



# ORAU TEAM Dose Reconstruction Project for NIOSH

Oak Ridge Associated Universities | Dade Moeller & Associates | MJW Corporation

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New     
 Total Rewrite     
 Revision     
 Page Change

**FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.**

**PUBLICATION RECORD**

<b>EFFECTIVE DATE</b>	<b>REVISION NUMBER</b>	<b>DESCRIPTION</b>
12/29/2004	00	New Technical Basis Document for the K-25 Site – Occupational Environmental Dose. First approved issue. Initiated by Jay J. Maisler.
09/26/2006	00 PC-1	<p>Approved page change revision to include new standard language on page 6 in Section 4.1. Adds reference to page 13 in Reference Section. No sections were deleted. No changes occurred as a result of internal formal review.</p> <p>OCAS comment was addressed. No changes were required due to the K25 Worker Outreach SPFPA and IGUA Worker Outreach meeting held on April 5, 2006 or K25 Worker Outreach PACE Local 5-288 and Pace International Union Worker Outreach meeting held on April 6, 2006. However, the document previously addressed the following comments:</p> <p>From K25 Worker Outreach SPFPA and IGUA Worker Outreach meetings April 5, 2006-</p> <p>Response to Comment #30: Atmospheric releases are addressed in Section 4.2.1.</p> <p>From K25 Worker Outreach PACE Local 5-288 and Pace International Union Worker Outreach comments April 6, 2006-</p> <p>Response to Comment #4: Fires are discussed in the reference "DOE (U.S. Department of Energy), 2000b, <i>Independent Investigation of the East Tennessee Technology Park.</i>"</p> <p>Response to Comment #33: Atmospheric releases of Uranium and other radioactive materials are addressed in Section 4.2.1</p> <p>Response to Comment #45: Because of the known limitations of air monitoring environmental intakes are calculated based on releases of materials; this is discussed in Section 4.2.</p> <p>Response to Comment #46: As documented in Section 4.3.1, neutron exposures were not reported for environmental results until 2003.</p> <p>This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Paul A. Szalinski.</p> <p>Approval:</p> <p><u>Signature on File</u> <span style="float: right;"><u>08/31/2006</u></span> Paul A. Szalinski, Document Owner</p> <p><u>Signature on File</u> <span style="float: right;"><u>09/05/2006</u></span> John M. Byrne, Task 3 Manager</p> <p><u>Signature on File</u> <span style="float: right;"><u>08/31/2006</u></span> Edward F. Maher, Task 5 Manager</p> <p><u>Signature on File</u> <span style="float: right;"><u>09/14/2006</u></span></p>

		<p>Kate Kimpan, Project Director</p> <p><u>Brant A. Ulsch Signature on File for</u> <span style="float: right;"><u>09/26/2006</u></span></p> <p>James W. Neton, Associate Director for Science</p>
06/22/2007	01	<p>Approved revision initiated to add Attributions and Annotations section. No further changes occurred as a result of formal internal and NIOSH review. This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Paul A. Szalinski.</p>

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**ACRONYMS AND ABBREVIATIONS**

Bq	becquerel
Ci	curie
cm	centimeter
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
GSD	geometric standard deviation
hr	hour
IEM	Integrated Environmental Management
m	meter
mR	milliroentgen
mrem	millirem
MW	megawatt
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
ORDR	Oak Ridge Dose Reconstruction
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORHASP	Oak Ridge Health Agreement Steering Panel
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
POC	probability of causation
RU	recycled uranium
TLD	thermoluminescent dosimeter
U.S.C	United States Code
yr	year
μR	microroentgen
§	section or sections

## 4.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions for particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word “facility” is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy [DOE] facility” as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located ... in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations ... pertaining to the Naval Nuclear Propulsion Program)” [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled “Exposure in the Performance of Duty.” That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer “shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer ... was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation<sup>1</sup>] guidelines established under subsection (c) ...” [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define “performance of duty” for DOE employees with a covered cancer or restrict the “duty” to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes “buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program” [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled “Exposure in the Performance of Duty”] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry monitoring results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

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<sup>1</sup> The U.S. Department of Labor is ultimately responsible under the EEOICPA for determining the POC.

The occupational environmental dose refers to the dose received by unmonitored workers outside the facilities. These doses can be internal and external depending on the characteristics of the individual radionuclides. When inhaled, most radionuclides would produce a dose to various organs in the body. These radionuclides are addressed in the following sections.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 4.5.

## 4.2 INTERNAL DOSE FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATIONS

The internal dose for workers outside the facilities is determined from the air concentrations resulting from individual facility releases, and from ground-level releases. The method used to predict air concentrations includes the contribution from soil resuspension indirectly.

Unmonitored workers can be exposed to occupational doses internally from onsite releases to the air and from the resuspension of radioactive materials in soil, and externally from ambient radiation and releases of radioactive noble gases to the air.

### 4.2.1 Onsite Releases to Air

The internal dose for workers outside the facilities is determined from the air concentrations resulting from releases from stacks, individual building releases, and from the purge cascade and other operations at the Oak Ridge Gaseous Diffusion Plant Site (ORGDP), which this document refers to as the K-25 Site. Unmonitored workers can be exposed to occupational doses internally from onsite releases to the air or from ambient radiation.

A calculation was performed using well-documented source terms developed for the Oak Ridge Dose Reconstruction (ORDR) (Burmeister 1996, 1997, Burns 1997), coupled with some documented environmental monitoring data, to estimate radionuclide-specific airborne concentrations for <sup>234</sup>, <sup>235</sup>, <sup>238</sup>U, <sup>238</sup>, <sup>239</sup>, <sup>240</sup>, <sup>241</sup>, <sup>242</sup>Pu, <sup>237</sup>Np, and <sup>99</sup>Tc (Shonka 2003). These radionuclides were determined to account for the majority of the potential missed dose from inhalation and submersion pathways. The 50th- and 95th-percentile air concentrations for the uranium nuclides were used to compute the geometric standard deviation (GSD) of the uranium source term. This GSD was applied on a year-by-year basis to all other nuclides in the source term. The 50th-percentile air concentration for uranium calculated air concentrations was then used to derive annual intakes based on an assumed individual ventilation rate of 2,400 cm<sup>3</sup>/yr. In addition, the GSD of these intakes was estimated based on the 95th-percentile source terms using the following relationship:

$$GSD = \left( \frac{\text{Nuclide activity 95}^{\text{th}} \text{ percentile}}{\text{Nuclide activity 50}^{\text{th}} \text{ percentile}} \right)^{\left( \frac{1}{1.65585} \right)}$$

These annual intakes and GSDs, by year of operation, are listed in Attachment A in Tables A-1 through A-3.

In general, the K-25 Site was a major industrial site with upwards of 2,500 MW of heat dissipated in the water and air during the years of operation. Releases from the gaseous diffusion plants had both mechanical momentum and significant thermal energy that lifts the effective height of the release point by 10 to 20 m. Depending on the location of a specific release point relative to other turbulent thermal

sources such as cooling towers, the diffusion can be considerable over that predicted by simple Gaussian plume models. There were multiple release points spread over the site.

Figure 4-1 is a drawing of the K-25 Site showing major buildings and the environmental stations selected to estimate dilution.

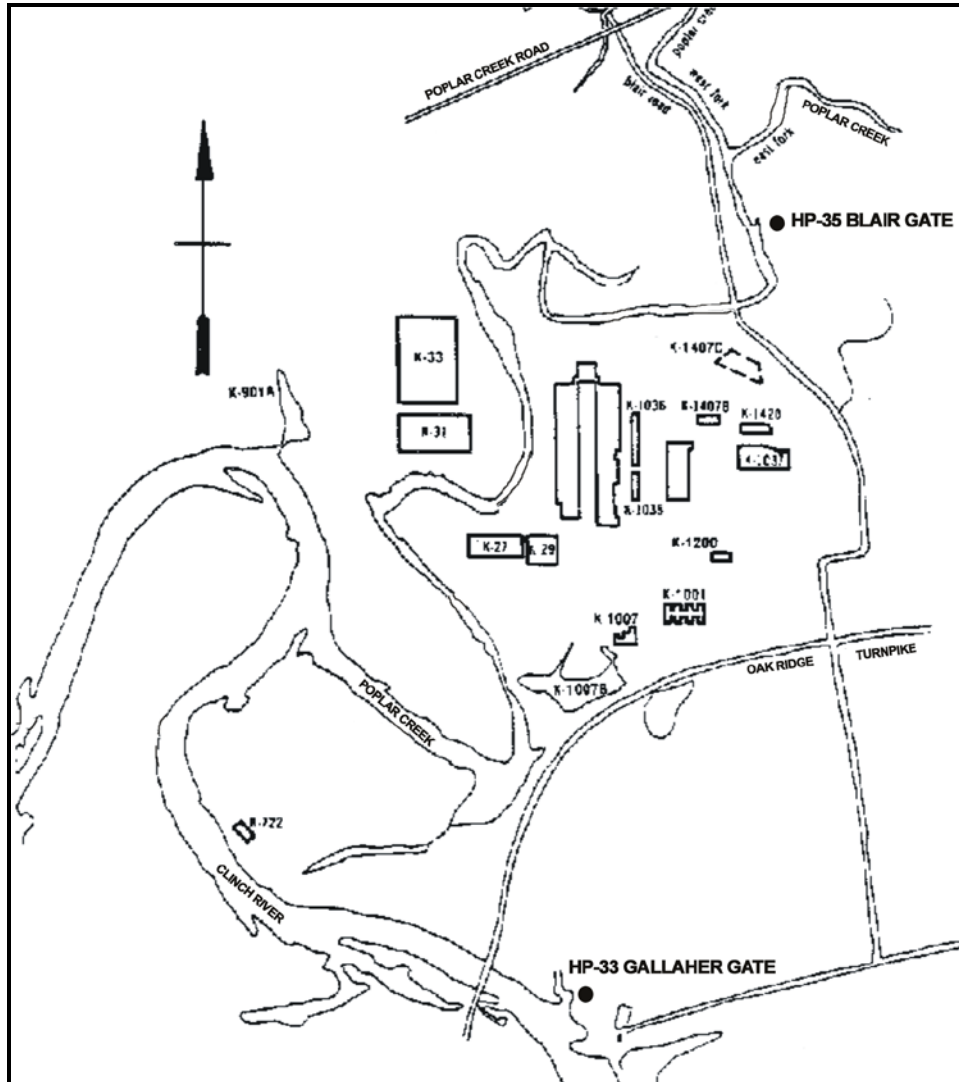


Figure 4-1. K-25 Site map with environmental monitoring stations noted.

To provide a conservative estimate, environmental monitors were chosen that were adjacent to the K-25 Site and generally located in upwind and downwind locations relative to release points. These were where maximum ground-level concentrations from the site would occur. The annual air concentrations for several years in gross alpha and gross beta were divided by the source term for the same years expressed in the same units to provide an equivalent annual dilution volume. This dilution volume was then applied to all years. Use of gross values provides added conservatism in that nearly all of the reported air concentration appears to be background. In addition, the administration area is generally crosswind from the bulk of the industrial site where most of the release points were located.

The values in Tables A-1 through A-3 in Attachment A are estimates of annual intakes derived from the calculated outdoor air concentrations at the K-25 Site and, as such, might not be appropriate for calculating organ doses for workers located inside buildings. However, these values probably represent the upper bound of potential intakes for an individual working in outside areas where individual monitoring was not required. It is assumed that these intakes occurred uniformly in the year listed, so for partial years of employment the intake can be proportionally adjusted by the fraction of the year worked. In addition, these intakes were derived based on an assumed breathing rate of 2,400 cm<sup>3</sup>/yr. Therefore, adjustments might be required based on the job classification depending on the individual performing light work or heavy work, for which the respiration rate would be 1.2 m<sup>3</sup>/hr or 1.7 m<sup>3</sup>/hr, respectively. For purposes of dose estimation, radioactive decay was not considered.

Plutonium and uranium releases to the atmosphere represent the greatest potential radiological risk of all the alpha-emitting radionuclides in the K-25 Site environment. For purposes of dose reconstruction, the isotopes of plutonium and uranium contained in the mix that results in the maximum organ dose should be selected and assumed to be present at 100%. This assumption will result in a small, but favorable to claimant, overestimation of the actual dose [1].

Releases of radionuclides for the K-25 Site were studied as a part of the ORDR. This study was conducted from 1994 to 1999 for the Tennessee Department of Health by scientists and engineers from ChemRisk, a service of McLaren/Hart Environmental Services, assisted by SENES Oak Ridge and Shonka Research Associates. As an element of Task 6 of that study, a source term reconstruction was performed for the primary nuclides of concern, that of the uranium nuclides at various enrichments. In addition, a screening source term was developed for <sup>237</sup>Np and <sup>99</sup>Tc as an element of Task 7 of the ORDR. The screening source term used plant data and did not independently reconstruct the release. These source terms were used as the starting point for this effort.

There were two uranium source terms developed for K-25 by ORDR. The final source term reported in the Task 6 Final Report did not have 50th- and 95th-percentile values, and several limitations of the work were noted (ChemRisk 1999). These included limited release information for the S-50 plant for 1944, the sole year of operation for that facility. In addition, the K-25 Site releases did not resolve releases from K-1131 against the large material unaccounted for (mass balance) for that building. Both of those source terms are primarily natural enrichment material of low specific activity. In addition, undocumented releases from the cascade were noted from frequent incident reports that had no quantity release data associated with the incident. Finally, corrections for losses from stack sampling were not rigorously treated. One of the primary stack monitors whose results would be impacted is the K-1131 stack, which is primarily a source of near-natural enrichment uranium.

The alternative uranium release estimate was an attempt to address some of the issues mentioned above, and provided 50th- and 95th-percentile estimates. It estimated uncertainty by fitting release information for periods when it was available, and sampling from the fitted data to fill in periods where monitoring data was unavailable. The Oak Ridge Health Agreement Steering Panel (ORHASP) felt that the conclusions reached were unchanged for either of these treatments, and preferred to use the data without fits, as it reflected the reported plant releases. The uranium release from the two estimates was 16.7 Ci (Burns 1997) and 23.2 Ci (Burmeister 1996) (50th percentile), respectively.

The screening estimate made for ORDR Task 7 took the inventory of <sup>99</sup>Tc and <sup>237</sup>Np estimated by the K-25 Site staff and the Site's release fraction and distributed that material throughout the years of recycled uranium (RU) use by establishing the ratio of uranium releases for that period. After 1977, a nominal continuing annual release was used. No estimate was made for plutonium in that Task 7 effort.

To provide a conservative value that was favorable to claimants, the 50th-percentile alternative release estimate from the ORDR source term was used for uranium, and the 95th-percentile was used to calculate the geometric standard deviation along with the following modifications. Plutonium was added in a manner consistent with the previous estimates for  $^{99}\text{Tc}$  and  $^{237}\text{Np}$ , and with an assumption that the material consisted of five plutonium nuclides in a ratio consistent with weapons-grade plutonium.

Estimates of site releases for  $^{99}\text{Tc}$  were used for 1981 and 1982 in lieu of the ORDR estimates because the reported value was larger than the estimate (Jordan 1983). On average, this serves to overstate the  $^{99}\text{Tc}$  releases, since the added curies (beyond those asserted by ORDR Task 7) had been distributed by the ORDR calculation among all years of RU use.

The K-25 Site is relatively small compared to larger U.S. Department of Energy sites, and radioactive material is released from a large number of release points of varying flow rates and elevations (Shonka 1996). Large quantities of electric power were used (depending on production), with heat rejected, in part, to the atmosphere using a combination of ventilation and cooling towers. Ventilation rates for removal of process heat varied to a considerable degree with the seasons. This, along with building wake effects, result in a highly turbulent environment that tends to mix and dilute the released materials far beyond the rates predicted by atmospheric transport codes. In light of the multiple release points and complexities of transport, a simple conservative method for estimating site concentrations was chosen.

The gross alpha and gross beta boundary air concentrations, reported by the site in environmental monitoring reports from the 1970s and 1980s, were ratioed to the source term (expressed in equivalent units) to establish a dilution volume that was used for all years. The reported boundary air concentrations were nearly identical to those recorded by offsite monitors, indicating that the concentrations came primarily from sources that were not associated with releases from K-25 operations. Thus, this method provides an estimate of annual concentrations that is overstated and conservative. This excess conservatism is used to account for the limitations in the source term noted above as well as other airborne sources including soil resuspension. No separate analysis for soil resuspension was performed.

Once the site boundary intakes are established, the intakes were scaled back to within the fence line using Fig 11.3.4 in the Radiological Health Handbook (Shleien 1992). From this figure based on ground level releases the concentration factor ( $\bar{u} \chi/Q$ ) to distance ( $x$ ) ratio is  $-10^2$  to  $10^1$  is evident. Ground level releases provides for the highest intake in the close distances.

In the concentration factor, the average wind speed ( $\bar{u}$ ) between the boundary location and the fence line would be the same, and therefore is not a contributing factor in relating the two distances. Also the release ( $Q$ ) is the same in both cases, leaving the only change in concentration ( $\chi$ ).

The boundary concentrations, as reported in referenced calculations and reports, were taken at approximately 2500 m from the center of the plant, the fence line is generally less than 100 m from release points. Therefore, reducing the distance by 1.5 magnitudes to 80 m increases the intake within the fence line by a magnitude of three over the site boundary intake. Intakes from the reference calculations have been increased by a factor of  $10^3$  and tabulated in the attachments and should be used for unmonitored environmental intake.











## GLOSSARY

### background radiation

The radiation received by man from natural and environmental sources including cosmic rays, radiation from the naturally radioactive elements in the environment, and natural concentrations of radionuclides in the body (carbon-14, potassium-40). The usually quoted average individual exposure from background radiation for a person living in the continental United States is 250 to 300 millirem per year.

### depleted uranium

On the ORR, depleted uranium consisted mostly of U-238 and usually contains between 0.14 and 0.20% uranium-235 by weight. Natural uranium contains 0.72% uranium-235, while enriched uranium contains greater than 0.72% uranium-235 by weight. For example, depleted uranium is generated as a result of the K-25 gaseous diffusion uranium enrichment and is found in the tailings portion of the process outputs.

### enriched uranium

On the ORR, enriched uranium typically contained between 0.95% and 99% uranium-235. Natural uranium contains 0.72% uranium-235, while depleted uranium contains less than 0.72% uranium-235.

### enrichment of uranium

A process in which the relative abundance of one of the isotopes of uranium is increased with respect to the others. These processes in the past used the difference in the mass of the isotopes to increase the relative fraction of one isotope over the others. The resultant material is enriched in one particular isotope (usually uranium-235) and depleted in its other isotope (uranium-238).

### gaseous diffusion enrichment

A process by which uranium hexafluoride is passed through a series of semipermeable molecular barriers for the purpose of separating the lighter uranium-235 isotope from the heavier, more naturally abundant uranium-238 isotope (see enrichment of uranium).

### natural uranium

Natural or "normal" uranium contains 0.72% uranium-235. Contrast with enriched uranium, which contains more than the natural concentration of uranium-235, and depleted uranium, which contains less than 0.72% uranium-235.

### percentiles

If a large set of data is arranged from its smallest value to its largest, and this list is divided into 100 classes containing nearly equal numbers of data, then each percentile represents the highest value within that class. Thus 5% of the data are less than or equal to the 5th percentile, and approximately 95% of the data are greater than or equal to the 5th percentile. The median is defined as the 50th percentile, which divides the data (approximately) into halves.

### source term

The quantity, chemical and physical form, and time history of contaminants released to the environment from a facility.

**uncertainty**

The level of confidence in a given estimate based on the quality and quantity of the available data. Inherent uncertainties are generated by a number of sources including uncertainties in measurements, absence of data due to the lack of environmental monitoring, lack of knowledge about some physical processes and operational procedures, and the approximate nature of mathematical models used to predict the transport of released materials.

**uranium**

A naturally occurring radioactive metal that, in natural ores, has an atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7%) and uranium-238 (99.3% of natural uranium). Natural uranium also includes a very small amount of the daughter uranium-234 by weight. The activity associated with this U-234 is significant as U-235 enrichment increases. Uranium has been used chiefly in nuclear reactors and nuclear explosives.









**ATTACHMENT A**  
**OCCUPATIONAL ENVIRONMENTAL DOSE**  
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Table A-4. Background gamma radiation levels ( $\mu\text{R/hr}$ ) at two perimeter ORGDP stations.

Date	Average	GSD	Date	Average	GSD	Date	Average	GSD	Date	Average	GSD
1944	9.8	1.08	1957	9.8	1.08	1970	9.8	1.08	1983	9.9	1.07
1945	9.8	1.08	1958	9.8	1.08	1971	9.8	1.08	1984	8.2	1.08
1946	9.8	1.08	1959	9.8	1.08	1972	9.8	1.08	1985	8.8	1.08
1947	9.8	1.08	1960	9.8	1.08	1973	7.4	1.09	1986	9.8	1.08
1948	9.8	1.08	1961	9.8	1.08	1974	7.6	1.09	1987	9.8	1.08
1949	9.8	1.08	1962	9.8	1.08	1975	8.2	1.08	1988	9.8	1.08
1950	9.8	1.08	1963	9.8	1.08	1976	10.5	1.07	1989	9.8	1.08
1951	9.8	1.08	1964	9.8	1.08	1977	7.6	1.09	1990	9.8	1.08
1952	9.8	1.08	1965	9.8	1.08	1978	8.8	1.08	1991	9.8	1.08
1953	9.8	1.08	1966	9.8	1.08	1979	9.6	1.07	1992	9.8	1.08
1954	9.8	1.08	1967	9.8	1.08	1980	7.7	1.09	1993	9.8	1.08
1955	9.8	1.08	1968	9.8	1.08	1981	7.8	1.09	1994	9.8	1.08
1956	9.8	1.08	1969	9.8	1.08	1982	10.2	1.07	1995	9.8	1.08

Denotes data derived from empirical site measurements.