An Update on Mortality among Workers at a 1,3-Butadiene Facility—Preliminary Results

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This is a cohort study of 2582 male workers employed at least 6 months between 1943 and 1979 at a 1,3-butadiene manufacturing facility. An earlier report on mortality through 1979 found a statistically significant deficit for all causes of death and lower than expected mortality for most of the leading causes of death. However, there was a statistically significant excess of deaths from lymphosarcoma. This report is a preliminary update of cohort information through 1985 and also a reanalysis of mortality. The all-causes standardized mortality ratio is 84 and that for all cancers is 80. These are statistically significant deficits; significant deficits were also seen for all cancer of the digestive system and all external causes of death. One additional death from lymphosarcoma was observed during the extended follow-up period giving a statistically significant standardized mortality ratio (SMR) of 229. The increase was concentrated in those employed less than 10 years and in those first employed before 1946. No increase was seen overall for leukemia (SMR = 102).

Introduction

This study reports on updated cause-specific mortality in a cohort of workers employed at a 1,3-butadiene production plant. The plant was built during World War II in Port Neches, TX, to supply 1,3-butadiene to two adjacent rubber manufacturing facilities. This cohort was the subject of an earlier report (1) that covered the period from the beginning of plant operation through 1979. The cohort consisted of all males who were employed at the plant for at least 6 months between the time the plant began operation in 1943 and the end of 1979.

The earlier report found a statistically significant deficit for all causes of death and lower than expected mortality for almost all the leading causes of death. The only significant excess cause of death seen was for lymphosarcoma and reticulum cell sarcoma. The cohort was divided into four exposure groups (routine, nonroutine, low, and unknown) and mortality was examined for each of the groups. The standardized mortality ratios (SMRs) for non-Hodgkin’s lymphomas (International Classification of Diseases codes 200, 202, 203, and 208) were elevated in all three known exposure groups. Direct comparisons between the low exposure group and each of the exposure groups for this cause of death were inconsistent. Because of the continuing interest in determining whether 1,3-butadiene is a human carcinogen, information on the original cohort was updated through 1985.

Methods

The study population is the same as that in the earlier report (1). The data were obtained from the previous investigators and merged with company computerized personnel files. Company data were used to update information on those persons still employed or known to be deceased. Dates of termination were obtained for those who left after the previous study end date. Further edits were done, and two duplicate records and two females were removed from the cohort.

Information was obtained from the Social Security Administration (SSA) for those whose vital status was unknown. This included all persons not known to be currently working for the company or those noted as deceased but for whom a death certificate was not located. SSA data were complete through 1985 although a number of deaths in 1986 and 1987 were also identified. Death certificates were requested from the states identified by SSA as most likely to have the information. At the time of this report, death certificates had been received from Texas, Louisiana, Ohio, and Mississippi. All death certificates were coded for underlying cause of death by a trained nosologist according to the Eight Revision rules of the International Classification of Diseases (ICD). Information on those whose vital status was unknown after the SSA search was submitted to the

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National Death Index (NDI). The NDI records were searched for possible matches for deaths from 1979 through 1986.

The qualitative exposure classification scale developed for the previous report (1) was again used. There were four exposure groups: low exposure, routine exposure, nonroutine exposure, and unknown exposure. Each person was assigned to an exposure group based on his department code. Although no industrial hygiene sampling data are available for most of the period covered by the study, a review of current sampling data results supports the groupings.

Analysis of mortality was performed using Monson’s computer program (2) to compare the observed and expected number of deaths with the U.S. white male population as the comparison group. White male rates were used because of uncertainties about the validity of the race information in the company files and because of the small number of blacks who worked at the plant. Person-years were accrued beginning when the person met the cohort eligibility criteria of 6 months of employment. Those persons with vital status unknown were assumed to be lost to study on the date last observed. Those persons who were alive as of the earlier study end-date of 12/31/79 and for whom the NDI could find no match were assumed to be alive. Persons known to be deceased but for whom no death certificate could be located were counted in the all-causes mortality but not in the cause-specific mortality results.

It should be noted that while the previous report (1) grouped all the non-Hodgkin’s lymphomas together in the tables (ICD codes 200, 202, 203, and 208), for this report lymphosarcoma (ICD code 200) and cancers of other lymphatic tissue (ICD codes 202, 203, and 208) are reported separately.

**Results**

The final cohort consisted of 2582 men who had worked for at least 6 months prior to the end of 1979. Table 1 shows the demographic and other characteristics of the total cohort and of the four exposure cohorts described above. There were 74,219 person-years of follow-up, and the mean duration of survival was 28.7 years. There were 826 deaths known to have occurred in the cohort through 1985, and death certificates were obtained for all but 49 (6%) of them. There were 1708 persons still alive at the end of the study (66%) and 48 (1.9%) lost to follow-up.

Table 2 shows the SMRs for selected causes of death for the total cohort and for those employed greater than 5, 10, and 20 years. The SMR for all causes of death for the total cohort is significantly low at 84, as well as the all-cancer SMR at 80. Deficits are again seen for almost all the leading causes of death. There is an elevated SMR of 130 for lymphatic and hematopoietic cancer, which is almost entirely due to the significantly increased SMR of 229 for lymphosarcoma and reticulosarcoma. The increase for lymphosarcoma is seen primarily in those employed fewer than 10 years. The only cause of death that increases as years of employment increases is cancer of the kidney, but both the observed and expected

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**Table 1. Demographic, employment, and other characteristics of the study population and exposure cohorts.**

| Cohort               | Low exposure I | Routine exposure II | Nonroutine exposure III | Unknown exposure IV | Total |
|----------------------|----------------|---------------------|-------------------------|---------------------|-------|
| Number of persons    | 433            | 705                 | 993                     | 451                 | 2582  |
| Percent of total     | (16.9%)        | (27.3%)             | (38.5%)                 | (17.5%)             | (100%)|
| Mean age of entry, years | 30.7          | 27.5                | 32.5                    | 32.0                | 30.7  |
| Mean year of entry   | 1954           | 1952                | 1951                    | 1949                | 1952  |
| Number hired between 1940–45 | 165 (38%) | 216 (31%)          | 462 (47%)               | 223 (49%)           | 1066  |
| Percent of cohort    |               |                     |                         |                     |       |
| Mean years of employment | 12.4          | 12.4                | 11.6                    | 14.3                | 12.4  |
| Number of lost to follow-up | 6 (1.4%) | 6 (0.9%)          | 26 (2.6%)               | 10 (2.2%)           | 48    |
| Percent of each cohort |              |                     |                         |                     |       |
| Number of person-years | 11851.7       | 21423.1            | 27433.8                 | 13512.8             | 74218.8 |
| Number of deaths     | 131 (30.0%)   | 163 (23.1%)        | 361 (36.4%)             | 171 (37.9%)         | 826   |
| Percent of deaths in each cohort |              |                     |                         |                     |       |
| Number without death certificates | 11 (8.4%) | 9 (5.5%)           | 24 (6.7%)               | 5 (2.9%)            | 49    |
| Percent of deaths    |               |                     |                         |                     |       |
| Mean age at death, years | 64.1          | 59.2                | 64.2                    | 65.3                | 63.4  |
| Mean year of death   | 1973           | 1973                | 1970                    | 1971                | 1971  |
| Mean duration of survival, years | 27.4          | 30.4                | 27.1                    | 30.0                | 28.7  |
Table 2. Observed and expected deaths and SMRs for selected causes for cohort members by length of employment.

| Cause of death (8th ICDA*) | Total cohort | Employed > 5 years | Employed > 10 years | Employed > 20 years |
|----------------------------|--------------|---------------------|----------------------|---------------------|
|                            | n = 2582, P-Y = 74219 | n = 1362, P-Y = 33859 | n = 1096, P-Y = 24167 | n = 781, P-Y = 11684 |
| All causes                  | 823          | 979.8              | 84 79-90             | 84 79-90            |
| All cancers (140-209)       | 163          | 202.7              | 80 69-94             | 83 70-94             |
| Cancer of buccal cavity and | 5            | 6.1                | 82 26-190            | 3 3.3 92 18-268     |
| pharynx (140-149)           |              |                     |                      | 2 2.8 71 8-256      |
| Cancer of digestive system  |              |                     |                      | 2 1.8 110 12-398    |
| (150-159)                   | 39           | 56.3               | 69 49-95             | 16 30.2 53 30-96    |
| Cancer of esophagus         | 4            | 4.8                | 63 13-184            | 0 2.6 0 0-143       |
| Cancer of stomach (151)     | 4            | 10.2               | 39 11-100            | 0 5.4 0 0-68        |
| Cancer of large intestine   |              |                     |                      | 0 4.5 0 0-82        |
| (153)                       |              |                     |                      | 0 2.4 0 0-151       |
| Cancer of rectum (154)      | 3            | 6.1                | 49 10-144            | 2 3.2 62 7-223      |
| Cancer of liver (155-156)   | 1            | 4.3                | 24 0-131             | 0 2.3 0 0-162       |
| Cancer of pancreas (157)    | 9            | 10.9               | 83 38-157            | 3 5.9 51 10-149     |
| Cancer of respiratory system|              |                     |                      | 3 5.2 58 12-170     |
| (160-163)                   | 57           | 69.8               | 82 62-106            | 30 37.9 79 53-113   |
| Cancer of the larynx (161)  | 3            | 3.0                | 136 37-347           | 0 1.6 0 0-232       |
| Cancer of the lung (162-163) |              |                     |                      | 0 1.4 0 0-266       |
| Cancer of bone (170)        | 1            | 0.9                | 114 1-635            | 0 0.4 0 0-837       |
| Cancer of skin (172-173)    | 3            | 3.5                | 86 17-252            | 1 1.8 55 1-304      |
| Cancer of prostate (185)    | 10           | 14.6               | 69 33-126            | 8 8.1 99 43-195     |
| Cancer of bladder (188)     | 3            | 6.2                | 49 16-142            | 2 3.4 59 7-214      |
| Cancer of kidney (189)      | 5            | 5.0                | 100 32-234           | 4 2.7 150 40-383    |
| Cancer of brain and central |              |                     |                      | 4 2.3 173 46-442    |
| nervous system (191-192)    | 4            | 5.7                | 70 19-179            | 3 2.9 102 20-298    |
| Lymphatic and               |              |                     |                      | 2 2.4 83 9-299      |
| hematopoietical cancer      | 25           | 19.2               | 130 84-192           | 11 10.1 109 54-195  |
| (200-209)                   |              |                     |                      | 6 8.6 70 26-152     |
| Lymphosarcoma and           |              |                     |                      | 3 5.2 58 12-169     |
| reticulosarcoma (200)       | 9            | 3.9                | 229 104-435          | 5 2.0 245 79-572    |
| Hodgkin's disease (201)     | 3            | 2.1                | 141 28-413           | 1 1.0 99 1-551      |
| Leukemia and aleukemia      | 8            | 7.9                | 102 44-200           | 2 4.2 48 5-174     |
| (204-207)                   |              |                     |                      | 1 3.5 28 0-158      |
| Other lymphmatic tissue     | 5            | 5.1                | 97 31-227            | 3 2.8 106 21-311    |
| (202, 203, 208)             |              |                     |                      | 2 2.5 80 9-299     |
| Benign neoplasms (210-239)  | 2            | 2.7                | 74 8-266             | 1 1.4 73 1-408     |
| Diabetes mellitus (250)     | 9            | 13.9               | 65 30-123            | 4 1.7 54 15-139    |
| Arteriosclerotic heart disease |            | 345.8              | 72 64-82             | 137 187.9 73 61-86  |
| (410-418)                   | 250          | 345.8              | 72 64-82             | 109 163.7 67 55-80  |
| Vascular lesions of central | 63           | 65.2               | 97 74-124            | 31 35.4 88 60-124   |
| nervous system (430-438)    |              |                     |                      | 27 30.7 88 58-128   |
| Nonmalignant respiratory    |              |                     |                      | 10 15.9 63 30-116   |
| disease (460-519)           | 49           | 62.1               | 79 58-104            | 32 33.6 95 65-135   |
| Pneumonia (480-486)         | 23           | 21.1               | 109 69-164           | 18 11.1 163 96-257  |
| Emphysema (492)             | 7            | 13.6               | 51 21-106            | 5 7.7 39 8-114     |
| Cirrhosis of liver (551)    | 10           | 22.9               | 44 21-80             | 12.0 33 9-86       |
| All external causes (800-998)| 64           | 84.1               | 76 59-97             | 31 38.6 80 55-114   |

*8th ICDA, 8th International Classification of Diseases; SMR, standardized mortality ratio; 95% CI, 95% confidence interval.
Table 3. Observed and expected deaths and SMRs for selected causes for all cohort members by time first employed.

| Cause of death (8th ICDA*) | Employed < 1946 (war) | | | Employed ≥ 1946 (postwar) | |
|---------------------------|------------------------|----------------|----------------|------------------------|----------------|----------------|----------------|----------------|
|                           | Observed deaths | Expected deaths | SMR* | 95% CI* | Observed deaths | Expected deaths | SMR | 95% CI |
| All causes | 593 | 683.4 | 86 | 79–93 | 233 | 286.2 | 81 | 71–93 |
| All cancers (140–208) | 106 | 140.9 | 75 | 62–91 | 57 | 61.8 | 92 | 70–120 |
| Cancer of buccal cavity and pharynx (140–149) | 3 | 4.2 | 72 | 14–211 | 2 | 2.0 | 102 | 11–367 |
| Cancer of digestive system (150–159) | 24 | 41.0 | 59 | 37–87 | 15 | 15.3 | 98 | 55–162 |
| Cancer of esophagus (150) | 3 | 3.3 | 91 | 18–267 | 0 | 1.5 | 0 | 0–250 |
| Cancer of stomach (151) | 2 | 7.8 | 26 | 3–93 | 2 | 2.5 | 81 | 9–293 |
| Cancer of large intestine (153) | 11 | 13.5 | 81 | 40–145 | 7 | 5.1 | 137 | 55–282 |
| Cancer of rectum (154) | 2 | 4.6 | 44 | 5–158 | 1 | 1.5 | 66 | 1–369 |
| Cancer of liver (155–156) | 0 | 3.1 | 0 | 0–117 | 1 | 1.1 | 90 | 1–502 |
| Cancer of pancreas (157) | 5 | 7.7 | 65 | 21–152 | 4 | 3.2 | 126 | 34–323 |
| Cancer of respiratory system (160–163) | 39 | 46.7 | 84 | 50–114 | 18 | 23.1 | 78 | 46–123 |
| Cancer of the larynx (161) | 3 | 2.1 | 146 | 29–426 | 1 | 0.9 | 112 | 1–624 |
| Cancer of the lung (162–163) | 36 | 44.2 | 82 | 57–113 | 17 | 22.9 | 77 | 45–124 |
| Cancer of bone (170) | 1 | 0.6 | 168 | 2–565 | 0 | 0.3 | 0 | 0–1303 |
| Cancer of skin (172–173) | 0 | 2.0 | 0 | 0–181 | 3 | 1.5 | 205 | 41–600 |
| Cancer of prostate (185) | 9 | 12.0 | 75 | 34–142 | 1 | 2.5 | 39 | 1–220 |
| Cancer of bladder (188) | 2 | 4.9 | 41 | 5–148 | 1 | 1.3 | 77 | 1–430 |
| Cancer of kidney (189) | 3 | 3.3 | 90 | 18–263 | 2 | 1.7 | 121 | 14–438 |
| Cancer of brain and central nervous system (191–192) | 2 | 3.3 | 60 | 7–218 | 2 | 2.4 | 83 | 9–301 |
| Lymphatic and hematopoietic cancer (200–209) | 16 | 12.7 | 126 | 72–205 | 9 | 6.5 | 138 | 63–262 |
| Lymphosarcoma and reticulosarcoma (200) | 7 | 2.6 | 269 | 108–555 | 2 | 1.3 | 155 | 17–558 |
| Hodgkin's disease (201) | 1 | 1.2 | 85 | 1–470 | 2 | 0.9 | 213 | 24–767 |
| Leukemia and lymphoma (204–207) | 6 | 5.4 | 112 | 41–244 | 2 | 2.5 | 80 | 9–287 |
| Other lymphatic tissue (202, 203, 208) | 2 | 3.4 | 59 | 7–212 | 3 | 1.7 | 174 | 35–509 |
| Benign neoplasms (210–239) | 2 | 1.8 | 111 | 12–491 | 0 | 0.9 | 0 | 0–399 |
| Diabetes mellitus (250) | 6 | 10.0 | 60 | 22–131 | 3 | 3.9 | 77 | 15–222 |
| Arteriosclerotic heart disease (410–413) | 176 | 254.6 | 69 | 59–80 | 74 | 91.2 | 81 | 64–102 |
| Vascular lesions of central nervous system (430–438) | 58 | 52.5 | 110 | 84–143 | 5 | 12.7 | 39 | 13–92 |
| Nonglomerular respiratory disease (460–519) | 33 | 47.5 | 70 | 48–88 | 16 | 14.6 | 109 | 62–178 |
| Pneumonia (480–486) | 16 | 16.4 | 98 | 56–159 | 7 | 4.7 | 148 | 59–305 |
| Emphysema (492) | 5 | 10.7 | 47 | 15–109 | 2 | 2.9 | 69 | 8–250 |
| Cirrhosis of liver (551) | 5 | 13.1 | 38 | 12–89 | 5 | 9.8 | 51 | 16–119 |
| All external causes (800–998) | 39 | 41.8 | 93 | 66–128 | 25 | 42.3 | 59 | 38–87 |

*8th ICDA, 8th International Classification of Diseases; SMR, standardized mortality ratio; 95% CI, 95% confidence interval.
numbers of deaths are small and the confidence intervals wide. One cause of death that is significantly elevated in this update, as compared to the previous report, is ill-defined symptoms and senility. (SMR = 200).

Table 3 shows the SMRs for selected causes of death for those first employed during World War II versus those who were first employed after the war. The all-causes SMR is similar for the two groups. The SMR is increased for lymphohematopoietic cancer for both subcohorts. Almost all the excess for those first employed during the war is due to the significantly elevated SMR for lymphosarcoma (SMR = 269). For those first employed after the war, elevated SMRs are seen for lymphosarcoma, Hodgkin's disease, and cancer of other lymphatic tissue. None of these is statistically significant, and the numbers of observed deaths are small. Cancers of the large intestine and the pancreas are nonsignificantly elevated for those first employed post-war, whereas deficits were seen for those first employed during the war. There is a slight elevation for leukemia (SMR = 112) in those first employed during the war, but it is based on less than one death.

Table 4 shows the SMRs for selected causes of death for each of the exposure groups for all in the subgroup and for those employed 10 years or more in the group. All groups except the unknown exposure group show elevated SMRs for lymphohematopoietic cancer for those ever in the group. For the low exposure group, the excess is due to elevated SMRs for lymphosarcoma and Hodgkin's disease; both of these are based on two or fewer observed deaths. The overall excess disappears when the analysis is restricted to those employed 10 years or more. The routine exposure group has a statistically significant excess of lymphosarcoma (SMR = 561), which accounts for most of the lymphohematopoietic excess. All of the lymphosarcomas occurred in persons employed fewer than 10 years. Cancer of both the large intestine and kidney increased from the group ever employed to those employed 10 years or more.

Most of the excess in lymphohematopoietic cancer for the nonroutine group is due to a nonsignificant increase in leukemia (SMR = 185), which is limited to those employed less than 10 years. Only a slight increase is seen for this group for lymphosarcoma (SMR = 126). Cancer of the prostate has a nonsignificant increase for those employed more than 10 years (SMR = 146), while there is a deficit for the group overall. There is a nonsignificant elevation for stroke for the group overall, but this disappears when the group is restricted to those employed more than 10 years. Cancer of the brain shows an elevated SMR (283) for the unknown exposure group, which increases for those employed more than 10 years (SMR = 415). These SMRs are based on three or fewer observed deaths, however. Both nonmalignant respiratory disease and cirrhosis of the liver show nonsignificantly elevated SMRs for the group employed 10 years or more, as compared to those ever in the group, but neither increase is statistically significant. The increase in respiratory disease is primarily due to an increase in deaths from pneumonia (SMR = 232).

The number of observed and expected deaths by years worked and latency for all males for all deaths, all cancer deaths, all hematopoietic deaths, lymphosarcoma, and leukemia are shown in Table 5. For all deaths the SMRs are essentially unchanged as either latency or duration increases. Similarly, no pattern with latency or duration is seen for all cancer deaths. For all hematopoietic deaths, the largest elevation is seen for those with latency and length of employment fewer than 10 years. The SMRs actually decrease with increasing employment. For lymphosarcoma, again the largest elevation is for those with the shortest employment and latency. The SMRs for leukemia increase with increasing latency but decrease with increasing length of employment.

Tables 6 through 9 show the same information for each of the four exposure groups. No overall pattern is seen for the low-exposure group other than that the SMRs for all cancers and for all hematopoietic cancer tend to decrease with increasing lengths of employment. For the routine exposure group, again no pattern is seen. The biggest excess is seen for lymphosarcoma; all deaths occurred in those employed fewer than 10 years; two were in those with fewer than 10 years latency, one in those with 20 to 29 latency, and two in those with 30 years or more of latency. The most interesting result for the nonroutine exposure group is for leukemia. Five of the six deaths occurred in those employed fewer than 10 years, and all had at least 10 years of latency although the deaths were spread out among the other latency categories. No pattern was seen for the unknown exposure group.

Discussion

The overall pattern of results for this update is essentially unchanged from the earlier report on this cohort (1). There was an overall reduction in expected mortality (SMR = 84) when compared with the U.S. white male population, which again was primarily due to a reduction in deaths because of arteriosclerotic heart disease (SMR = 72). The major finding is still the significantly elevated SMR for lymphosarcoma. The group with the highest risk for this cause of death appears to be those employed fewer than 10 years, first hired during World War II, and employed in a job with the potential for routine exposure. The fact that the risk does not increase with increasing length of employment (and presumably increasing cumulative exposure) must be incorporated into any theory that this excess is related to 1,3-butadiene exposure.

Although the leukemia SMR is not elevated for the cohort overall, it is nonsignificantly elevated for the nonroutine exposure group. Half of the leukemia deaths in this group occurred in persons who were first employed during the war and employed less than 5 years. Overall, six of the eight total leukemia deaths were first employed during the war. Again, the risk does not increase with length of employment. The increased risk
for the category symptoms, senility, and ill-defined conditions is not readily explainable. The increase is concentrated in persons who were employed fewer than 20 years, were first employed during the war, and were not in the low exposure group. Obviously this category would decrease with more specific cause of death information from the attending physician.

Two other studies have examined mortality in cohorts exposed to 1,3-butadiene although both cohorts consisted of persons engaged in the manufacture of styrene-butadiene rubber (SBR) and so had the opportunity for multiple exposures. The first study by Matanoski and Schwartz (3) covered males who had worked at eight SBR manufacturing facilities in the U.S. and Canada. The overall SMR (81) was very similar to that seen for the current study. The only significant excess seen was for arteriosclerotic heart disease among black males. Risks were examined by major work areas as well as by pay grade, and no significant differences in cancer mortality for specific sites were seen. In particular, no increase was seen for lymphosarcoma (SMR = 49) or leukemia (SMR = 91).

The second study by Meinhardt et al. (4) covered persons employed at the two SBR plants supplied by the facility in the current study. The Meinhardt study found an elevated SMR for leukemia that was concentrated in people hired during the war. Elevated SMRs for lymphosarcoma were also seen although they were not statistically significant and were not as high as those seen in this study. One major problem with comparisons between the Meinhardt study and the current study is the overlap between the study cohorts. There were 116 persons who were employed both at the 1,3-butadiene and the SBR manufacturing facilities, including at least one of the leukemia deaths and one of the lymphosarcoma deaths. The increases for each of these populations may be exaggerated because of this.

Another report among oil refinery workers also saw an increase in a number of causes of deaths for those persons first employed during World War II (5). The increase was seen for many of the specific cancer sites including leukemia as well as for external causes of death. This study and the Meinhardt study show the elevation for leukemia but not for external causes of death. There are two possibilities for the wartime differences if they are real. One is that this group of people is
somewhat different from those hired at other times, perhaps because they were not eligible for the draft because of health reasons. The other is that there were major differences in exposure during the war that led to the increases.

In examining work history records for an earlier study of Texaco workers (6), it became obvious that a number of experienced persons were lent to the 1,3-butadiene plant during the war. In fact, 122 persons overlapped between the two studies. It is very likely that similar overlaps exist with cohorts from other petroleum and chemical facilities in the area. Since most of the elevations of interest were concentrated primarily in persons with short-term employment, the question remains of where else these persons were employed and what other exposures could have lasted substantially longer than those at the butadiene facility.

As mentioned in the earlier report on this cohort (1), there are several weaknesses in this study. Because of unreliable race designations, conclusions based on race-specific rates could not be generated. For this reason, all comparisons were made using white male mortality rates. Second, no work histories or industrial hygiene data were available for the time period of the study. Almost half of the cohort worked fewer than 5 years and obviously spent considerable working time elsewhere with the possibility for numerous other exposures. As mentioned above, it is this portion of the cohort where the increased SMRs are concentrated. Finally, the cohort size is small, and the numbers become even smaller for the exposure group analyses.

However, the study does cover one of the largest cohorts involved solely in the manufacture of butadiene. The cohort has been followed for 43 years and includes all those with 6 months or more employment since the plant began production. The numbers with vital status unknown (1.9%) and without cause of death information (6%) are relatively small, and qualitative measures of exposures were available.

Further efforts are underway to increase the information available for this cohort. Information has been received from the NDI for those persons with vital status unknown or for whom no death certificate could be located based on SSA information. There are outstanding requests for death certificates from other state health departments, and additional death certificates
### Table 5. Observed and expected deaths by years worked and latency for the total cohort.

| Years worked | Latency, years | All deaths | 0–9 | 10–19 | 20–29 | 30+ | Totals |
|--------------|---------------|------------|-----|-------|-------|-----|--------|
|              |               | Observed   | 84  | 98    | 123   | 167 | 472    |
|              |               | Expected   | 101.3| 91.8  | 145.9 | 199.9| 538.9 |
|              |               | SMR        | 8.3 | 107   | 84    | 88  |        |
|              |               | 10–19      | Observed | 56   | 54    | 44   | 154  |
|              |               | Expected   | 89.0 | 52.6  | 40.6  | 182.2|       |
|              |               | SMR        | 63  | 103   | 108   | 85  |        |
|              |               | 20+        | Observed | 76   | 124   | 200  |       |
|              |               | Expected   | —    | 100   | 158   | 258.0|       |
|              |               | SMR        | 75  | 79    | 75    | 84  |        |
|              |               | Totals     | Observed | 154  | 253   | 335  | 826  |
|              |               | Expected   | 101.3| 180.8 | 288.5 | 398.5| 979.6|
|              |               | SMR        | 83  | 85    | 86    | 84  |        |
| Cancer deaths|               | All deaths | Observed | 11   | 19    | 26    | 38   | 94    |
|              |               | Expected   | 13.8 | 16.2  | 30.2  | 47.6 | 107.3 |
|              |               | SMR        | 80  | 117   | 86    | 80   | 87    |
|              |               | 10–19      | Observed | 7    | 9     | 6     | 22   |
|              |               | Expected   | 16.2 | 9.8   | 7.4   | 33.4 |       |
|              |               | SMR        | 43  | 92    | 81    | 66  |       |
|              |               | 20+        | Observed | —    | 20    | 27    | 47   |
|              |               | Expected   | —    | 22.1  | 39.3  | 61.4 |       |
|              |               | SMR        | —   | 91    | 59    | 77  |       |
|              |               | Totals     | Observed | 11   | 25    | 56    | 71   | 163  |
|              |               | Expected   | 13.8 | 32.4  | 62.1  | 94.3 | 202.7|
|              |               | SMR        | 80  | 80    | 77    | 130 |       |

### Table 6. Observed and expected deaths by years worked and latency for the low-exposure group.

| Years worked | Latency, years | All deaths | 0–9 | 10–19 | 20–29 | 30+ | Totals |
|--------------|---------------|------------|-----|-------|-------|-----|--------|
|              |               | Observed   | 124 | 84    | 85    | 84  | 293    |
|              |               | Expected   | 18.8 | 14.5  | 9.1   | 53.3 |       |
|              |               | SMR        | 80  | 80    | 77    | 130 |       |
| Cancer deaths|               | All deaths | Observed | 2    | 2     | 7    | 13   | 24    |
|              |               | Expected   | 2.2  | 2.1   | 4.8   | 7.2  | 16.3  |
|              |               | SMR        | 91  | 55    | 64    | 83  | 71    |
| Lymphosarcoma|               | deaths     | Observed | 1    | 0     | 0    | 2    | 3     |
|              |               | Expected   | 0.3  | 0.3   | 0.4   | 0.6  | 1.6   |
|              |               | SMR        | 333 | 0     | 0     | 333  | 188   |
| Leukemia     |               | Observed   | 0    | 0     | 0     | 0    |       |
|              |               | Expected   | 0.5  | 0.2   | 0.8   | 0.1  |       |
|              |               | SMR        | 0   | 0     | 0     | 0    |       |
| Leukemia     |               | Observed   | 0    | 0     | 0     | 0    |       |
|              |               | Expected   | 0.5  | 0.5   | 1.0   | 0.2  |       |
|              |               | SMR        | 4   | 0     | 0     | 0    |       |

### Notes
- SMR, standardized mortality ratio.
Table 7. Observed and expected deaths by years worked and latency for the routine exposure group.

| Years worked | 0–9 | 10–19 | 20–29 | 30+ | Totals |
|--------------|-----|-------|-------|-----|--------|
| All deaths   |     |       |       |     |        |
| < 10         | 14  | 20    | 26    | 42  | 102    |
| Expected     | 18.1| 18.9 | 35.0  | 56.0| 128.0  |
| SMR          | 77  | 106   | 74    | 75  | 80     |
| Cancer deaths|     |       |       |     |        |
| < 10         | 2   | 6     | 8     | 11  | 27     |
| Expected     | 2.1 | 3.2   | 7.5   | 14.0| 26.8   |
| SMR          | 95  | 107   | 107   | 101 | 101    |
| Leukemia     |     |       |       |     |        |
| < 10         | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.1   | 0.2   | 0.2 | 0.6    |
| SMR          | 0   | 0     | 0     | 0   | 0      |
| Lymphosarcoma|     |       |       |     |        |
| < 10         | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.1   | 0.0   | 0.0 | 0.1    |
| SMR          | 0   | 0     | 0     | 0   | 0      |
| Totals       |     |       |       |     |        |
| All hematopoietic deaths |     |       |       |     |        |
| < 10         | 2   | 1     | 1     | 3   | 7      |
| Expected     | 0.4 | 0.5   | 0.7   | 1.1 | 2.7    |
| SMR          | 500 | 200   | 143   | 273 | 259    |
| 10–19        |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.3 | 0.1   | 0.1   | 0.5 | 0.9    |
| SMR          | 0   | 0     | 0     | 0   | 0      |
| 20+          |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.5 | 0.8   | 1.3   |     |        |
| SMR          | 0   | 0     | 0     | 125 | 77     |
| Totals       |     |       |       |     |        |
| Observed     | 2   | 1     | 1     | 4   | 8      |
| Expected     | 0.4 | 0.7   | 1.3   | 2.0 | 4.5    |
| SMR          | 500 | 143   | 77    | 200 | 178.7  |
| Leukemia     |     |       |       |     |        |
| < 10         | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.2 | 0.2   | 0.3   | 0.5 | 1.2    |
| SMR          | 0   | 0     | 0     | 200 | 83     |
| 10–19        |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.0   | 0.0   | 0.1 | 0.2    |
| SMR          | 0   | 0     | 0     | 0   | 0      |
| 20+          |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.2 | 0.3   | 0.5   | 0.8 | 1.8    |
| SMR          | 0   | 0     | 0     | 125 | 56     |

Table 8. Observed and expected deaths by years worked for the nonroutine exposure group.

| Years worked | 0–9 | 10–19 | 20–29 | 30+ | Totals |
|--------------|-----|-------|-------|-----|--------|
| All deaths   |     |       |       |     |        |
| < 10         | 43  | 46    | 53    | 65  | 207    |
| Expected     | 45.4| 39.2  | 57.6  | 76.9| 219.1  |
| SMR          | 95  | 119   | 94    | 85  | 95     |
| Cancer deaths|     |       |       |     |        |
| < 10         | 6   | 8     | 9     | 29  | 53     |
| Expected     | 6.5 | 7.0   | 11.8  | 18.0| 43.3   |
| SMR          | 92  | 86    | 68    | 50  | 67     |
| Leukemia     |     |       |       |     |        |
| < 10         | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.8 | 0.2   | 0.3   | 0.8 | 0.8    |
| SMR          | 125 | 100   | 82    | 61  | 71     |
| Lymphosarcoma|     |       |       |     |        |
| < 10         | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.2   | 0.3   | 0.8 | 0.2    |
| SMR          | 1000| 0     | 0     | 0   | 0      |
| 10–19        |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.2 | 0.2   | 0.3   | 0.8 | 1.2    |
| SMR          | 0   | 0     | 0     | 200 | 83     |
| 20+          |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.0   | 0.0   | 0.1 | 0.2    |
| SMR          | 0   | 0     | 0     | 0   | 0      |
| Totals       |     |       |       |     |        |
| All hematopoietic deaths |     |       |       |     |        |
| < 10         | 1   | 1     | 2     | 3   | 7      |
| Expected     | 0.8 | 0.8   | 1.1   | 1.5 | 4.2    |
| SMR          | 125 | 125   | 182   | 200 | 167    |
| Lymphosarcoma|     |       |       |     |        |
| < 10         | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.2   | 0.3   | 0.8 | 0.8    |
| SMR          | 1000| 0     | 0     | 0   | 0      |
| 10–19        |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.2 | 0.2   | 0.3   | 0.8 | 1.2    |
| SMR          | 0   | 0     | 0     | 200 | 83     |
| 20+          |     |       |       |     |        |
| Observed     | 0   | 0     | 0     | 0   | 0      |
| Expected     | 0.1 | 0.0   | 0.0   | 0.1 | 0.2    |
| SMR          | 0   | 0     | 0     | 0   | 0      |
| Totals       |     |       |       |     |        |
| Observed     | 1   | 1     | 2     | 3   | 7      |
| Expected     | 0.8 | 1.6   | 2.3   | 2.9 | 7.8    |
| SMR          | 125 | 125   | 182   | 200 | 167    |

*SMR, standardized mortality ratio.
Table 9. Observed and expected deaths by years worked for the unknown exposure group.

| Years worked| Latency, years | 0–9 | 10–19 | 20–29 | 30+ | Totals |
|-------------|---------------|-----|-------|-------|-----|--------|
| All deaths  |               |     |       |       |     |        |
| < 10        | Observed      | 13  | 21    | 27    | 29  | 90     |
|             | Expected      | 22.0| 21.7  | 30.6  | 37.8| 112.1  |
|             | SMR           | 59  | 97    | 88    | 77  | 80     |
| 10–19       | Observed      | —   | 11    | 12    | 7   | 30     |
|             | Expected      | —   | 18.1  | 10.7  | 6.4 | 35.2   |
|             | SMR           | —   | 61    | 112   | 109 | 85     |
| 20+         | Observed      | —   | —     | 23    | 26  | 51     |
|             | Expected      | —   | —     | 19.2  | 28.5| 47.7   |
|             | SMR           | —   | —     | 120   | 98  | 110    |
| Totals      | Observed      | 13  | 32    | 62    | 64  | 171    |
|             | Expected      | 22.0| 39.8  | 60.5  | 72.7| 194.9  |
|             | SMR           | 59  | 80    | 103   | 88  | 88     |
| Cancer deaths|               |     |       |       |     |        |
| < 10        | Observed      | 1   | 5     | 7     | 8   | 21     |
|             | Expected      | 3.2 | 3.9   | 5.8   | 8.4 | 21.3   |
|             | SMR           | 31  | 128   | 181   | 95  | 94     |
| 10–19       | Observed      | —   | 2     | 0     | 0   | 2      |
|             | Expected      | —   | 3.2   | 1.9   | 1.2 | 6.3    |
|             | SMR           | —   | 63    | 0     | 0   | 63     |
| 20+         | Observed      | —   | —     | 6     | 9   | 15     |
|             | Expected      | —   | —     | 4.1   | 7.3 | 11.4   |
|             | SMR           | —   | —     | 140   | 123 | 132    |
| Totals      | Observed      | 1   | 7     | 13    | 17  | 38     |
|             | Expected      | 3.2 | 7.1   | 11.8  | 16.9| 38.4   |
|             | SMR           | 31  | 99    | 110   | 101 | 97     |
| All hematopoietic deaths|       |     |       |       |     |        |
| < 10        | Observed      | 0   | 1     | 1     | 0   | 2      |
|             | Expected      | 0.4 | 0.4   | 0.6   | 0.7 | 2.1    |
|             | SMR           | 0   | 250   | 167   | 0   | 95     |
| 10–19       | Observed      | —   | 0     | 0     | 0   | 0      |
|             | Expected      | —   | 0.4   | 0.2   | 0.1 | 0.7    |
|             | SMR           | —   | 0     | 0     | 0   | 0      |
| 20+         | Observed      | —   | —     | 0     | 0   | 0      |
|             | Expected      | —   | —     | 0.4   | 0.6 | 1.0    |
|             | SMR           | —   | —     | 0     | 0   | 0      |
| Totals      | Observed      | 0   | 1     | 1     | 0   | 2      |
|             | Expected      | 0.4 | 0.8   | 1.2   | 1.4 | 3.7    |
|             | SMR           | 0   | 125   | 83    | 0   | 55     |
| Lymphosarcoma deaths|               |     |       |       |     |        |
| < 10        | Observed      | 0   | 0     | 0     | 0   | 0      |
|             | Expected      | 0.1 | 0.1   | 0.1   | 0.1 | 0.4    |
|             | SMR           | 0   | 0     | 0     | 0   | 0      |
| 10–19       | Observed      | —   | 0     | 0     | 0   | 0      |
|             | Expected      | —   | 0.1   | 0.0   | 0.0 | 0.1    |
|             | SMR           | —   | 0     | 0     | 0   | 0      |
| 20+         | Observed      | —   | —     | 0     | 0   | 0      |
|             | Expected      | —   | —     | 0.1   | 0.1 | 0.2    |
|             | SMR           | —   | —     | 0     | 0   | 0      |
| Totals      | Observed      | 0   | 0     | 0     | 0   | 0      |
|             | Expected      | 0.1 | 0.2   | 0.2   | 0.2 | 0.7    |
|             | SMR           | 0   | 0     | 0     | 0   | 0      |
| Leukemia    |               |     |       |       |     |        |
| < 10        | Observed      | 0   | 0     | 0     | 0   | 0      |
|             | Expected      | 0.2 | 0.2   | 0.2   | 0.3 | 0.9    |
|             | SMR           | 0   | 0     | 0     | 0   | 0      |
| 10–19       | Observed      | —   | 0     | 0     | 0   | 0      |
|             | Expected      | —   | 0.2   | 0.1   | 0.1 | 0.4    |
|             | SMR           | —   | 0     | 0     | 0   | 0      |
| 20+         | Observed      | —   | —     | 0     | 0   | 0      |
|             | Expected      | —   | —     | 0.2   | 0.2 | 0.4    |
|             | SMR           | —   | —     | 0     | 0   | 0      |
| Totals      | Observed      | 0   | 0     | 0     | 0   | 0      |
|             | Expected      | 0.2 | 0.4   | 0.5   | 0.6 | 1.5    |
|             | SMR           | 0   | 0     | 0     | 0   | 0      |

*SMR, standardized mortality ratio.

have been requested based on the NDI search results. The analyses will be repeated when these data are available. In addition, the company intends to continue to update cause of death information on the cohort at periodic intervals.

REFERENCES

1. Down, T. D., Crane, M. M., and Kim, K. W. Mortality among workers at a butadiene facility. Am. J. Ind. Med. 12: 311–329 (1987).
2. Monson, R. R. Analysis of relative survival and proportionate mortality. Comput. Biomed. Res. 7: 325–332 (1974).
3. Matanoski, G. M., and Schwartz, L. Mortality of workers in styrene-butadiene polymer production. J. Occup. Med. 29: 675–680 (1987).
4. Meinhardt, T. J., Lemen, R. A., Crandall, M. S., and Young, R. J. Environmental epidemiologic investigation of the styrene-butadiene rubber industry: mortality patterns with discussion of the lymphohematopoietic and lymphatic malignancies. Scand. J. Work. Environ. Health 8: 250–259 (1982).
5. Wen, C. P., Tsai, S. P., Weiss, N. S., and Gibson, R. L. Long-term mortality study of oil refinery workers: V. Comparison of workers hired before, during, and after World War II (1940–1945) with a discussion of the impact of study designs on cohort results. Am. J. Ind. Med. 9: 171–180 (1986).
6. Divine, B. J., Barron, V., and Kaplan, S. D. Texaco Mortality Study. I. Mortality among refinery, petrochemical, and research workers. J. Occup. Med. 27: 445–447 (1985).