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An Evaluation of the Adequacy of Vital Status Follow-Up in the Hanford Worker Mortality Study

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November 1993

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AN EVALUATION OF THE ADEQUACY OF VITAL STATUS FOLLOW-UP IN THE HANFORD WORKER MORTALITY STUDY

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SUMMARY

The purpose of the study described in this report was to evaluate the completeness of vital status ascertainment in the Hanford worker cohort. Identifying information on 17,708 Hanford workers, including all workers who were monitored for external radiation exposure, employed at least six months at the Hanford site, and whose vital status remains unknown, was submitted to a private search organization, Equifax Government and Special Systems. Equifax then linked Social Security numbers of these workers with death information files. For the period 1945-86 that has been emphasized in recent dose-response analyses of the Hanford data, Equifax ascertained only 12 new deaths, an increase of only 0.2% over deaths that had been ascertained previously. In addition, Equifax ascertained 23 deaths that were judged to be mismatches based on comparison of names and birth-dates on their files and ours; it is shown that this number can be regarded as a rough estimate of the number of deaths missed because workers had incorrect Social Security numbers. Overall the study suggests that the number of deaths missed was not large, but the confidence one can place in this conclusion is limited by the fact that Equifax's ascertainment procedures are not perfect, especially for the period before 1965.

In order to evaluate the adequacy of the methods used by Equifax, information on 2254 Hanford workers who had been previously identified as dead was also submitted. Equifax missed less than 2% of known Hanford deaths occurring in the period 1965-86, but missed about 18% of deaths occurring before 1965.

Although recent analyses have focused on the period 1945-86, some analyses have included deaths ascertained using direct linkage with Washington state death files for the period 1987-89. Equifax identified 49 new deaths during this period in Washington state, an increase of 9% over those that had been previously ascertained. Forty of the 49 deaths occurred in 1988. It is clearly important to take additional steps to insure that the annual files provided by the state of Washington are complete.

A stratified random sample of 1600 of the 17,708 workers with unknown vital status was submitted to Equifax for a more extensive investigation of

follow-up status, and information on these workers was compared against consumer credit databases to determine the last date these workers were known to be alive. The results of this part of the study indicate that if these procedures had been applied to all workers with unknown vital status, about 90% of these workers would have been confirmed to be alive. About 5% of the total study population would have remained lost to follow-up, primarily because they could not be located by Equifax.

This study suggests several follow-up steps that are needed, and these are noted in the Conclusions section. Although this study has yielded interesting information, routine use of Equifax services, in addition to ascertainment procedures already in use, does not seem justified.

CONTENTS

TABLES

1.0 INTRODUCTION

Several analyses of data on mortality of workers at the Hanford site have been published (most recently by Gilbert et al. 1993), and have relied on vital status information from several sources including periodic searches of earnings and benefits files of the Social Security Administration (1944-1986), and use of the U.S. National Death Index (1979-1986). In addition, probability linkages (of Social Security numbers and names) have been made with the State of Washington vital statistics computerized files for 1968-1989 and the State of California vital statistics computerized files for 1960-1986. An advantage of the use of probability linkages is that they are not dependent on exact matches of social security number or name, but rather on high probability matches.

The only attempt to evaluate the completeness of death ascertainment in the Hanford cohort was an examination of the proportion of deaths in the State of Washington (where mortality ascertainment was judged close to 100% complete) that were also identified through the Social Security Administration (SSA) or National Death Index (NDI). Based on this approach, Gilbert and Petersen (1989) determined that for the period 1968-1981, 97% of deaths occurring in the state of Washington had been identified by the SSA or NDI.

The study described in this report provides a more comprehensive attempt to evaluate the completeness of follow-up in the Hanford cohort. A protocol for the study was prepared and is attached as Appendix A.

2.0 METHODS

The Hanford study population includes more than 44,000 employees of U.S. Department of Energy contractors. However, recent dose-response analyses (Gilbert et al. 1993) were restricted to 32,643 workers (24,672 males and 7,971 females) who were monitored (through the use of personnel dosimeters) for exposure to external radiation, and who were employed at least six months at the site. The follow-up study described in this report was also restricted to this group. Additional information on the study population is found in Gilbert et al. (1993), and a detailed description of the creation of the Hanford database is given by Gilbert et al. (1992)

The initial step in this evaluation was to identify Hanford workers with unknown vital status for analyses including deaths for the period 1944-86. This group was defined as workers who had terminated employment at Hanford prior to January 1, 1987, and who had not been identified dead. Workers were considered to be terminated if both the last date of external dosimetry monitoring and the last employment history date (obtained from files maintained at HEHF) were earlier than 1987. Known deaths were excluded from the unknown vital status group even if the death had occurred more recently than 1986 provided that death certificates had been found. Deaths for whom certificates have not been found were included in the unknown vital status group; there were 48 such deaths with years of death indicated as 1944-86, and 18 such deaths with no information on the year the death occurred. A total of 17,708 workers who met the criteria for the unknown vital status group were identified[(a)]; in previous analyses, it has been assumed that these workers were alive at the end of the follow-up period.

Identifying information on the 17,708 workers whose vital status remains unknown was submitted to the private search organization, Equifax Government and Special Systems. Equifax was selected after consideration of 1) capabilities to access numerous vital status resources beyond those methods currently

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(a) The protocol for this report indicated that 18,571 workers were in the unknown vital status group. However, since the calculations for this protocol were conducted, additional deaths have been identified, reducing this group to 17,708 workers.

employed by the Hanford Health and Mortality Study; 2) procedures used to protect confidentiality of information; 3) cost of search efforts; and 4) length of time required by agency to perform such services. Equifax then linked Social Security numbers (SSNs) of the group submitted with their death information file. The Equifax death file is composed of death information from the Social Security Administration, Fortune 500 companies, Fortune 100 companies, Armed Forces, and federal, state and county agencies. As described in Gilbert et al. (1992), some Hanford workers have been known under more than one SSN. When this occurred, the worker was submitted separately under all his or her SSNs. Of the 17,708 workers with unknown vital status, 91 had two or more SSNs; in these cases the SSN judged most likely to be correct is referred to as the "primary" SSN, while others are referred to as the "alternative" SSNs.

Equifax then supplied us with date of death and, where known, name, state of death, and date of birth for those cohort members identified as dead through this process. Information on name and date of birth was compared with that on our files to determine if the identified death was that of the Hanford worker submitted to Equifax. Eventually, death certificates on the additional deaths identified through Equifax need to be retrieved, but this has not yet been done; it is possible that some deaths will not be confirmed. Also, we had no information on cause of death for the new deaths identified by Equifax. Invalid SSNs (numbers that were never issued) were also identified.

In order to evaluate the adequacy of the methods used by Equifax, we also submitted information on 2254 Hanford workers, who had been previously identified as dead, and for whom we had death certificates. Fifty-four of these deaths were those identified through our Washington State linkage for the years 1968-82, which had *not* been ascertained by the SSA. We thought that these might be deaths that were especially difficult to ascertain, and were interested in whether or not Equifax would find them.

The remaining group of 2200 deaths were selected as a random sample of 7705 available deaths. Because of a decrease in Equifax's cost per death as the number of deaths increased, the total cost of submitting 2200 deaths (in addition to the 54 deaths and the 17,708 workers with unknown vital status) was less than the cost for submitting a smaller number of deaths. Of the

2200 deaths, 277 occurred in the years 1987-1990, after the end of the 1945-1986 follow-up period; these additional deaths were primarily deaths in the states of Washington and California.

A sample of the 17,708 workers with unknown vital status was also submitted to Equifax for a more extensive (and more costly) investigation of follow-up status. This investigation is referred to as "phase 2", while the investigation described in the preceding paragraphs is sometimes be referred to as "phase 1". Information on workers in the sample for phase 2 was compared against consumer credit databases in order to determine the last date these workers were known to be alive, and to determine last known addresses. The sample for this phase of the study was restricted to male workers born before 1935, and was stratified by three categories of cumulative dose 10 years before the end of follow-up at the end of 1986. As demonstrated in the protocol, these workers contribute most of the dose-response information. This investigation included a total of 1600 workers: 800 workers with cumulative doses less than 10 mSv, 400 workers with doses in the range 10-100 mSv, and 400 workers in the range 100+ mSv.

3.0 RESULTS

3.1 PHASE 1: DEATHS IDENTIFIED BY EQUIFAX AMONG KNOWN DEATHS OF HANFORD WORKERS

Before presenting results for the unknown vital status group, we consider Equifax's performance on Hanford workers already known to be dead. Table 3.1 shows the distribution of the 2200 randomly selected deaths by calendar year period, and also shows the number and percent that were missed by Equifax. Of the 2200 deaths, 1,923 occurred in the years 1945-86, the follow-up period of primary interest. An additional 167 deaths occurred in the period 1987-89 in the State of Washington, and this group was also considered in recent analyses.

For the period 1945-86, Equifax missed 5.0% of the deaths, and missed a higher percent for deaths occurring before 1965 than for deaths occurring more recently. Of deaths occurring in the period 1965-86, the percent missed was

TABLE 3.1. Number and Percent of Deaths Missed by Equifax in a Random Sample of Known Deaths of Hanford Workers

Calendar Year Period of Death	Number of Deaths in Sample	Number and Percent (in Parentheses) of Deaths Missed by Equifax
1945-54	81	7 (8.6)
1955-59	103	21 (20.4)
1960-64	186	40 (21.5)
1965-69	197	3 (1.5)
1970-74	312	1 (0.3)
1975-79	374	2 (0.5)
1980-84	452	14 (3.1)
1985-86	218	8 (3.7)
Total 1945-86	1,923	96 (5.0)
Total 1965-86	1,553	28 (1.8)
1987-89[a]	167	29 (17.4)
1987-89[b]	69	10 (14.5)
1990+	41	5 (12.2)

(a) Includes only deaths occurring in Washington State.
(b) Includes only deaths occurring in states other than Washington.

only 1.8. Equifax missed 82 of 1738 (4.7%) deaths in males compared with 14 of 185 deaths (7.6%) in females, and missed 21 of 488 deaths (4.3%) where the underlying cause of death was cancer, compared with 75 of 1435 deaths (5.2%) due to other causes.

Most of the information on dose-response is found in male workers born before 1935 and for the period 1965 or later; 97% of the statistical information for investigating dose-response for all cancer mortality is found in this segment of the data. In our random sample, there were 1,346 deaths in males born before 1935 and occurring after 1964. Of these, only 14 deaths (1.0%) were missed by Equifax; of 341 cancer deaths occurring in the same group, three (0.9%) were missed. Thus, Equifax performed better in the group of deaths that is of greatest importance for evaluating dose-response relationships. We also found no obvious bias in Equifax ascertainment by cumulative dose, especially when this evaluation was limited to deaths in males born before 1935 and occurring 1965 or later.

Equifax missed 17% of the deaths occurring in Washington State in the period 1987-89; in this case, the probability linkage with state files provided us with a special resource that was apparently not used by Equifax. It is also possible that some sources used by Equifax would not have information available as recently as 1989; this may also be the explanation for many of the other recent deaths that were missed. For deaths occurring before 1987, however, Equifax's performance did not vary greatly by state of death. For deaths occurring after 1964, Equifax missed 13 of 886 deaths (1.5%) occurring in the State of Washington, 5 of 156 deaths (3.2%) occurring in California, and ten of 511 deaths (2.0%) occurring elsewhere.

Finally, of the 54 deaths that occurred in the State of Washington in the period 1968-81 and that were *not* identified by the SSA, 11 (20%) were missed by Equifax.

3.2 PHASE 1: DEATHS IDENTIFIED BY EQUIFAX AMONG HANFORD WORKERS WITH UNKNOWN VITAL STATUS

We first consider the 66 workers, included in the unknown vital status group, who have been identified as dead but for whom no certificates have been

found, and for whom there is thus uncertainty regarding whether death has actually occurred. Equifax determined that 45 of the 48 workers with death-years of 1945-86 on our files were dead, but, for three of the 45 deaths, the year of death given by Equifax was later than 1986, and, for another two of the deaths, comparison of names and birth dates indicated the Equifax deaths were unlikely to be those of the Hanford workers submitted. Equifax ascertained that three of the 18 deaths with no data on death-year on our files occurred in the period 1945-86, and also ascertained that six deaths from this group occurred after 1986. In several cases, Equifax indicated a state of death that had not been on our files; this new information could possibly be helpful in finding death certificates. Until certificates are found for these workers, it is difficult to evaluate the validity of the information.

Of the remaining 17,642 workers in the unknown vital status group, Equifax identified 35 deaths occurring in the period 1945-86 that had not been identified previously. For 10 of these deaths, Equifax provided no information on name; however, none of the 10 birth-dates matched information on our files exactly, and in all but one case, the years of birth did not match. For the remaining 25 deaths, names and birth-dates on Equifax files were compared with similar information on our files; based on this comparison, 12 of these deaths were judged to match, while 13 were judged not to match.[(a)] Thus, Equifax added only 12 new deaths, an increase of about 0.2% over the 6,407 certified deaths in this period that had been identified previously. This information is summarized in Table 3.2. The 23 "mismatches" are likely to represent instances where either the SSNs on our files or on those of Equifax are incorrect.

(a) For males, information was judged to match if names agreed except for obvious spelling and typographical errors; in all cases where names did not match, birth-dates also failed to match, and in all but two such cases, birth-years did not match. For one male, only the last name matched, but because the birth-date matched exactly, this was judged a match. In three of the mismatched cases, first names indicated that the sex was different on the two files. For females, information was judged to match if first names matched and the year of birth matched; in all but one case where only the first name matched, the birth-dates matched exactly.

TABLE 3.2. Number of Deaths Identified by Equifax Among Hanford Workers with Unknown Vital Status (Number of Deaths in Females Given in Parentheses)

	Calendar Year Period		
	1945-86	1965-86	1987-89[a]
Deaths newly identified			
Correct "matches"[b]	12 (5)	12 (5)	49[c] (11)
No data on name provided by Equifax[d]	10 (3)	10 (3)	0 (0)
Data on name does not match	13 (2)	13 (2)	0 (0)
Certified deaths previously identified[e]	6,407 (621)	5,180 (553)	546 (98)

(a) Includes deaths occurring in Washington State only.
(b) Based on information on name and birth-date from our files and those provided by Equifax matches. See text.
(c) Forty of these deaths occurred in 1988.
(d) Birth-dates in this group did not match, and these deaths were judged to be non-matches.
(e) These numbers are given for perspective. These deaths were not included in the unknown vital status group.

Because Equifax was much more successful in identifying known Hanford deaths occurring 1965 and later than earlier deaths, this group is shown separately in Table 3.2; all of the 35 newly identified deaths came from this period. Table 3.2 also shows the number of newly identified deaths occurring in females. Of the 12 deaths that were judged correct matches, five (42%) occurred in females, even though overall, only about 10% of deaths occurred in females.

All 35 of the deaths noted above were identified based on the primary SSN. Equifax also identified 10 deaths in the period 1945-86 based on alternative SSNs. However, based on comparison of information on names and birth-dates, all of these deaths were clearly mismatches, indicating that for these workers, the alternative SSN is very unlikely to be correct.

In addition to the 35 deaths in the years 1945-86, Equifax identified 49 new deaths occurring in the state of Washington in the period 1987-89, comprising an 8% increase over the 547 deaths already identified. Based on a comparison of information on name and birth-date, all these deaths were judged

to be correct matches. Of the 49 deaths, 48 were identified based on the primary SSN, and one was identified based on the alternative SSN. Closer examination of these deaths indicated that 40 of the 49 deaths occurred in 1988. It is noted that of the 12 "matches" identified by Equifax for the period 1945-86, only one death was indicated as occurring in Washington, and two were indicated as occurring in California; all three were in the time period covered by the state linkages. It is possible, of course, that some of the deaths indicated by Equifax as occurring in Washington or California actually occurred elsewhere.

In addition to the deaths shown in Table 3.1, Equifax identified 181 deaths occurring in 1987-89 in states other than Washington, and 949 deaths occurring in 1990 or later. However, it is known that our files are not yet complete for these recent deaths, and such deaths have not been included in analyses conducted thus far.

An objective of this study was not only to evaluate the overall adequacy of death ascertainment methods, but also to determine if ascertainment might depend on various worker characteristics. Because the number of newly identified deaths with correct matches was very small, such dependencies could not be evaluated reliably. Also Equifax may ascertain deaths for some groups more adequately than for others. However, Equifax ascertained proportionally more new deaths in females than in males even though their ascertainment of known Hanford deaths was slightly better for males.

Differential ascertainment by radiation dose is of particular concern as this could bias results of dose-response analyses. Of the 12 deaths judged to be correct matches, nine (75%) had cumulative doses less than 10 mSv, three (25%) had cumulative doses in the 10-99 mSv range, and none had doses 100 mSv or greater. For comparison, it is noted that of the 5,180 deaths previously identified as occurring in the years 1965-86, 3,044 (59%) had cumulative doses less than 10 mSv, 1,718 (33%) had cumulative doses in the 10-99 mSv range, and 418 (8%) had cumulative doses 100 mSv or greater. Small numbers and potential biases in Equifax's ascertainment make it impossible to draw firm conclusions regarding dose-related bias.

Equifax also identified SSNs on our files that had never been issued. There were three such numbers in the unknown vital status group, one of whom was indicated as dead on our files, but with no certificate or year of death. The birth-years for these three workers were 1939, 1943, and 1952, and thus they are unlikely to have died (and thus have their deaths missed) by the end of 1986. In addition, Equifax indicated that six of the alternative SSNs had never been issued.

3.3 PHASE 2: VITAL STATUS FOR SAMPLE OF 1600 HANFORD WORKERS WITH PREVIOUSLY UNKNOWN VITAL STATUS

A stratified random sample of the 8027 male workers born before 1935 in the unknown vital status group was submitted to Equifax for more extensive follow-up. The sample included 800 workers with cumulative doses less than 10 mSv, 400 workers with doses in the range 10-100 mSv, and 400 workers in the range 100+ mSv; cumulative dose was defined as the total dose received 10 years prior to the end of follow-up.

Equifax assigned each of these workers to one of three categories: workers for whom a last activity date (based on credit records) could be determined, workers who were identified as deceased (usually with a date of death), and workers who could not be located. Table 3.3 shows the number of workers in each of these three categories and also indicates whether or not the date provided by Equifax was before or after the end of the follow-up period (December 31, 1986). Results are shown separately for each of the three dose categories. The line just above the total shows the total number of workers that Equifax confirmed as being still alive; this number was obtained as the sum of those with either activity dates or death dates after the end of 1986.

Overall, 89% of the sample were identified as being alive at the end of the follow-up period, and results did not differ greatly by exposure category. This proportion was also compared by birth year and by general job category. The proportion identified as alive tended to increase with increasing birth-year, and was 77% for those born before 1915 compared to 92% those born

TABLE 3.3. Number of Workers and Proportion (in Parentheses) by Vital Status Determined by Equifax for a Sample of Hanford Workers with Previously Unknown Vital Status[a]

	Cumulative dose (in mSv) 10 years prior to 1987			
	0-	10-	100+	Total
Identified as alive	642 (0.80)	308 (0.77)	308 (0.77)	1258 (0.79)
Last activity date				
before 1987	9	8	8	25
1987 or later	633	300	300	1233
Identified as deceased	95 (0.12)	48 (0.12)	55 (0.14)	198 (0.12)
Date of death				
before 1987	5	2	1	8
1987 or later	89	46	53	188
unknown[b]	1	0	1	2
Could not be located	63 (0.08)	44 (0.11)	37 (0.09)	144 (0.09)
Identified as alive at end of 1986(c)	722 (0.90)	346 (0.87)	353 (0.88)	1421 (0.89)
Total	800	400	400	1600

(a) All workers in sample were males born before 1935 who were monitored for external radiation and employed at least six months at Hanford.
(b) For seven additional workers, the phase 2 date of death was indicated as unknown, but was available and utilized based on phase 1 results.
(c) Includes those identified as alive with last activity date 1987 or later and those identified as deceased with date of death 1987 or later.

between 1915 and 1935. The proportion identified as alive was also larger for professional, technical and clerical workers (93%) than for skilled and unskilled manual workers (85%).

An estimate of the overall completeness of follow-up was obtained as follows. For each dose category, the sample proportions of those identified as alive at the end of 1985 (from Table 3.3) were multiplied by the number of workers in the unknown vital status group. This yielded the estimated number of workers in the unknown group that would have been identified as alive if the entire group had been submitted to the more extensive phase 2 follow-up by Equifax. To obtain the total "known to be alive", these numbers were then added to the number known to be alive either because they had employment history or external dosimetry data after the end of 1986, or because they were

known to have died after 1986. Finally, the number "lost to follow-up" was estimated by subtracting the sum of the number "known to be alive" and "known to be dead" from the total number in the study population. Results of these calculations are shown in Table 3.4. Overall, about 5.5% of the study population of males born before 1935 were estimated to be lost to follow-up.

TABLE 3.4. Estimated Vital Status for Hanford Workers Based on Phase 2 Equifax Results[a]

	Cumulative Dose (in mSv) 10 years Prior to 1987			
	0-	10-	100+	Total
1. Number of workers with previously unknown vital status	4596	2710	721	8027
2. Proportion of workers identified as alive at the end of 1986 in phase 2 study[b]	0.903	0.865	0.883	
3. Estimated number of workers that would be identified as alive at the end of 1986[c]	4147.9	2344.2	636.3	7128.4
4. Additional workers known to be alive at the end of 1986[d]	1045	1261	482	2788
5. Total alive workers (sum of 3. and 4.)	5192.9	3605.2	1118.3	9916.4
6. Workers known to be dead[e]	3927	1421	302	5650
7. Total in study population[a]	9568	5392	1505	16.465
8. Estimated number of workers "lost to follow-up" (5. and 6. subtracted from 7.)	448.1	365.8	84.7	898.6
9. Estimated proportion of workers "lost to follow-up"	0.047	0.068	0.056	0.055

(a) Applies to males born before 1935 who were monitored for external radiation and employed at least six months at Hanford.
(b) See Table 3.3.
(c) Based on assumption that results of phase 2 Equifax follow-up apply to other workers with previously unknown vital status.
(d) Includes workers with employment history or external radiation monitoring data 1987 or later, and workers with certified deaths occurring 1987 or later
(e) Includes certified deaths occurring before 1987

Another way of using the information from phase 2 of this study is to consider the number of person-years that were perhaps inappropriately included in statistical analyses because workers "lost to follow-up" were considered as remaining alive until the end of 1986. Table 3.5 shows information similar to Table 3.4, but based on person-years; workers in the sample with either last

TABLE 3.5. Estimated Person-Years for Hanford Workers Based on Phase 2 Equifax Results[a]

	Cumulative Dose (in mSv) 10 Years Prior to 1987			
	0-	10-	100+	Total
1. Number of person-years in sample of workers subjected to phase 2 follow-up				
a. Based on assuming workers alive until the end of 1986	20,582	12,195	12,500	45,277
b. Based on use of phase 2 information	18,905	11,485	12,039	42,430
2. Number of person-years in group with previously unknown vital status				
a. Based on assuming workers alive until the end of 1986	121,688	83,039	22,342	227,068
b. Reduced by proportion estimated as 1b divided by 1a.	111,770	78,214	21,518	211,502
3. Number of person-years in remaining group of workers[b]	83,468	70,787	22,260	176,514
4. Total person-years				
a. Obtained as sum of 3. and 2a.	205,156	153,826	44,602	403,584
b. Obtained as sum of 5. and 2b.	195,238	149,001	43,778	388,016
5. Reduction in person-years with adjustment for phase 2 information	0.952	0.969	0.982	0.961

(a) Applies to males born before 1935 who were monitored for external radiation and employed at least six months at Hanford.

(b) Includes workers with employment history or external radiation monitoring data 1987 or later, and workers with certified deaths.

activity dates or dates of death earlier than 1987 were removed on these dates, while workers who could not be located were removed on the last date for which employment or dosimetry data were available. For person-year calculations, workers were assumed to start their follow-up five years after their date of first monitoring for external radiation, the procedure used in dose-response analyses described by Gilbert et al. (1993).

Overall, if all workers in the unknown vital status groups had been submitted to the Equifax phase 2 investigation, and workers were then removed from follow-up on the dates determined as described above, it is estimated that the total person-years would have been reduced by about 4%. Reductions for the dose categories less than 10 mSv, 10-100 mSv, and 100+ mSv were respectively 5%, 3%, and 2%.

Because workers in the sample submitted to the phase 2 Equifax procedures were also included in the phase 1 death ascertainment, it is of interest to compare the deaths ascertained by Equifax in the two phases. Only two deaths were identified in phase 2 that had not been identified in phase 1, and in neither case was a death date given. Three of the deaths identified in the sample in phase 1 as correct matches were designated in phase 2 as "could not locate" with no indication of death in the phase 2 results. These deaths occurred in 1986, 1988, and 1990. An additional three deaths from phase 1, all indicated as occurring in 1992, had phase 2 "last activity dates" in 1993. Apparently, the resources used to identify deaths in phase 1 were not applied to those submitted for phase 2 procedures.

4.0 DISCUSSION

A major objective of this study was to evaluate the proportion of deaths that might have been missed by ascertainment procedures used in the Hanford mortality study. For the period 1945-86, Equifax ascertained only 12 new deaths, an increase of only 0.2% over deaths that had been ascertained previously. However, this cannot necessarily be taken as strong evidence that the percentage of deaths missed was very small.

Equifax missed about 18% of known Hanford deaths occurring before 1965, and thus this study provides little information on the completeness of ascertainment for early deaths. For later deaths, Equifax missed less than 2% of known Hanford deaths, and thus we can be somewhat more confident about this later period. However, if current ascertainment methods failed to ascertain a substantial number of deaths, these unascertained deaths might also be difficult for Equifax to identify, and thus the proportion of these deaths missed by Equifax could be much greater than 2%. For example, deaths missed by linkage with the SSA may potentially be missed by both our ascertainment methods and Equifax's.

Because of our direct linkage with the State of Washington death files, we are probably less likely to miss deaths of workers who die while still employed at Hanford. In fact, all but one of the 35 deaths shown in Table 3.2, including both those newly ascertained by Equifax and those involving mismatched SSNs, were of Hanford workers who had terminated employment five or more years prior to death. Of the 12 new deaths of Hanford workers, ten were under age 55 at the time of termination of employment at Hanford. Thus, these workers could have had a subsequent employer after their employment at Hanford, and may have been ascertained because of Equifax's access to death files from Fortune 500 and Fortune 100 companies.

The large number of missed deaths in Washington State for the period 1987-89 is especially troublesome. For all the new Washington deaths identified by Equifax, both SSNs and names agreed with information on our files, and thus these deaths should have been picked up in our Washington State linkage. In conducting this linkage, files of deaths are provided by the state for each calendar year, and the probability linkage is then

performed by Advanced Linkage Technologies of America. The most likely explanation for missing deaths would appear to be incompleteness of files provided by the state. There apparently was a problem with the 1988 file, and possibly there were less severe problems with the files for 1987 and 1989.

Because we do not yet have death certificates for the newly ascertained Equifax deaths (and thus do not have information on cause of death), it is not possible to examine the effect of dose-response analyses of the addition of the new deaths. However, because the number of deaths is so small, and because none of the 12 newly ascertained deaths had cumulative doses exceeding 100 mSv, it is highly unlikely that the addition of these deaths would have a large impact on results. The deaths missed for Washington State for the period 1987-89 could potentially have a larger impact on analyses that included these deaths. However, results from these supplementary analyses were not emphasized by Gilbert et al. (1993). It is also noted that even without the Equifax deaths, most of the missed Washington State deaths would probably have been identified by the NDI or SSA before cohort-based analyses were conducted.

Equifax ascertainment was based on exact matches of SSNs on our files with those on their death files. Thus, mismatches of information on name and birth-date probably indicate that SSNs on either our files or Equifax's are incorrect. If it is assumed that all mismatches result from incorrect SSNs on our file, the number of such mismatches can be regarded as a very crude estimate of the number of deaths that would be missed because of incorrect SSNs. The reasoning for this follows.

Let W indicate the number of Hanford workers who have unidentified incorrect SSNs. Let the proportion of these workers that have died by the end of 1986 for these Hanford workers be designated by P_H, and let the comparable proportion for the actual persons with these SSNs be designated by P_A. If Equifax ascertainment were perfect, the number of mismatched deaths identified by Equifax would be $P_A \times W$. Thus, if P_A were known, W could be estimated by the actual number of mismatched deaths, w, divided by P_A. Among the W Hanford workers with incorrect SSNs, $P_H \times W$ will have died by the end of 1986, and will be missed because of their incorrect SSNs; this number could be estimated by $w \times P_H/P_A$.

A difficulty is that neither P_H nor P_A are known. However, if it is assumed that P_H is approximately equal to P_A, then the number of missed deaths can be estimated by w. The relationship of P_A and P_H can be roughly evaluated by comparing the birth-year distribution of the Hanford workers holding incorrect SSNs (based on information on our files) to that of the persons who actually hold those SSNs (based on information provided by Equifax). The mean year of birth on our files was 1919.1, while that on the Equifax file was 1915.3. Because the group to whom the actual SSNs belong is slightly older than the Hanford workers with these numbers, it can be expected that P_A will be larger than P_H, and thus $w \times P_H/P_A$ is likely to be smaller than w.

Other factors also make w a very crude estimate of the number of deaths missed because of erroneous SSNs. Because Equifax's ascertainment is not perfect, w should probably be increased; on the other hand, if some of the mismatches result from incorrect SSNs on the Equifax files rather than ours, w should be decreased. However, the fact that w, the number of mismatches, is fairly small (23) can be regarded as reassuring, and would seem to indicate that the number of deaths missed because of incorrect SSNs is not large.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Deaths can fail to be ascertained for a number of reasons including the use of incorrect SSNs, and incompleteness and inaccuracies of information on death files providing the basis for mortality information. For example, deaths cannot enter the SSA system if no claim for benefits is filed. This study provides limited information both on the number of deaths missed because of incorrect SSNs and on the number of deaths missed because of other problems. The study suggests that the number of deaths missed for either reason was not large, but the confidence one can place in this conclusion is limited by the fact that Equifax's ascertainment procedures are not perfect, especially for the period before 1965.

This study identified a problem with Washington State deaths in 1988, and indicates that it is important to take additional steps to insure that files provided by the state are complete. One simple check would be to compare the numbers of deaths by year, both for the state as a whole and for those linked with Hanford workers. For example, the numbers of Washington State deaths occurring in Hanford workers for the years 1986, 1987, 1988, and 1989 were respectively 191, 196, 158, and 192; the drop in 1988 could have served to alert us to the possibility of a problem.

Certain other findings also need to be followed up. Certificates need to be sought for deaths newly ascertained by Equifax, including those occurring beyond 1986 (which will be needed in future updated analyses). For deaths we were previously aware of but had no certificates, and where Equifax indicated a state that had not been indicated previously, attempts to obtain the certificate from the state need to be made. For workers where SSNs were indicated as numbers that were never issued, or where deaths were found with information on name and birth-date that did not match, efforts need to be made to determine correct SSNs. If this is not possible, then consideration should be given to dropping these workers from the study population included in various statistical analyses.

With regard to future use of Equifax, their ascertainment methods would identify about 98% of the deaths ascertained using current methods, and thus probably should not be considered as a substitute for other methods. As a

supplement to sources already in use, the number of additional deaths identified was very small, and probably does not justify the cost. Even though the cost per name submitted was very small, the cost of each newly identified death was in the range of $200-$300 dollars. In addition to Equifax fees, costs are also incurred for staff time spent in preparing files, interacting with Equifax, and interpreting results. In a future submission, the yield in deaths that would not be identified by other sources can be expected to be even smaller (increasing the cost per death); based on the current study, about a half a death per year might be expected.

The results of the phase 2 portion of this study indicate that if the procedures used by Equifax in this phase were applied to all workers with unknown vital status, about 90% of these workers would be confirmed to be alive. Also, about 5% of the total study population would remain "lost to follow-up". This more extensive follow-up does not seem to be a cost-effective means of ascertaining new deaths, as few deaths were identified that were not also identified in the much less costly phase 1. A possible advantage of the phase 2 type follow-up is that it would provide a means of identifying workers who should perhaps have a portion of their person-years removed from statistical analyses. However, it is not clear that it is fully appropriate to remove workers in the "could not locate" group, when it is possible that their deaths will eventually be identified. Overall, the large costs of applying phase 2 methods to the entire cohort do not seem justified.

6.0 REFERENCES

Gilbert E. S., G. R. Petersen, and J. A. Buchanan. 1989. "Mortality of workers at the Hanford Site: 1945-1981." Health Phys. 56:11-25.

Gilbert E. S., E. Omohundro, J. A. Buchanan, and N. A. Holter. 1993. "Mortality of Workers at the Hanford Site: 1945-1986." Health Phys. 64(6):577-590.

Gilbert, E. S. 1992. Description of the Process Used to Create the 1992 Hanford Mortality Database. PNL-8449, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

PROTOCOL FOR VITAL STATUS FOLLOW-UP STUDY

APPENDIX A

PROTOCOL FOR VITAL STATUS FOLLOW-UP STUDY

Title: Evaluation of the Adequacy of Follow-up for Hanford-site Workers.

Prepared by the Hanford Environmental Health Foundation (HEHF) and Pacific Northwest Laboratory (PNL).

Principal investigators: Ellen Omohundro (HEHF) and Ethel S. Gilbert (PNL)

I. Specific Aims

The objectives of the study are: 1) to determine the adequacy of vital status capture techniques; and 2) to determine the impact that loss of vital status information may have on results of analyses of data from the Hanford worker study.

This study will be conducted by HEHF in collaboration with PNL. Methods employed will identify persons whose vital status is unknown, obtain additional vital status information, and determine the impact exclusion of this information has on the Hanford Health and Mortality Study. This protocol will be reviewed and approved by the Scientific Advisory Committee and approval for the protection of human subjects will be acquired form the Internal Review Boards of HEHF and PNL.

Professional tracking services will used to determine vital status for selected groups for workers. Information has been collected indicating that some workers are known by multiple names and social security numbers. The study will fully utilize multiple personal identifiers. Because the Death Certificate Retrieval Office at Oak Ridge Associated Universities is the official coordinator for activities relating to death ascertainment and death certificate procurement for DOE studies, their involvement in retrieving death certificates on additional deaths identified through professional tracking services will be requested.

PNL will assist HEHF in designing the study and in interpreting the results. PNL has identified terminated workers who are not known to be dead, and has determined the distribution of such workers by current age, sex, length of employment, cumulative dose, and other variables. This information has been considered by PNL and HEHF in designing a study that can effectively estimate the proportion of deaths that have not been ascertained, and that can also estimate the potential bias that incomplete ascertainment may introduce in dose-response analyses, and in other analyses that are conducted. This study design is described in Section IV of this protocol.

II. Background

Frequently, the end points of retrospective and prospective cohort studies are based upon mortality events, making accurate identification of vital status an important methodological component. The Social Security Administration and National Death Index (NDI) provide computerized sources of national mortality information for epidemiological investigations. Researchers have reported that up to 98 percent of deaths in defined cohorts submitted to NDI for which vital status of all cohort members was known were correctly identified by NDI. However, false positives may be high when social security numbers are not known (1). Motor vehicle registrations, Veterans Administration, post office, and union records have also been used as sources for vital status information. Utilization of these resources in combination with the Social Security Administration has been reported to result in the identification of vital status information on 94 percent of a defined cohort (2).

Use of probability linkages with state death files has also proved to successfully identify vital status of cohort members (3). This method employs the use of probabilistic and deterministic decision criteria to establish associations between study population and mortality or hospital record file (3). An advantage of this technique for occupational cohort studies is that it is not dependent on an exact match of social security number, but rather a high probability match. There are instances where an individual's occupational history identifies them by more than one social security numbers or invalid social security numbers (4). This probability linkage technique allows for the identification of death when a social security number in the study file is different from the vital status file, but based on deterministic decision criteria has a high probability of being an associated record (3). Thus, additional death information on a cohort may be identified through application of this technique that would not be identified if only an exact match were considered.

Alternative methods involve identifying last known addresses from consumer databases and identifying credit activities (application for insurance, customer transaction, mortgage transaction, etc.) associated with that address (2). Verification of last known address and vital status may be further made through telephonic investigations (2). This process, although very successful, is generally very time consuming and costly. Many cohort studies may find it prohibitive on a large scale but useful for stratified subsets of the cohort.

III. Overview of the Hanford Health and Mortality Study

The study population, exposure data, vital status ascertainment and analysis methods have been described elsewhere (5). Methods currently used to ascertain vital status will be emphasized here.

Mortality ascertainment methods currently used by the Hanford Health and Mortality Study. With the assistance of Oak Ridge Associated Universities, death certificates of former Hanford-site employees are identified by utilizing multiple data sources of death information.

The Social Security Administration (SSA) has been utilized since 1965 by submitting name, sex, race, birthdate and social security number of employees who have terminated employment and who are not known to be dead. This information is compared against earnings records. Workers who are receiving benefits or paying into the SSA system are assumed to be alive. Workers not assumed to be alive are then compared against SSA application, name change, death, disability and beneficiary records. Date of death, and city and state of where the claim was filed are supplied for those persons that match information contained in these files. This comparison also identifies social security numbers that do not match the SSA information (e.g., our files have a different name compared to the SSA file) and numbers that have never been issued.

The direct interface with SSA and death certificate procurement is performed on Hanford data by the DCRO under a cooperative arrangement. The DCRO is managed by Center for Epidemiologic Research, Oak Ridge Associated Universities. After employees are identified as dead by SSA, the DCRO performs searches on deaths, locates and obtains death certificates, then sends the death certificates to HEHF. DCRO does not search for death certificates where the death was identified as occurring in Washington or California. We have established direct linkages with these two states as described below.

In 1988, use of the SSA was suspended until review of the system's use with respect to confidentially assurance could be completed. Thus, DCRO has sought alternative data sources for obtaining this information. Pension Benefits Information (PBI), a for-profit company located in California, has been utilized by DCRO to obtain vital status information. This organization compares names, social security number and date of birth files against U.S. Department of Health, Education and Welfare, civil service, Railroad Retirement, Department of Defense and State of California pension files. Matches resulting form this linkage provide users with date and place of death information. Comparisons of Hanford data against PBI files were performed by DCRO in 1990.

The National Death Index (NDI) is a central, computerized index of death record information complied from magnetic tapes submitted by state vital statistic offices under contractual agreements to the National Center for Health Statistics established in 1979. The data are used in searches to identify and locate death records. The names of states where the deaths occurred, dates of death, and the corresponding death certificate numbers are

provided to NDI users. The investigators utilizing this index must make arrangements with independent states to obtain requested death certificates. A list of employee information including name, social security number, date and state of birth, state of residence, sex, age and martial status, is submitted to the National Center for Health Statistics. The Center compares the list with NDI information. The NDI search results are post-processed by Advanced Linkage Technologies of America, Inc. using a statistical program (REFINER) to reorganize the files. This program identifies matches that have a high likelihood of being Hanford employees. The output is reviewed and death certificates are requested from the appropriate states for those verified as being Hanford workers.

About 50% of Hanford site employees die in the state of Washington and 10% in California. Direct linkage with these states provides us with death information in a more timely fashion than is capable of achieving through national linkages. This technique involves comparing the employee rosters to state death information. Statistical probabilities of a match are calculated via the Refiner software designed by Advance Linkage Technologies of America. Death certificates are then requested for those deaths that are verified as being former Hanford site employees. To date, Hanford records have been linked with Washington mortality records for the years 1968 through 1989 and with California mortality records for the years 1960 through 1989.

Death certificates are sent to certified nosologists at the National Center for Health Statistics (NCHS), and all medical conditions recorded on the certificate are coded according to the Ninth Revision on the International Classification of Diseases (ICD9). Coded certificates are then returned to HEHF where the information is automated, and again sent to NCHS. NCHS software is used to verify consistency of the codes and to assign underlying cause of death. PNL translates ICD9 codes back to ICD8 for analysis.

IV. Research Design and Methods

A. Size and description of population to be studied. Recent dose-response analyses have included operations workers who were monitored for external radiation and who were employed at least six months at the Hanford site. Table 1 shows the distribution of these workers by their follow-up status at the end of 1986. The category "known to be dead" includes workers identified as dead prior to 1987. The category "known to be alive" includes workers with dosimetry data or employment records 1987 or later and also workers identified as dead 1987 and later. Remaining workers are included in the "vital status unknown" category; for past analyses it has been assumed that these latter workers were alive at the end of the follow-up period (end of 1986).

Separate distributions are shown for males and females and for those born before and after 1935. Those born after 1935 would generally be under 50 at the end of the follow-up period, and a relatively small proportion of these workers have died. In dose-response analyses of all cancer, 98.3% of the statistical information was contributed by the over 50 years of age segment of the population; 97.8% was contributed by males in this age group. For this reason, we propose restricting the more costly components of the follow-up investigation to males born before 1935.

Table 2 shows the distribution of workers by the dose accumulated 10 years prior to the end of the follow-up period, again separating males and females and those born before and after 1935. Most dose-response analyses have been based on doses that have been lagged for 10 years. It can be seen that most workers with higher doses (> 100 mSv) were males born before 1935.

B. Objective of the study. The objective of the study is to determine the impact that loss of vital status information may have on results of analyses of data from the Hanford worker study.

C. Vital status ascertainment methods. Information has been collected indicating that some workers are known by multiple names and social security numbers. The study will fully utilize multiple personal identifiers. In addition to vital status search efforts previously described, additional search efforts will be made.

Services of private search organizations were investigated by HEHF. These search organizations were requested to supply the sources of information that are available to them and methods of how those data sources would be utilized. The following factors were considered: 1) capabilities to access numerous vital status resources beyond those methods currently employed by the Hanford Health and Mortality Study; 2) procedures used to protect confidentiality of information; 3) cost of search efforts; and 4) length of time required by agency to perform such services. After consideration of available agencies, Equifax Government and Special Systems was deemed most appropriate.

The private search organization, Equifax, will compare all of the identifying information on the 18,571 persons whose vital status remains unknown against their death information files. The Equifax death file is composed of death

information from the Social Security Administration, Fortune 500 companies, Fortune 100 companies, Armed Forces, and federal, state and county agencies. Date of death and state of death will be supplied for those cohort members identified as dead through this process. Invalid social security numbers will also be identified. The cost of this service is $0.185 per name; thus the cost of submitting all records will be $3,436. Assistance from the DCRO will be requested to retrieve death certificates on additional deaths identified through Equifax.

In addition, a stratified random sample of persons for whom vital status still could not be determined by other techniques will be identified by PNL. Equifax will compare these persons against consumer credit databases, and thus determine the last date these workers were known to be alive. Last known addresses and activity dates associated with those addresses will be identified. The cost of this service is $10.00 per name. Due to funding constraints, we will be able to submit approximately 1600 names to be compared against the consumer credit databases. Again, the primary purpose of this process is to identify former workers who are alive. In the event that a worker is identified as dead, the worker will be indicated as "deceased"; however, the place of death will not be indicated.

We propose restricting this second phase of the investigation to male workers born before 1935 for the reasons noted above. The distribution of these workers by cumulative dose 10 years before the end of follow-up and by follow-up status is shown in Table 3. We propose randomly selecting 400 workers from the 764 workers in the highest dose group (> 100 mSv), 400 workers from the 2,942 workers with cumulative doses 10-100 mSv, and 800 workers from the 4,747 workers with doses less than 10 mSv.

D. Data analysis. Upon completion of the first submission to Equifax, new deaths identified through this process will used to estimate the proportion of deaths that were not ascertained previously for various subgroups of the population defined by cumulative dose, birth cohort, calendar year period, length of employment, socio-economic status, sex, and other variables. Particular emphasis will be put on examining the possibility that mortality ascertainment is related to cumulative radiation dose. We will also conduct dose-response analyses similar to those reported in Gilbert et. al. (1993) to determine if the addition of new deaths modifies results in any important way. Finally, we will evaluate whether the additional deaths identified through this process warrant its routine use in the future.

The second submission to Equifax will allow us to classify the 1600 workers (currently of unknown follow-up status) as dead (through information obtained in the first submission), known to be alive (if their last date known to be alive is 1987 or later), or still of unknown vital status (if their last date known to be alive is 1986 or earlier). The proportions of workers with unknown vital status will be estimated and compared for various subgroups, with particular attention to potential differences related to cumulative dose. Analyses addressing the correlation with dose will be adjusted for those variables that have been considered in dose-response analyses. For those workers who continue with unknown vital status, we will use the new last dates

supplied by Equifax in combination with last dates of employment or dosimetry at Hanford to evaluate the length of time that workers in various categories have been lost to follow-up.

E. Data reporting.

PNL and HEHF will collaboratively prepare a final report that will discuss the benefits of additional search techniques and the impact loss of vital status information has on the Hanford Health and Mortality Study.

References

1. Curb, J.D., Ford, C.E., Pressel, S., Palmer, M., Babcock, C. and Hawkins, C.M. Ascertainment of vital statistics through the National Death Index and the Social Security Administration. American Journal of Epidemiology, 1985; 121:754-766.

2. Johnson, E.S. Treatment of subjects lost to follow-up in the analysis of mortality studies. Journal of Occupational Medicine, 1988; 30:60-62.

3. Arellano, M.G., Petersen, G.P., Petitti, D.B. and Smith, R.E. The California automated mortality linkage system (CAMLIS). The American Journal of Public Health, 1984; 74:1324-1330.

4. Gilbert, E.S. A study of detailed dosimetry records for a selected group of workers included in the Hanford mortality study. Richland WA: Pacific Northwest Laboratory; Report No. PNL-7439; 1990.

5. Gilbert, E.S., Petersen, G.R. and Buchanan, J.A. Mortality of workers at the Hanford site: 1945-1981. Health Physics, 1989; 56:11-25.

TABLE A.1. Distribution of monitored workers employed at least six months at the Hanford site by follow-up status, sex, and whether born before or after 1935.

Subgroup	Follow-up status: Known to be dead	Known to be alive	Unknown	Total
Males born before 1935	5,691	2,332	8,453	16,476
Males born 1935 and later	142	3,467	4,609	8,218
Females born before 1935	587	492	2,797	3,876
Females born 1935 and later	43	1,342	2,712	4,097
Total	6,463	7,633	18,571	32,667

TABLE A.2. Distribution of monitored workers employed at least six months at the Hanford site by cumulative dose 10 years prior to the end of follow-up, sex, and whether born before or after 1935.

Subgroup	Cumulative dose: 0-10 mSv	10-99 mSv	100+ mSv	Total
Males born before 1935	9,471	5,482	1,523	16,476
Males born 1935 and later	6,713	1,326	179	8,218
Females born before 1935	3,289	527	60	3,876
Females born 1935 and later	3,993	104	0	4,097
Total	23,466	7,439	1,762	32,667

TABLE A.3. Distribution of male monitored workers employed at least six months at the Hanford site and born before 1935 by cumulative dose 10 years prior to the end of follow-up, and follow-up status.

	Cumulative dose			
Follow-up status	0-10 mSv	10-99 mSv	100+ mSv	Total
Known to be dead	3,947	1,440	304	5,691
Known to be alive	777	1,100	455	2,332
Unknown	4,747	2,942	764	8,453
Total	9,471	5,482	1,523	16,476

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