). The mean age-at-hire for the ‘ever’ workers (36.7) was 10 years older than for the ‘only’ workers (27.7). This difference in age-at-hire may reflect a difference in the skill level of the two groups; the ‘ever’ workers being more ‘skilled.’

As mentioned before, the period of 1975–1979 were anomalous hiring years compared to the 46 years of the PGDP

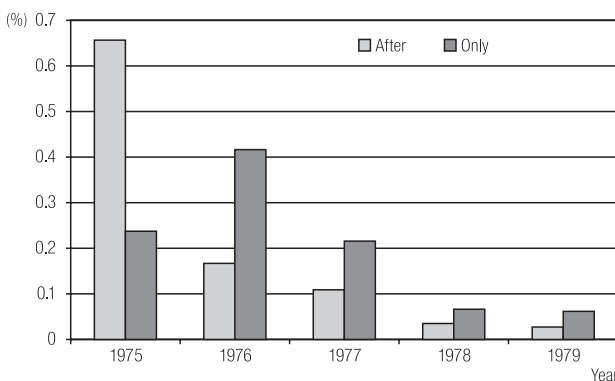


Fig. 5. Fraction of comparison groups, hired by year.

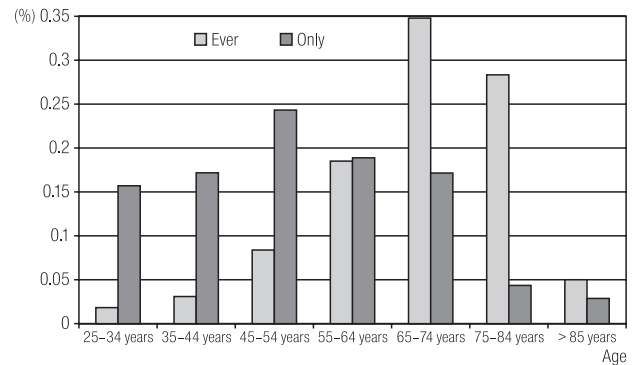


Fig. 6. Age at death for comparison groups.

cohort. The sharp workforce rise in 1975 concerned mainly the workers who would continue employment after 1979; 58% of the total ‘ever’ workers versus 24.5% of the ‘only’ workers were hired then (see Figure 5). In the following four years, the ‘only’ workers were a larger fraction of the annual hires.

A distinction between the mortality pattern of the ‘only’ versus ‘ever’ workers appears with the age at death (see Figure 6). The mean age at death for 70 deaths of the 754 ‘only’ workers’ up to 2003 was 52.8 years. For the 490 deaths of 1554 ‘ever’ workers’, the mean age at death was 66.2 years.

The ‘ever’ work group held 6.3-times as many Cascade workers as the ‘only’ 1975–1979 workers (see Figure 7). In the ‘only’ group, the proportion of workers who worked in the converter shop was twice as high as among the ‘ever’ workers. The ‘only’ group had 39% more of their workers assigned to ‘general’ maintenance; twice as many assigned to roads/grounds maintenance; and 28% more who worked in ‘offices.’ This contrast in the proportion of ‘skilled’ workers

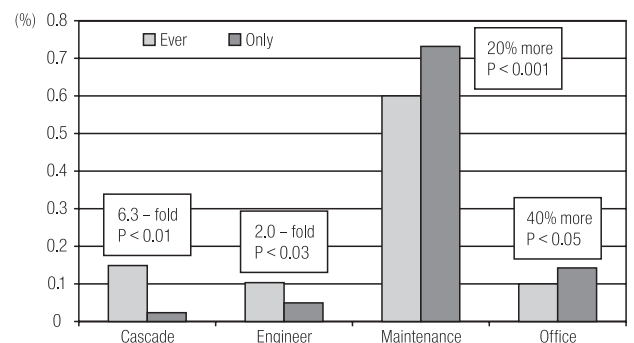
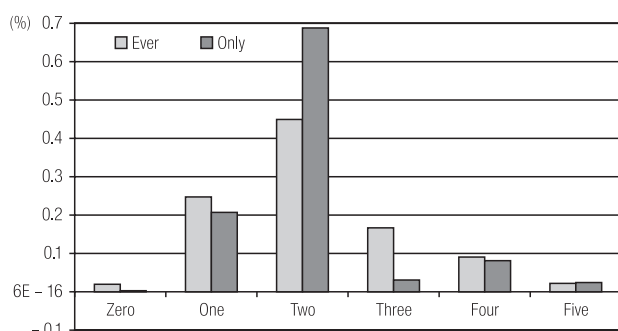


Fig. 7. Proportion of occupational categories within the ‘ever’ and ‘only’ employment groups.



0 — never; 1 — possibly exposed; 2 — somewhat likely to be exposed; 3 — likely to be exposed; 4 — probably exposed; 5 — certain to be exposed.

Fig. 8. Proportion of TCE exposure distribution by levels of exposure.

in the 'ever' group and 'unskilled' workers in the 'only' group is well illustrated by the distribution of 'health physicists.' There were seven health physicists employed among the 'ever' group, versus a single one in the 'only' group.

A particular interest for the PGDP workers that our team spoke with, was the chemical exposure. The likelihood of trichlorethylene (TCE) exposure was quite different for the two study groups. Three of the TCE exposure levels had similar patterns for the two groups (see Figure 8). The workers who were employed 'only' during the refit period had a lower likelihood of TCE exposures for categories 0, 1, 3, and 4. A much larger proportion (68%) of the 'only' workers were classified as level 2 (somewhat likely to be exposed to elevated levels of TCE) than of the 'only' workers 44% ($p < 0.001$). However, the 'ever' group had five-fold as large a fraction of their workers exposed at level 3 as did the 'only' group. Furthermore, in level 5 category (certain to be exposed to elevated levels of TCE), there were 3% of the 'only' workers versus 2% of the 'ever' workers.

For the metals, however, the 'only' group had a considerably larger fraction exposed to inorganic metals, than did the 'ever' workers. The 'only' workers had a significantly larger proportion of their workers exposed to uranium, nickel, beryllium, and arsenic at level 5, than did the 'ever' group ($p < 0.01$) (see Figure 9). From inspection of the sub-title specifications, this appears to be an effect of a larger group of the 'only' workers who worked

in 'General' Maintenance. For chromium exposures, the 'only' group had a larger fraction of workers exposed at levels 4 and 5 ($p < 0.03$). This seems to be the impact of a larger fraction of the 'only' workers in 'machining' maintenance.

In a previous report from the PGDP Plant Worker's Health Study, "Non-significant elevated SMR's were noted for »other« diseases of the nervous system and sense organs ($SMR = 1.18$; 48 observed versus 40.6 expected). When stratified by year and age, statistically significant excesses in mortality were observed for deaths related to suicides during certain specific time periods; $SMR=2.19$ ($p < 0.05$) for years 1970–1974 and $SMR=8.12$ ($p < 0.05$) for years 1975–1979 in the 40–44 age group." This earlier report was the impetus for us to examine the 'period' of 1975–1979, to try to discern whether the employees who were employed 'only' in those five years had a different mortality pattern than the employees who were employed before and/or after the period of interest.

Local union workers reported that these 'short-term' workers were systematically hired in January and discharged in December (with pay until the end of the month), then rehired in January to prevent their being eligible for health benefits. Because of the clustering of suicides during this period, we expressly wanted to examine to what extent the 'period only' workers were involved. Table 1 provides the findings from these cause-of-death analyses.

The all-cause mortality standardized rate ratio (SRR) was 1.58 (95% CI: 0.97–2.42). Most of the national leading causes of death (heart disease, cancer, stroke) were

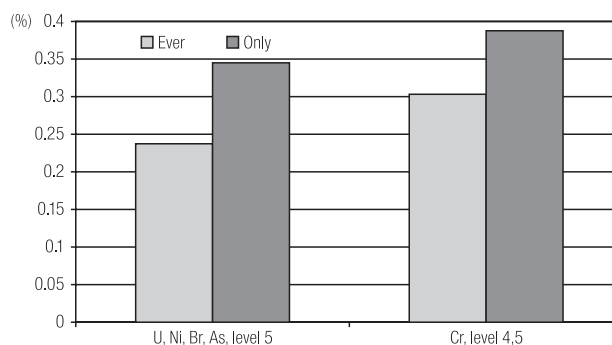


Fig. 9. Exposure levels 4 and 5 combined for exposure to specific metals for the 'ever' versus 'only' groups.

Table 1. Counts of selected causes of death, by less than 35-year-olds and total workers. Standardized Rate Ratios [SRRs] for comparisons between the 'only'/'ever' groups

Causes of death	Ever	Only	Ever	Only	SRR	P value
	< 35	< 35	all	all	only/ever	
All Ca	2	1	145	15	0.72	–
GI Ca	1	1	24	6	1.75	–
Lung	0	0	45	3	0.47	–
CHD	0	1	211	17	0.08	–
MI	0	1	125	7	0.06	–
Stroke	1	0	20	4	0.20	–
Accidents	2	2	7	6	1.18	–
Suicide	1	3	5	6	3.74	< 0.05
Homicide	1	2	1	4	11.71	< 0.05
Total	8	11	490	70	1.54	–

SRR — Standardized Rate Ratios.

Ca — Cancer.

CHD — Coronary Heart Disease.

MI — Myocardial Infarction.

found to be protective (SRR < 1.0), whether due to age-at-death or different risk factors. This provides evidence to an accentuated Healthy Worker Effect for the 'only' workers compared to the already reduced mortality pattern found for the PGDP cohort (attributed to the Healthy Worker Effect) and seen with the 'ever' worker group. The 'only' workers had slightly more deaths before the age of 35 years than did the 'ever' group (11 vs. 9) despite the great distinction in total deaths (70 vs. 490). Specifically, the SRR for 'all digestive cancers' was elevated for the 'only' workers (pancreas was the largest single site), but not so for lung cancer. Deaths by accidents were also slightly elevated, but none of these differences were statistically significant. It is with the suicides and homicides that statistically significant SRRs were found; 3.74 for suicides (95% CI: 1.10–12.76, based on 11 events), and 11.71 for homicides (95% CI: 1.05–131.22, four deaths), respectively.

DISCUSSION

We studied a cohort of 6 820 workers at the Paducah (KY) Gaseous Diffusion Plant for the period from 1953 to 2003. Other articles describe the cohort characteristics and findings from those studies. This article is focused on the

assessment of mortality risk in a group of workers who were employed exclusively during the period of 1975–1979. This interval took place when the enriched (ionizing radioactive) uranium hexafluoride gaseous diffusion cascade facilities were dismantled and re-fit for compliance with new federal occupational safety standards.

These short-term employees do not show evidence of having elevated disease risks due to their exposures at PGDP. However, they seem to represent a group that is disposed to violent deaths. Socio-economic situation may be a greater determinant for the murder-suicide-accident pattern [23]. The brief income period, followed by unemployment may have contributed to depression and a penchant for risky behavior among this group [24,25]. The impact was mainly in the years immediately after PGDP employment, and returned to 'expected' levels by the 1990's. This group of findings provides guidance for communities with a dominant workforce employer who may have cycles of short-term hiring. The individuals who take such jobs or for whom lives have radical, abrupt changes, may warrant public health services or programs to mitigate their risk of such 'unusual' deaths. A case-control study of these deaths is recommended to provide clarification of individual risk behaviors.

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