ORAU Team **Dose Reconstruction Project for NIOSH** Technical Information Bulletin: Individual Dose Adjustment Procedure for Y-12 Dose Reconstruction	Document Number: ORAUT-OTIB-0013 Effective Date: 09/09/2004 Revision No.: 00 Controlled Copy No.: _______ Page 1 of 9
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	05/26/2004	00-A	New technical information bulletin which describes an individual dose adjustment procedure that can be used as part of the dose reconstruction for certain workers at the Oak Ridge Y-12 Plant. Initiated by Judson L. Kenoyer.
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1.0 INTRODUCTION

This document describes an individual dose adjustment procedure that can be used as part of the dose reconstruction for certain workers at the Oak Ridge Y-12 Plant. It provides a derivation of the "scaling procedure", tables required for the calculation, and an example. The method can be used for workers who were not monitored prior to 1961 who have at least five quarters of monitoring data during the period from 1961 through 1965. For a detailed explanation of how to use this procedure see Kerr and Smith (2004).

2.0 BACKGROUND

Kerr (2003), Watkins et al. (2004), and Watkins et al. (1993) provide a detailed description of the film badge dosimetry program at the Oak Ridge Y-12 facility. Prior to 1961 only workers with the highest potential for external radiation exposure were required to wear personnel dosimeters. A recent review of all film badge monitoring data from Y-12 workers used data available at the Center for Epidemiological Research (CER) at Oak Ridge Associated Universities (ORAU; Watkins et al. 2004). This review determined that the population dose for each quarter can be described by a lognormal distribution. The "missed dose" in each quarter of employment for a worker who was not monitored is based on the lognormal population distribution. This is consistent with procedures described in NIOSH (2002, Sections 1.1.4 and 1.6).

The probability density function for the lognormal distribution (Johnson, Kota, and Balakrishnan 1994) is

$$p(d;\mu,\sigma) = \exp[-\frac{1}{2}(\log d - \mu)2/\sigma 2]\ (\sqrt{2\pi}\ \sigma d)^{-1}\ , \qquad (1)$$

where d is film badge dose and μ and σ are lognormal parameters. For a review of the lognormal distribution with alternative parameterization and its use in risk analysis see Strom and Stansbury (2000). Table 1 at the end of this document contains the lognormal parameters for each quarter from 1947 through 1965. These values were obtained based on assumptions described in Watkins et al. (2004) using statistical methods described in Frome and Watkins (2004). Starting in the fourth quarter of 1956 the values of σ in column 5 of Table 1 are slightly larger than the corresponding values in column 4 of Table 5 in Watkins et al.(2004). This difference is the result of an unnecessary bias adjustment that was applied to Table 1---see Frome and Watkins (2004) for details. The values of σ in Table 1 are always larger by about 0.1 percent and therefore claimant favorable. In the scaling procedure, these parameters are considered as known values because they are based on population data and their relative uncertainty will have little material effect on the individual quarterly dose distribution required for dose reconstruction.

3.0 SCALING PROCEDURE BASED ON MAXIMUM LIKELIHOOD METHOD

If a Y-12 worker was employed for at least five quarters from 1961 to 1965, that individual's monitoring data can be used to "adjust" the dose distributions for unmonitored quarters from 1951 through 1960. The method is based on the assumption that the individual's potential for exposure during the 1950s is similar to that from 1961 to 1965, and that the individual's doses differ from the population dose by a constant factor. Suppose that d_t is the recorded dose during quarter t and μ_t and σ_t are the known lognormal parameter values for that same quarter from the first quarter of 1961 to the fourth quarter of 1965 (see Table 1, columns 4 and 5).

Then $y_t = \log(d_t)$ follows the normal distribution with mean $\mu_t + \varphi$, and standard deviation σ_t , where φ represents the average relative difference (on the log scale) of the individual's doses from the population values. The likelihood function for φ is

$$\mathcal{L}(\varphi|\mathbf{d},\boldsymbol{\mu},\boldsymbol{\sigma}) = \prod_t \exp[-\frac{1}{2}\{\log d_t - (\mu_t + \varphi)\}^2/\sigma_t^2]\,(\sqrt{2\pi}\,\sigma_t d_t)^{-1}, \qquad (2)$$

where $t = t_1, \ldots, t_n$ are quarters (see column 1 of Table 2 from 1961 through 1965 during which the worker was employed. The maximum likelihood estimate $\hat{\varphi}$ is the value of φ that maximizes equation (2) or equivalently the log-likelihood

$$L(\varphi|\mathbf{d},\boldsymbol{\mu},\boldsymbol{\sigma}) = -\frac{1}{2}\Sigma_t\, w_t(v_t-\varphi)^2 + \text{constant}. \qquad (3)$$

In equation (3), $w_t = 1/\sigma_t^2$, and $v_t = y_t - \mu_t$. The likelihood equation is

$$\partial L/\partial\varphi = \Sigma_t\, w_t(v_t-\varphi) = 0 ,$$

and the ML estimate of φ is $\hat{\varphi} = \Sigma_t w_t v_t/\Sigma_t w_t$. The variance of φ is $[-\partial^2 L/\partial\varphi^2]^{-1} = [\Sigma_t w_t]^{-1}$. If for any quarter $d_t = 0$ (indicating a non-detect), then replace y_t with y_t^o, the conditional expectation of y given it is less than the log (LOD), where LOD is the limit of detection. To obtain y_t^o, first calculate $z_t = (\log(LOD) - \mu_t) / \sigma_t$ and then $y_t^o = \mu_t - [n(z_t)/N(z_t)]\,\sigma_t$, where n(z) is the standard normal density and N(z) is the standard normal cumulative distribution function (Johnson, Kota, and Balakrishnan 1994, Section 10.1). Table 2 lists the values of μ, σ, w, y^o (based on a LOD of 30 mrem).

Example

Consider a worker with recorded dose d_t for each quarter from 1961 through 1965 as listed in column 8 of Table 2. The calculated values of y_t and v_t are in columns 9 and 10 of Table 2. Then

$$\hat{\varphi} = \Sigma_t w_t v_t/\Sigma_t w_t = 0.46976 \text{ and}$$
$$\text{var}(\hat{\varphi}) = 1/\Sigma_t w_t = 0.03661 .$$

Note that the values in columns 4-7 of Table 2 are the same for each worker, whereas the values in columns 8, 9, and 10 will be determined by the individual recorded doses for each quarter of employment from 1961 through 1965.

The estimate of the scaling factor φ and its variance described above are based on the maximum likelihood principle. Equivalent results can be obtained using a Bayesian approach Groer (2004).

4.0 APPLICATION OF THE SCALING PROCEDURE

Let t indicate a quarter for which a dose distribution is required for a worker unmonitored between January 1951 and December 1960. Without scaling, the unmonitored dose is lognormal with parameters (on the log scale) μ_t and σ_t (from Table 1), i.e. $y_t = \log(d_t)$ is normally distributed with mean μ_t and standard deviation σ_t . The mean and standard deviation of the adjusted log dose are

$$\mu_t^* = \mu_t + \hat{\varphi}$$
$$\sigma_t^* = [\sigma_t^2 + \mathrm{var}(\hat{\varphi})]^{1/2}, \qquad (4)$$

i.e., the unmonitored dose in quarter t is lognormal with mean μ_t^* and standard deviation σ_t^*. If a worker was unmonitored for all four quarters in a given year, the adjusted lognormal parameters are calculated for each quarter and the annual dose estimate is obtained by Monte Carlo sampling as described by Kerr and Smith (2004).

Example – continued

To estimate the unmonitored dose in the first quarter of 1957 for the worker in the example, use $\hat{\varphi}$ = 0.46976, var($\hat{\varphi}$) = 0.03661 in equation 4.

$$\mu_t^* = 4.5501 + 0.46976 = 5.0198$$
$$\sigma_t^* = [0.7486^2 + 0.03661]^{1/2} = 0.7727,$$

where μ_t = 4.5501 and σ_t = 0.7486 are obtained from line 39 of Table 1. The unmonitored dose for the quarter is lognormal with μ_t^* = 5.0198 and σ_t^* = 0.7727. The adjusted geometric mean is exp(μ_t^*) = 151.38 and the adjusted geometric standard deviation of exp(σ_t^*) = 2.166.

The 1st percentile of this distribution is 25 mrem and the 99th percentile is 914 mrem. These are shown as red triangles connected by a vertical straight line in Figure 1 for the first quarter of 1957. The open red circle is the geometric mean. The solid green circles are the recorded doses that are known for this individual (see column 8 of Table 2 for 1961 through 1965). If this individual had not been monitored prior to 1961, Monte Carlo sampling from the quarterly lognormal distribution (described by the vertical bars in Figure 1) would be used to estimate the annual dose distribution in the dose reconstruction procedure.

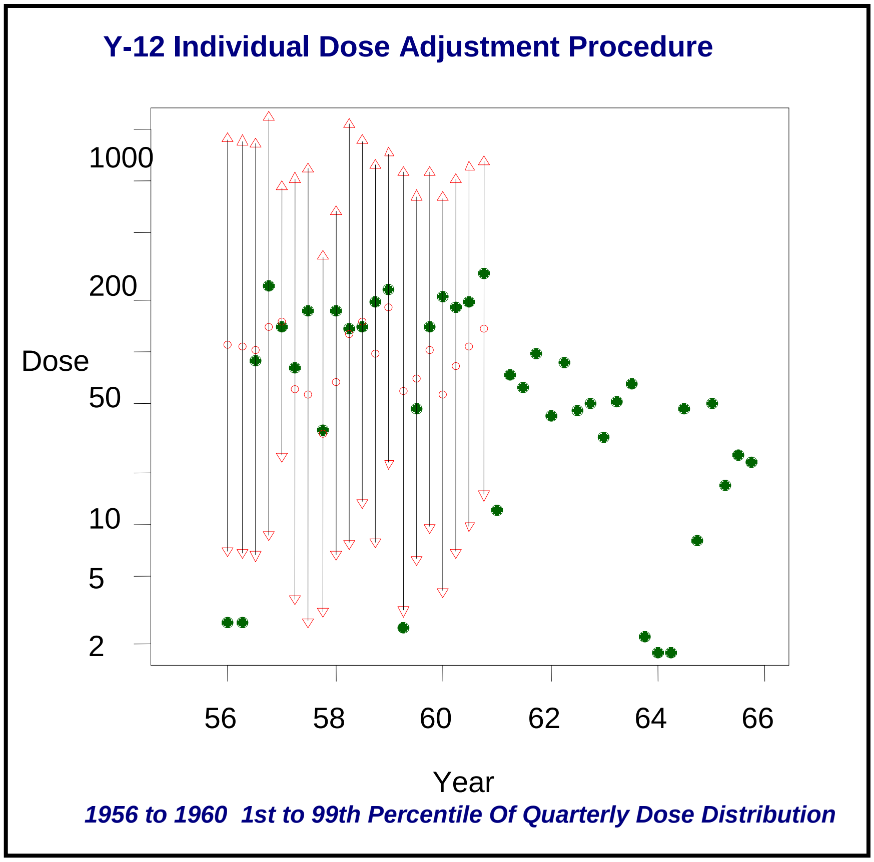
Y-12 Individual Dose Adjustment Procedure
Dose
1000
200
50
10
5
2
56
58
60
62
64
66
Year
1956 to 1960 1st to 99th Percentile Of Quarterly Dose Distribution

Figure 1

REFERENCES

Frome, E. L. and J. Watkins, (2004), *Statistical Analysis of Data with Non-detectable Values*, ORNL/TM-2004/146. (http://www.csm.ornl.gov/~frome/sand/)

Groer, P. G., 2004, *Bayesian Methods for Estimation of Unmonitored Y-12 External Penetrating Doses with a Time Dependent Lognormal Model*, ORAUT-OTIB-0015-00-A.

Johnson, N. L, S. Kota, and N. Balakrishnan, 1994, *Continuous Univariate Distributions*, Vol. 1, 2nd Edition, J. Wiley and Sons, New York, New York.

NIOSH (National Institute for Occupational Safety and Health), 2002, *External Dose Reconstruction Implementation Guideline*, OCAS-IG-001, Revision 1, Cincinnati, Ohio.

Kerr, G. D., 2003, *Technical Basis Document for the Y-12 National Security Complex – Occupational External Dosimetry*, ORAUT-TBBS-0014-6, Oak Ridge, Tennessee.

Kerr, G. D., and M. H. Smith, 2004, *A Procedure to Account for Incomplete Personal Monitoring Data on Penetrating Gamma-Ray Doses to Workers in Radiation Areas at the Oak Ridge Y-12 Plant Prior to 1961*, ORAUT-PROC-0042.

Strom, D. J., and P. S. Stansbury, 2000, *Determining Parameters of Lognormal Distributions from Minimal Information*, *AIHAJ* 61:877-880.

Watkins, J. P., J. L. Reagan, D. L. Cagle, E. L. Frome, C. M. West, D. J. Crawford-Brown, and W. G. Tankersley, 1993, *Data Collection, Validation, and Description for the Oak Ridge Nuclear Facilities Mortality Study*, ORISE-93/J-42, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee. (http://www.orau.gov/cer/reports.htm)

Watkins, J. P., G. D. Kerr, E. L. Frome, W. G. Tankersley, and C. M. West, (2004), *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Facility in Oak Ridge, Tennessee*, ORAU Technical Report # 2004-0888. (http://www.orau.gov/cer/reports.htm)

Table 1. Lognormal parameters for Y-12 population for penetrating gamma-ray doses 1951 to 1965.

t	Yr	Qt	μ	σ	GM	GSD
1	47	3	5.2684	1.1710	194.109	3.2254
2	47	4	5.2380	1.1710	188.302	3.2251
3	48	1	5.2077	1.1709	182.668	3.2248
4	48	2	5.1773	1.1708	177.203	3.2245
5	48	3	5.1469	1.1707	171.901	3.2243
6	48	4	5.1165	1.1706	166.758	3.2240
7	49	1	5.0862	1.1706	161.769	3.2238
8	49	2	5.0558	1.1705	156.929	3.2235
9	49	3	5.0254	1.1704	152.233	3.2233
10	49	4	4.9950	1.1703	147.679	3.2230
11	50	1	4.9647	1.1703	143.260	3.2228
12	50	2	4.9343	1.1702	138.974	3.2226
13	50	3	4.9039	1.1701	134.816	3.2224
14	50	4	4.8735	1.1701	130.782	3.2222
15	51	1	4.8432	1.1700	126.870	3.2220
16	51	2	4.8128	1.1699	123.074	3.2217
17	51	3	4.7824	1.1699	119.392	3.2216
18	51	4	4.7520	1.1698	115.819	3.2214
19	52	1	4.7217	1.1698	112.354	3.2212
20	52	2	4.6913	1.1697	108.993	3.2210
21	52	3	4.6609	1.1696	105.732	3.2208
22	52	4	4.6305	1.1696	102.568	3.2206
23	53	1	4.6002	1.1695	99.500	3.2205
24	53	2	4.5698	1.1695	96.523	3.2203
25	53	3	4.5394	1.1694	93.635	3.2202
26	53	4	4.5090	1.1694	90.833	3.2200
27	54	1	4.4787	1.1694	88.116	3.2199
28	54	2	4.4483	1.1693	85.479	3.2197
29	54	3	4.4179	1.1693	82.922	3.2196
30	54	4	4.3875	1.1692	80.441	3.2195
31	55	1	4.3571	1.1692	78.034	3.2193
32	55	2	4.3268	1.1691	75.699	3.2192
33	55	3	4.2964	1.1691	73.435	3.2191
34	55	4	4.2660	1.1691	71.237	3.2190
35	56	1	4.2356	1.1690	69.106	3.2189
36	56	2	4.2053	1.1690	67.039	3.2188
37	56	3	4.1749	1.1690	65.033	3.2187
38	56	4	4.4804	1.1860	88.267	3.2740
39	57	1	4.5501	0.7486	94.643	2.1140
40	57	2	3.6461	1.1936	38.324	3.2990
41	57	3	3.5629	1.2879	35.267	3.6250
42	57	4	3.0381	1.0039	20.865	2.7290
43	58	1	3.7262	0.9666	41.523	2.6290
44	58	2	4.3847	1.1885	80.218	3.2820
45	58	3	4.5488	1.0217	94.520	2.7780
46	58	4	4.1164	1.0668	61.337	2.9060
47	59	1	4.7269	0.8705	112.948	2.3880
48	59	2	3.6119	1.2459	37.037	3.4760
49	59	3	3.7927	1.0260	44.374	2.7900
50	59	4	4.1740	1.0047	64.972	2.7310
51	60	1	3.5687	1.1151	35.469	3.0500
52	60	2	3.9611	1.0561	52.513	2.8750
53	60	3	4.2164	1.0160	67.792	2.7620
54	60	4	4.4589	0.9381	86.396	2.5550
55	61	1	2.0601	1.2390	7.847	3.4520
56	61	2	3.8154	0.5983	45.395	1.8190
57	61	3	3.0126	0.8527	20.341	2.3460
58	61	4	3.9514	0.5300	52.006	1.6990
59	62	1	2.4602	0.9400	11.707	2.5600
60	62	2	3.9103	0.5839	49.915	1.7930
61	62	3	3.6301	0.7948	37.718	2.2140
62	62	4	3.3465	1.0791	28.402	2.9420
63	63	1	2.4188	1.2170	11.232	3.3770
64	63	2	2.7573	0.8825	15.758	2.4170
65	63	3	1.9958	1.5819	7.358	4.8640
66	63	4	2.4319	0.9034	11.381	2.4680
67	64	1	2.1856	1.3010	8.896	3.6730
68	64	2	2.1811	1.2667	8.856	3.5490
69	64	3	3.0904	1.2069	21.986	3.3430
70	64	4	2.1822	1.3368	8.866	3.8070
71	65	1	2.7352	1.0438	15.413	2.8400
72	65	2	2.4326	1.1581	11.388	3.1840
73	65	3	2.7134	0.9353	15.080	2.5480
74	65	4	3.5052	0.5289	33.288	1.6970

Table 2. Calculation of scaling factor with example.*

t	yr	qt	μ	σ	w	y^0	d	y	v
1	61	1	2.060	1.239	0.651	1.740	12	2.485	0.425
2	61	2	3.815	0.598	2.794	3.047	74	4.304	0.489
3	61	3	3.013	0.853	1.375	2.559	62	4.127	1.114
4	61	4	3.951	0.530	3.559	3.127	98	4.585	0.634
5	62	1	2.460	0.940	1.132	2.190	43	3.761	1.301
6	62	2	3.910	0.584	2.933	3.079	88	4.477	0.567
7	62	3	3.630	0.795	1.583	2.843	46	3.829	0.199
8	62	4	3.346	1.079	0.859	2.520	51	3.932	0.585
9	63	1	2.419	1.217	0.675	1.975	32	3.466	1.047
10	63	2	2.757	0.883	1.284	2.406	52	3.951	1.194
11	63	3	1.996	1.582	0.400	1.473	66	4.190	2.194
12	63	4	2.432	0.903	1.225	2.196	0	2.196	-0.236
13	64	1	2.186	1.301	0.591	1.779	0	1.779	-0.407
14	64	2	2.181	1.267	0.623	1.799	0	1.799	-0.382
15	64	3	3.090	1.207	0.687	2.316	47	3.850	0.760
16	64	4	2.182	1.337	0.560	1.753	8	2.079	-0.103
17	65	1	2.735	1.044	0.918	2.275	50	3.912	1.177
18	65	2	2.433	1.158	0.746	2.025	17	2.833	0.401
19	65	3	2.713	0.935	1.143	2.343	25	3.219	0.506
20	65	4	3.505	0.529	3.575	3.015	23	3.135	-0.370

*Note- The last three columns depend on individual workers' film badge doses.