

Examination of Potential Sources of Bias in the US Coal Workers' Health Surveillance Program

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Twenty years ago, the National Institute for Occupational Safety and Health (NIOSH) reported on the trend in pneumoconiosis prevalence among US coal miners for 1970–1986.¹ The primary conclusions from those data were that the reduction in underground coal mine dust exposure mandated by federal regulations in 1969 led to lower prevalence of pneumoconiosis among underground coal miners. Overall, these results and conclusions were uncontroversial. Since that time, NIOSH has continued to report findings from the Coal Workers' Health Surveillance Program (CWHSP) in the scientific literature,² in government reports,^{3,4} and on the NIOSH Web site.^{5,6} Figure A (available as a supplement to the online version of this article at <http://www.ajph.org>) shows trends in the national prevalence of coal worker pneumoconiosis (CWP) from 1970 to 2009 as reported on the Web site in early 2012. In addition to showing the previously reported decline in prevalence from 1970 to 1986, it also indicates an increase in CWP prevalence in recent years. NIOSH and others have recently reported on and investigated this phenomenon.^{7–15} These more recent findings have generated concern among the public health community and others.^{16–19}

In reporting CWHSP statistics, NIOSH is aware that the data are collected primarily for worker monitoring. That is, the purpose is to prevent CWP progression in affected miners via secondary prevention. The use of any data for public health surveillance is potentially vulnerable to various factors that could affect its integrity and validity. For instance, these data are susceptible to potential biases from worker participation and selection effects, as well as to effects related to temporal changes in employment and participation among coal mining regions across the country. Coal is ranked based on carbon content, with the highest rank coals (those with the highest carbon content) associated with increased risk of development and progression of CWP. We

Objectives. We examined the potential influences of certain selection factors on the utility of the Coal Workers' Health Surveillance Program (CWHSP) data for tracking disease distribution and trends.

Methods. We combined data from the CWHSP and the Energy Information Administration to examine any influence of variable worker participation on observed disease prevalence. We evaluated effects of differential participation by coal mining region, temporal changes in employment, and active surveillance efforts.

Results. The published findings of pneumoconiosis distribution and trends from the CWHSP were robust compared with the various participation factors that might have affected their validity for population-based estimates of disease burden. Exploration of factors that could potentially bias the findings generally led to small increases in the primary estimates, mostly for the early years of the program.

Conclusions. We confirmed previously reported findings that there was a high prevalence of coal worker pneumoconiosis (CWP) around 1970–1974, a substantial decline in 1995–1999, and indications of an increase since then. Overall our findings suggest that the previously reported distribution and trends in CWP prevalence were broadly accurate. (*Am J Public Health*. 2014;104:165–170. doi: 10.2105/AJPH.2012.301051)

compiled this report to examine such issues. Our objectives were to formally address the following questions. (1) Do the overall data, as shown in Figure A, provide an accurate picture of temporal trends in national pneumoconiosis prevalence among underground coal miners? (2) Do the national figures conceal trends of concern or interest in specific regions? (3) Are there factors that affect the utility of the program data for population-based surveillance?

METHODS

A detailed description of the operation of the CWHSP is provided by Attfield and Althouse.¹ Briefly, mine operators make a chest x-ray available within 6 months of employment for all underground coal miners. A second x-ray is available at 3 years, and thereafter, coal miners are eligible for a free chest x-ray every 5 years. Employees at each mine are notified of the availability of such x-rays, and miners choose whether they wish to obtain the x-ray. Miners attend a local medical facility, at which

a preliminary classification is made using the International Labor Office classification system for classification of radiographs of pneumoconioses.²⁰ The x-ray and accompanying forms, including a work history, are sent to NIOSH, which obtains at least 1 further classification by a NIOSH B Reader (i.e., a physician who is required to demonstrate competence in classifying pneumoconiosis by passing a rigorous examination every 4 years; see <http://www.cdc.gov/niosh/topics/chestradiography/breader.html>).

The present analyses employed the NIOSH final determination of the radiographic classification, which is made using a standardized process in the US code of federal regulations Title 42²¹ and summarized in Figure A of a previous publication.² In 2005, NIOSH supplemented the CWHSP with an active surveillance component named the Enhanced Coal Workers Health Surveillance Program (ECWHSP).²² The ECWHSP emphasizes community outreach and utilizes a mobile examination unit to collect radiographs at or near mine sites.

Unless otherwise specified, all results in this report were based on miners with 20 or more years of tenure. Mines and miners were grouped by geographical region as follows (Figure B, available as a supplement to the online version of this article at <http://www.ajph.org>): Appalachia as a whole and also subdivided into the high-rank bituminous region and the northern and southern low-rank Appalachian regions; the Midwest; and the West. The high-rank bituminous region consists of central Pennsylvania, western Maryland, the eastern edge of West Virginia, and western Virginia. In 1 analysis, the high-rank region was separated into northern (Pennsylvania and Maryland) and southern (West Virginia and Virginia) components. Because there are few currently active mines operating in the Anthracite region, we omitted the miner radiographs from this region from this analyses. In analyses that focused on the level of CWP (regional, background), Alabama was included in the Midwest category because of insufficient data to create a "South" subgroup. The prevalence of CWP in Alabama was similar to the Midwest and lower than that in the Appalachian subgroups. In the analysis that focused on factors that affected the interpretation of the summary figures (representativeness), Alabama was included with southern Appalachia because those analyses included trends in regional employment over time.

We describe the details of the particular methods used for each subanalysis in the following.

RESULTS

The following findings are organized according to the 3 questions posed in the Introduction section.

Temporal Trends in Pneumoconiosis Prevalence Among US Coal Miners

The risk of CWP development was not only related to level and duration of dust exposure but also to increases with higher coal rank. Coal rank increases from west to east across the country.^{23–25} During the last 40 years, the coal mining workforce in the West has increased, whereas Appalachia has lost workers (information abstracted from Energy Information Administration reports).²⁶ In 1970–1974,

about 88% of underground coal miners worked in the Appalachian region, with 10% in the Midwest and 2% in the Western coal fields. By 2005–2009, the Appalachian coal miner population decreased to 74% of the total workforce, whereas the Midwest and Western regions grew to 16% and 10%, respectively. These demographic changes took place gradually and continuously over the 40-year period.²⁶ Given the coal rank effect, these regional employment trends would be expected to lead to a reduction in the estimate of national CWP prevalence, even if the region-specific prevalence remained unchanged. This issue was explored by deriving adjusted national prevalences for miners with 20 or more years of tenure for 1970–1974 and 2005–2009 using the regional (Appalachia, Midwest, and Western) CWP prevalence data for 1970–1974 adjusted to the regional employment distributions in 1970–1974 and 2005–2009 (Table 1). The results showed that the employment-adjusted prevalence for 1970–1974 was 29.9% compared with 28.9% for 2005–2009. This suggested that, if there was no change in the dust exposures and disease risk, the change in regional employment from 1974 to 2009 would have resulted in a 1% drop in the observed national prevalence for miners with longer tenure. The employment-adjusted national prevalence for 1970–1974 was marginally higher than that observed (29.9 compared with 29.8%—see the following). This was because of slightly fewer miners from Appalachia participating compared with the number of employed miners.

Employment had not only moved westward over time, but proportionally more of the western miners participated in the x-ray program over time. Initially, in 1970–1974, Appalachian miners made up 86% of the CWHSP participants, with the remainder consisting of the Midwest (11%) and West (3%). By 2005–2009, the distribution was 68%, 21%, and 12% for the 3 regions, respectively. As with the employment changes, this would be expected to have contributed to a reduction in the observed national CWP prevalence over time.

This effect was evaluated using the regional program participation rates for 1970–1974 and 2005–2009 and the regional CWP prevalences for 1970–1974. The estimated national prevalence rates based on these data were

29.8% and 28.6%, respectively, again indicating an approximate 1% drop. This reduction, and that associated with changes in employment across the regions, was much less than what was observed over the time period both nationally (29.8%–6.5%), and within regions (Table 1). Overall, geographical trends in employment and participation had little effect on the observed temporal trend in national prevalence estimates and could not account for the major decline in prevalence observed over the period.

National Figures and Concealed Trends of Interest

Regional temporal trends in CWP prevalence were derived and examined (see Figure B for regions). CWP prevalences for these regions over time are shown in Figure 1 for miners with 20 or more years of tenure; all showed a decline from 1970–1974 to 1995–1999. After that, there was evidence of increases in disease prevalence in all regions, with the greatest observed increase in prevalence in the high-rank and southern Appalachian regions (Figure 1b). As would be expected from knowledge of coal rank effects, CWP prevalence was greatest in the high-rank bituminous region. However, the CWP prevalence in the southern Appalachian region, which was initially much lower than that for the high-rank region, decreased less rapidly over time, and in recent years, was close to that in the high-rank area. In the other regions, the prevalences fell to similar low levels in 1995–1999, with those for the northern Appalachian region declining the fastest. As noted previously, there were some indications of increases in prevalence since 1995–1999.

The high-rank region is composed of 2 geographically distinct areas: central Pennsylvania and Maryland in the north, and eastern West Virginia and western Virginia in the south. The southern high-rank area lies adjacent to the southern Appalachian region, which had the previously noted elevated disease rates. To further evaluate the high-rank region, we divided it into its 2 geographical subregions (northern = PA + MD; southern = WV + VA). Initially, the prevalences in the 2 high-rank subregions were similar (Figure 2), but after 1975–1979, the prevalence in the northern subregion declined much faster than it did in the south. After reaching a low in 1995–1999

TABLE 1—Regional Prevalence, Employment, and Participation for Underground Coal Miners With ≥ 20 Years Tenure: United States, 1970–1974 and 2005–2009

	1970–1974			2005–2009		
	Observed Prevalence	Employment (Proportion) ^a	Participation (Proportion) ^b	Observed Prevalence	Employment (Proportion) ^a	Participation (Proportion) ^b
Appalachia	30.3	0.88	0.86	8.6	0.74	0.68
Midwest	29.0	0.10	0.11	1.6	0.16	0.21
West	18.2	0.02	0.03	2.8	0.10	0.12
National	29.8	1.00	1.00	6.5	1.00	1.00
Adjusted national prevalence		29.9	29.8		28.9	28.6

Note. Participation indicates the proportion of all participating miners who were in the corresponding region, not the proportion of eligible miners participating.

^aThe adjusted national prevalence adjusted for regional employment distribution.

^bThe adjusted national prevalence adjusted for regional participation rates.

at 2.2% (a similar level to that seen in other low-rank regions), the disease prevalence began to rise and was at 9.8% in 2005–2009. By contrast, the low for the southern subregion was 9.7%, with a rise to 16.7% in 2005–2009. In recent years, the prevalence in the southern subregion was similar to, but slightly greater than, that in the southern Appalachian low-rank bituminous region.

Factors That Affect Use of the Program Data

There were several factors beyond those described in the Temporal Trends section that could potentially affect the use of the program data for the assessment of disease extent and

severity. The most important factor of possible consequence was perhaps the addition of active surveillance efforts to this historically passive regular x-ray surveillance program. A mobile examination unit has operated since 2005 (ECWHSP), initially visiting coal fields where hot spots of rapid CWP progression have been noted.⁷ It follows that the act of supplementing the regular program with participants from areas with potentially higher prevalence of CWP could have led to an upward spike in prevalence, perhaps creating a false impression of increased disease risk.

To explore this possibility, we tabulated the ECWHSP data separately from that of the regular program (Table 2). Overall, the concern

that the enhanced data might have biased the findings upward was not substantiated. Instead, CWP prevalence from the regular program was higher than that for the enhanced program for every region, except the Midwest.

Another factor that might have affected the use of program data for population-based surveillance related to the possibility that motivation for continued participation in the program might be diminished once miners knew they had CWP. The primary purpose of the program was to notify miners of their CWP status and provide them with the legal right to transfer to a low-dust job if they had evidence of CWP. Once miners were told that they had CWP, it was possible they felt less need

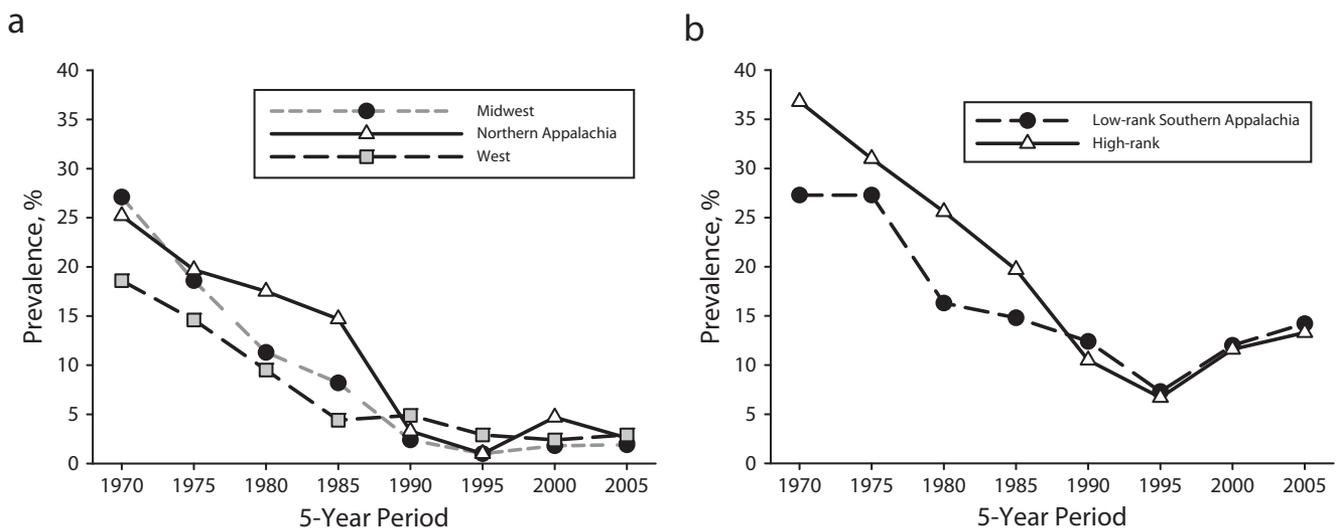


FIGURE 1—Temporal prevalences of coal worker pneumoconiosis category 1+ for miners with ≥ 20 years tenure in (a) the Midwest, Northern Appalachia, and West regions, and (b) the high-rank subregions and the Southern Appalachia region: United States, 1970–2009.

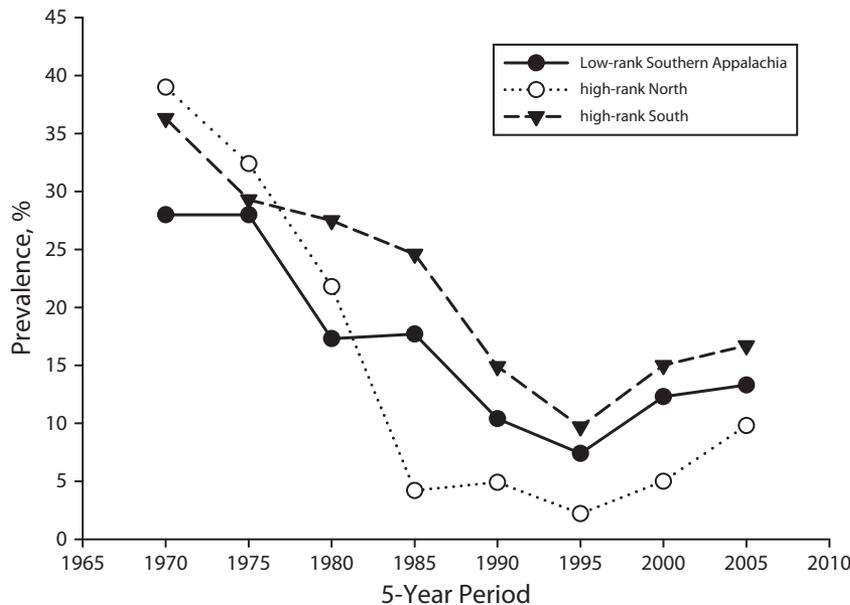


FIGURE 2—Prevalence of coal worker pneumoconiosis category 1+ for miners with ≥ 20 years tenure for the 2 high-rank subregions and the (low-rank) Southern Appalachian region: United States, 1970–2009.

to participate in the future. In this way, miners with CWP might tend to remove themselves from the program, whereas those without CWP might continue to participate until disease was detected. The overall result would be a systematic undercounting of CWP cases, particularly in older age groups.

This possibility was examined by evaluating 5-year periods of data (e.g., 1970–1974 to 1975–1979). We derived the probability of participation at the final survey depending on CWP status at the initial visit. We analyzed those with 15 or more years of tenure at the first survey so that the findings from the final survey were consistent with the focus on those with 20

or more years of tenure (i.e., 15 + 5 = 20 years). This showed that the hypothesis was largely correct: miners without CWP were 0.79 times less likely to participate at the next opportunity if they were told they had CWP category 1 or higher at the initial visit. Over the course of this program this ratio remained fairly steady, varying from 0.64 to 0.86 between 1970 and 1999. Only for 2000–2004 to 2005–2009 were those with CWP more likely to re-participate than those without CWP, although the difference was small (1.05 times more likely).

An attempt was made to correct for the previously noted effect of the differential participation rate based on disease. At any round

of surveys, the prevalence was derived from those who attended for the first time and from those who had a previous radiograph. To compensate for different participation rates among those who had a previous radiograph but different disease status, we adjusted the 20-year tenure prevalences so that participation of those with and without CWP at the previous survey was set to be equally likely. This led to slightly higher estimates in the early years of the program (25% vs 23% for 1975–1979, or 8% higher), with a mean increase over the whole period of about 4%. Overall, the analysis showed that the reduction in participation by miners after they were known to have disease resulted in underestimates of CWP prevalence over the life of the program.

The issue of a so-called “background” prevalence of abnormality mimicking pneumoconiosis was also examined. Aging and smoking are factors that could lead to minor radiographic changes that could be classified by some readers as small opacities.²⁷ If these phenomena were consistent among all individuals examined, it would lead to differential misclassification of disease and thus systematically bias the actual prevalence upward. To understand the magnitude of this effect, we evaluated the prevalence of reported CWP by region, time period, and age group for those with less than 5 years of self-reported mining tenure. Among this group, few would be expected to have developed genuine CWP. Using these data, we adjusted the observed cases downward proportionately. The results, expressed as observed and adjusted CWP prevalences by time period, are shown in Table 3.

DISCUSSION

The results demonstrated that the overall findings published by NIOSH, (i.e., those from our surveillance Web site and related documents),^{1,2,5–13,15} were robust compared with factors that might have affected their accuracy as population-based estimates of temporal changes. Every subanalysis undertaken to explore various factors revealed the same basic trend—high prevalence of CWP around 1970–1974 (~30%), a substantial decline in 1995–1999 (~3%), and indications of an increase since then (~10%). We concluded that the analyses provided of temporal trends in CWP

TABLE 2—Coal Worker Pneumoconiosis (CWP) Category 1+ Prevalence for Miners With ≥ 20 Years Tenure: United States, 2005–2009

	CWP Prevalence (%)		
	Overall	Without Enhanced Program Data	Enhanced Program Alone
High-rank	13.3	17.6	11.5
Northern Appalachia	2.6	4.1	1.8
Southern Appalachia	14.2	25.0	11.4
Midwest	1.9	1.9	2.0
West	2.9	4.8	1.5

TABLE 3—Observed Prevalences and Prevalences of Coal Worker Pneumoconiosis Adjusted for the Background Effect by Time Period: United States, 1970–2009

Year	Time Period							
	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004	2005–2009
Prevalence	29.3	24.1	18.0	14.1	6.5	3.2	6.1	6.4
Adjusted prevalence	25.5	21.5	14.5	14.1	6.1	2.5	3.3	5.9

Note. Downward proportional adjustment of coal worker pneumoconiosis prevalence calculated by subtracting the prevalence of coal worker pneumoconiosis in miners with less than 5 years of mining tenure from the total observed prevalence.

prevalence were broadly accurate, although the data likely underestimated the national prevalence of CWP.

The biggest concern was that the national prevalence estimates perhaps concealed some important trends in certain coal fields and regions (although those trends were noted elsewhere in reports focused on those areas). These provided reason for concern. Although most regions had CWP prevalence reasonably close to that predicted from epidemiological studies, the region formed by southern West Virginia, eastern Kentucky, and western Virginia, including both low and high coal rank areas, showed that CWP prevalence was considerably greater than predicted.¹³ Moreover, CWP prevalence has clearly been rising in this region. Various reasons were hypothesized for this increase. These included (1) longer working hours, (2) increased exposure to respirable silica, and (3) less effective control of dust, related in part to a preponderance of small mines and mining of thin coal seams.

Working hours for coal miners have steadily been increasing consistently over the last 40 years. Longer hours means the potential for more dust to be inhaled and less time for it to be cleared, both potentially increasing the risk of CWP development. Smaller mine operators often have limited knowledge and resources, as do small operations in other industries, for optimum maintenance of a safe and healthy working environment. Hence, overexposure to coal mine dust would likely result, with the ensuing elevated risk of disease. Also, in thin seam mining, there is often the need to cut the surrounding rock to provide access. Because the rock may be siliceous, there is the potential for excessive silica exposure. There has been some radiographic evidence that

this has occurred, giving rise to either silicosis or mixed-dust pneumoconiosis.^{11,28} However, only a minority of cases have had evidence of silica-related nodules. Other factors, such as overexposure to coal mine dust, either in terms of level or duration of exposure, have also been implicated.

It was argued that the low prevalence seen in some regions simply reflected a so-called “background effect” in radiographic abnormality that was not caused by dust exposure, but was the result of aging and smoking.²⁹ This background effect was examined in various settings, with some being more appropriate and valid than others. One examined US coal miners with 0 to 1 year of tenure and found a prevalence of category 1/0 or greater in 0.44% of those screened.³⁰ In 3 studies that supplied information on nonexposed individuals and for which the methodology was appropriate, the overall prevalences of category 1 small opacities were 0.21%, 0.8%, and 0.4%, respectively.^{27,31,32} Our present findings indicated higher prevalences in some time periods, although not enough to fully account for the elevated prevalence of CWP in working underground coal miners. One plausible explanation that our background prevalences were somewhat elevated might be caused by inadequacies in the work histories. We included miners with up to 5 years of mining tenure and did not include previous exposure histories, such as work in other dusty trades, in our “unexposed” group.

Our findings suggested a minor to modest bias because of differential participation by disease status. Working miners notified they had a radiographic classification consistent with CWP tended to be less likely to re-participate, and the program was restricted

to working miners. Therefore, retired and disabled miners who likely had the highest prevalence of CWP were not included in the prevalence estimates NIOSH reports. A limitation of our data was that we were unable to assess potential participation biases based on exposure status. It might be that, proportionally, the most heavily exposed miners participated more or less than those less exposed. This likelihood would seem to be evident in the prevalence data because of the well-established relationship between exposure and disease. Overall participation in the program varied over time, but decreased from the program’s inception. The estimated participation for 2000–2006 was 30% (<http://www2.cdc.gov/drds/worldreportdata/FigureTableDetails.asp?FigureTableID=525&GroupRefNumber=F02-06>).

In 1995, NIOSH recommended that the federal coal mine dust compliance level be reduced from 2 to 1 milligram per cubic meter.³³ This recommendation was made before the increase in CWP prevalence was first apparent (~1998; Figure A). The recommendation was based on epidemiological information arising from exposure–response analyses, and showed that there would be clear public health benefits from reducing the dust limit in all coal mining regions, not just in Appalachia. Information reported since 1995 has not changed that conclusion.⁴

In conclusion, these results demonstrated that the reports based on the CWHSP likely represented an accurate reflection of both the burden of pneumoconiosis among US underground coal miners and recent disease trends and geographic patterns. We concluded that no upward bias in the reported prevalence would be expected from the effects of trends in employment and program participation, or the addition of an active surveillance component to the CWHSP. This analysis demonstrated that the CWHSP likely underestimated the true burden of CWP among underground coal miners in the United States. Although it was previously well established, we noted again that the geographic hot spots and increasing prevalence of pneumoconiosis among coal miners could only be attributed to inhalation of unsafe amounts of coal mine dusts, and could not be attributed to age, smoking, other diseases, or background radiographic

abnormalities. Currently, the Department of Labor Mine Safety and Health Administration has put forth a proposed rule that would reduce the current federal coal mine dust compliance level from 2 to 1 milligram per cubic meter.³⁴ NIOSH recommends it be adopted.^{4,33} ■

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Human Participant Protection

This study was conducted with the approval of the National Institute for Occupational Safety and Health.

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