Thermal Stabilization of $^{233}$UO$_2$, $^{233}$UO$_3$, and $^{233}$U$_3$O$_8$

S. M. Thein
P. J. Bereolos
Thermal Stabilization of $^{233}\text{UO}_2$, $^{233}\text{UO}_3$, and $^{233}\text{U}_3\text{O}_8$

S. M. Thein  
P. J. Bereolos

ADVANCED INTEGRATED MANAGEMENT SERVICES, INC.  
702 S. Illinois Avenue, Suite B-203  
Oak Ridge, Tennessee 37830

Date Published: July 2000
ABSTRACT

This report identifies an appropriate thermal stabilization temperature for $^{233}$U oxides. The temperature is chosen principally on the basis of eliminating moisture and other residual volatiles. This report supports the U. S. Department of Energy (DOE) Standard for safe storage of $^{233}$U (DOE 2000), written as part of the response to Recommendation 97-1 of the Defense Nuclear Facilities Safety Board (DNFSB), addressing safe storage of $^{233}$U.

The primary goals in choosing a stabilization temperature are (1) to ensure that the residual volatiles content is less than 0.5 wt % including moisture, which might produce pressurizing gases via radiolysis during long-term sealed storage; (2) to minimize potential for water readsorption above the 0.5 wt % threshold; and (3) to eliminate reactive uranium species. The secondary goals are (1) to reduce potential future chemical reactivity and (2) to increase the particle size thereby reducing the potential airborne release fraction (ARF) under postulated accident scenarios.

The prevalent species of uranium oxide are the chemical forms UO$_2$, UO$_3$, and U$_3$O$_8$. Conversion to U$_3$O$_8$ is sufficient to accomplish all of the desired goals. The preferred storage form is U$_3$O$_8$ because it is more stable than UO$_2$ or UO$_3$ in oxidizing atmospheres. Heating in an oxidizing atmosphere at 750°C for at least one hour will achieve the thermal stabilization desired.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>ACRONYMS</td>
<td>vii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. URANIUM OXIDE PROPERTIES</td>
<td>3</td>
</tr>
<tr>
<td>2.1 THERMAL CONDUCTIVITY</td>
<td>3</td>
</tr>
<tr>
<td>2.2 PARTICLE SIZE</td>
<td>3</td>
</tr>
<tr>
<td>2.3 STABILITY</td>
<td>4</td>
</tr>
<tr>
<td>3. HEATING EFFECTS ON VOLATILES</td>
<td>5</td>
</tr>
<tr>
<td>3.1 MOISTURE</td>
<td>5</td>
</tr>
<tr>
<td>3.2 OTHER VOLATILES</td>
<td>5</td>
</tr>
<tr>
<td>4. HEATING EFFECTS ON SELECTED URANIUM OXIDES</td>
<td>7</td>
</tr>
<tr>
<td>4.1 $^{233}\text{UO}_2$</td>
<td>7</td>
</tr>
<tr>
<td>4.2 $^{233}\text{UO}_3$</td>
<td>7</td>
</tr>
<tr>
<td>4.3 $^{233}\text{U}_3\text{O}_8$ AND OTHER OXIDES</td>
<td>8</td>
</tr>
<tr>
<td>5. SELECTION OF A STABILIZATION TEMPERATURE</td>
<td>11</td>
</tr>
<tr>
<td>6. REFERENCES</td>
<td>13</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Fig. 1. Rate of decomposition of UO$_3$ to U$_3$O$_8$ in air..........................................................9
Fig. 2. Thermal profile of selected uranium oxides.................................................................12

LIST OF TABLES

Table 1. Uranium oxide thermal conductivities........................................................................3
Table 2. Crystalline uranium trioxides.....................................................................................7

ACRONYMS

ADU Ammonium Diuranate
ARF Airborne Release Fraction
DNFSB Defense Nuclear Facilities Safety Board
DOE U.S. Department of Energy
IAEA International Atomic Energy Agency
ORNL Oak Ridge National Laboratory
PWR Pressurized Water Reactor
1. INTRODUCTION

The purpose of this report is to select a thermal stabilization temperature to treat $^{233}$U oxides. This report supports the U. S. Department of Energy (DOE) Standard for the safe storage of $^{233}$U (DOE 2000), written in response to Recommendation 97-1 of the Defense Nuclear Facilities Safety Board (DNFSB) (DNFSB 1997).

The existing prevalent $^{233}$U oxide powder species present are UO$_2$, UO$_3$, and U$_3$O$_8$. The merits and deficiencies of different temperatures for the treatment of each species will be discussed. The U:O systems discussed are stoichiometric ratios that indicate the 3 major crystalline phases (with some variation in stoichiometry depending on oxygen potential).

For reasons that will be detailed further in this report, the desired final stabilized form for the uranium oxides is U$_3$O$_8$ powder. Moisture and residual volatiles content will be less than 0.5 wt %. Reactive uranium species will have been eliminated; and for some starting materials, the particle size should be increased and the specific surface area reduced.

The primary goal of thermal stabilization is to eliminate moisture and other residual volatiles that could potentially produce pressurizing gases via radiolysis during long-term sealed storage. This goal can be accomplished while converting the material to the most stable form, U$_3$O$_8$. Stabilization also minimizes the potential for water readsorption above the 0.5 wt % threshold, stabilizes reactive uranium species, and increases particle size (reduces specific surface area) for some starting species. These characteristics will enable the safe long-term storage of $^{233}$U-bearing materials.
2. URANIUM OXIDE PROPERTIES

2.1 THERMAL CONDUCTIVITY

Because of the relatively low thermal conductivity of \( \text{UO}_2 \), \( \text{UO}_3 \), and \( \text{U}_3\text{O}_8 \), the temperature for heating the uranium material in this document refers to the temperature of the material itself instead of the oven temperature. Table 1 is a compilation of the uranium oxide thermal conductivities.

<table>
<thead>
<tr>
<th>Uranium oxide</th>
<th>Thermal conductivity (W m(^{-1}) °C(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{UO}_2 )</td>
<td>0.705(^a)</td>
</tr>
<tr>
<td>( \text{U}_3\text{O}_8 )</td>
<td>0.0838(^b)</td>
</tr>
</tbody>
</table>

\(^a\)Prepared from Mallinckrodt pressurized-water reactor (PWR)-grade powder; 85% theoretical density, 1400 K (Touloukian 1967).
\(^b\)Pressed at 100 psi, 775 K (Touloukian 1967).

For comparison, the thermal conductivity of aluminum metal is 240 W m\(^{-1}\) °C\(^{-1}\) at 100°C (McCabe, Smith, and Harriot 1993). Because of the relatively low thermal conductivity of uranium oxides, measurement of the material temperature (or compensation for thermal conductivity), rather than relying solely on the oven temperature, is required.

2.2 PARTICLE SIZE

By increasing particle size, the inhalation hazard from uranium oxide powders is reduced. It is generally expected that particle size will increase upon heating (Belle 1961). Heating \( \text{UO}_3 \) powder to form \( \text{U}_3\text{O}_8 \) has been shown to reduce the surface area, indicating larger particles. This effect seems to be more significant at temperatures in excess of 500°C (Harrington and Ruehle 1959). Heating \( \text{UO}_2 \) powder at 800°C also decreased the surface area (Smith and Leitnaker 1971).

Much of the current Oak Ridge National Laboratory (ORNL) inventory of \( ^{233}\text{U} \) oxides was prepared by heating pregranulated ammonium diuranate (ADU) for 6 h at an oven temperature of 800°C. The particle size distribution for these powders shows that greater than 90% of the particles have less than 10 microns equivalent of spherical diameter (Parrott, Sr. et al 1979). Therefore, the magnitude of particle size increase may be significantly more dependent on the characteristics of the starting material than on temperatures in the 500-800°C range.
2.3 STABILITY

Conversion to $\text{U}_3\text{O}_8$ creates a more stable chemical form of uranium than other oxides. Upon heating in an oxidizing atmosphere above 650°C, all other uranium oxides (and many other uranium compounds) decompose or convert to $\text{U}_3\text{O}_8$. Furthermore, oxygen lost from heating $\text{U}_3\text{O}_8$ above 800°C is rapidly replaced upon cooling (Katz, Seaborg, and Morss 1986). Because of this chemical stability, $\text{U}_3\text{O}_8$ is the preferred storage form.
3. HEATING EFFECTS ON VOLATILES

3.1 MOISTURE

There has been a continuing concern that moisture and other volatiles theoretically can produce pressurizing gases during long-term, sealed storage via radiolysis. Reduction of this potential source of pressurization is a primary reason for treating the uranium oxides. Heating uranium oxide will reduce moisture content to less than 0.5 wt % and similarly reduce equivalent quantities of residual species (e.g., hydrates), which might produce pressurizing gases. The 0.5 wt % specification is a generally accepted limit that is reasonable to achieve and for which no negative affects have been identified. Reducing the amount of moisture present also reduces the potential for and rate of container corrosion.

Free water is eliminated during heating at temperatures above 100°C (i.e., simple evaporation in a vented vessel). The three principal uranium oxides (UO$_2$, UO$_3$, and U$_3$O$_8$) all form hydrates. However, UO$_2$ and U$_3$O$_8$ form hydrates only when prepared via a precipitation reaction. On the other hand, UO$_3$ can form hydrates directly through reaction with H$_2$O between temperatures of 5 and 75°C (Vdovenko 1960). Heating above 400°C converts hydrated UO$_3$ to dry UO$_3$ by driving off all waters of hydration (Harrington and Ruehle 1959). The UO$_2$ powders fabricated at Oak Ridge National Laboratory (ORNL) have moisture contents between 0.10 and 0.36 wt %, which is below the specified 0.5 wt % (Parrott, Sr. et al. 1979).

The potential for moisture readsorption (during prolonged interim ambient storage before packaging) is reduced by heating. The potential for moisture readsorption is proportional to the surface area. When oxides are stabilized at higher temperatures, the surface area tends to be reduced, thus reducing the potential for readsorption. For stabilized UO$_2$ and U$_3$O$_8$, moisture does not tend to be readsorbed in significant amounts. However, UO$_3$ hydrates may be able to reform under direct exposure to H$_2$O below 60°C (Harrington and Ruehle 1959).

3.2 OTHER VOLATILES

Uranyl nitrate, UO$_2$(NO$_3$)$_2$, which generally appears with multiple waters of hydration (up to six), is the principle intermediary for the purification of $^{233}$U oxides from thorium fuel (Storch 1999). Above 300°C, the uranyl nitrate is denitrated. Since all $^{233}$U oxides produced by this method were treated above 300°C, no uranyl nitrate is expected to be present. The conversion to U$_3$O$_8$ will eliminate any postulated residual uranyl nitrate.

With the exception of materials existing as part of the packaging (e.g., elastomeric gaskets in container lids, plastic bagging around closed inner containers, or plastic inner containers), there is no known significant quantity of organics in existing $^{233}$U materials. If moisture and organics are eliminated, then radiolytic gases cannot be generated.
4. HEATING EFFECTS ON SELECTED URANIUM OXIDES

4.1 $^{233}$UO$_2$

$^{233}$UO$_2$ is one of three prevalent, stable, uranium oxides that is present in the inventory. In an oxidizing atmosphere, starting from 300°C, UO$_2$ can be oxidized to form U$_3$O$_8$ via the following reaction (Belle 1961, Bowie 1970, and Katz, Seaborg, and Morss 1986):

$$3\text{UO}_2 + \text{O}_2 \xrightarrow{300-700^\circ\text{C}} \text{U}_3\text{O}_8$$

The rate of this reaction is a function of particle size, and the temperature requirement will change accordingly. Generally, the reaction rate is fast, and UO$_2$ may even be pyrophoric when the particle size is very fine. When the particle size is large, the O:U ratio steadily increases as a function of exposure time to oxygen. UO$_2$ with particle size diameters of 0.05–0.08 μm can take up appreciable amounts of oxygen, while at particle diameters above 0.2–0.3 μm, controlled reaction can be maintained while oxidizing UO$_2$ to U$_3$O$_8$ (Katz, Seaborg, and Morss 1986).

4.2 $^{233}$UO$_3$

Five distinct crystalline modifications (structural isomers) of $^{233}$UO$_3$ have been found. In Table 2, these five crystalline modifications are shown along with several of their properties.

Table 2. Crystalline uranium trioxides

<table>
<thead>
<tr>
<th>Phase</th>
<th>Color</th>
<th>Structure</th>
<th>UO$_3$ decomposition temperature in air (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>Brown</td>
<td>Hexagonal</td>
<td>450</td>
</tr>
<tr>
<td>β</td>
<td>Red, orange</td>
<td>Orthorhombic</td>
<td>530</td>
</tr>
<tr>
<td>γ</td>
<td>Yellow</td>
<td>?</td>
<td>650</td>
</tr>
<tr>
<td>δ</td>
<td>Reddish-brown</td>
<td>Cubic</td>
<td>400</td>
</tr>
<tr>
<td>ε</td>
<td>Red</td>
<td>?</td>
<td>400</td>
</tr>
</tbody>
</table>

Source: Belle 1961

The decomposition of ADU at 450–500°C is the mechanism by which β–UO$_3$ is formed (Hoekstra and Siegel 1961). Since the UO$_3$ currently in inventory was formed by this method (Burney 1966), the β–UO$_3$ crystalline modification is of primary interest. The β–UO$_3$ begins to decompose from the 3.0 U:O ratio at 530°C, but it does not completely convert to the 2.67 U:O ratio of U$_3$O$_8$ until it approaches about 650°C (Hoekstra and Siegel 1961). Since the β–UO$_3$
predominates the current inventory, a temperature of at least 650°C is needed for conversion to U₃O₈.

The rate of the reaction

$$3\text{UO}_3 \rightarrow \text{U}_3\text{O}_6 + \frac{1}{2}\text{O}_2$$

is rapid at elevated temperatures. Figure 1 shows the theoretical rate based on reported rate constants for the range 600-650°C (Harrington and Ruehle 1959). At 650°C, the reaction is essentially complete in 1 hour. Based on the trend with temperature, the reaction should be even faster at higher temperatures.

### 4.3 **233**U₃O₈ AND OTHER OXIDES

Heating **233**U₃O₈ drives off any existing free water. However, there is an upper limit as to what temperature U₃O₈ can be heated. At atmospheric pressure, U₃O₈ is stable up to about 800°C; above this temperature, oxygen is gradually lost, favoring U₃O_{2.61 ± 0.05} (Hoekstra, Siegel, and Gallagher 1970) having a stoichiometry range of about UO_{2.61} to UO_{2.67}. Other work considers this latter phase to be substoichiometric U₃O₈-x (Cordfunke 1969, Ackerman and Chang 1973).

A melting point of U₃O₈ cannot be determined because when U₃O₈ melts, oxygen is evolved. At higher temperatures in an oxidizing atmosphere, starting at 925°C, U₃O₈ may “vaporize” (presumably, this means measurable vapor pressure), forming mainly monomeric gaseous UO₃, an undesirable product (Powers, Welch, and Trice 1949 and 1961).

Though it is unlikely that any significant amount of higher uranium oxides are present, it is useful to note that all higher uranium oxides and many other uranium compounds decompose to U₃O₈ above 650°C (Katz, Seaborg, and Morss 1986).
Fig. 1. Rate of decomposition of UO$_3$ to U$_3$O$_8$ in air.
5. SELECTION OF A STABILIZATION TEMPERATURE

Figure 2 illustrates a thermal profile of selected uranium oxides. It is a summary of the reactions of the uranium oxides when heated for conversion to U₃O₈. The standard boiling point of water is used as a baseline.

Heating at a temperature of 700°C is sufficient to convert both the UO₂ and UO₃ to the more stable U₃O₈. However, since some UO₂ may still be present at 700°C, a higher temperature of 750°C is chosen to ensure a more complete reaction within a reasonable heating time. From a practical perspective, this might translate into an operating specification of 750 ± 25°C to ensure that the material is exposed to a greater than 700°C environment.

Since U₃O₈ is stable up to 800°C, existing U₃O₈ will not be affected by this heating—except for the release of moisture, other residual volatiles, and the elimination of residual reactive uranium species. It also will serve to convert any other uranium oxides to U₃O₈. Heating U₃O₈ above 800°C for further stabilization introduces undesirable U₃O₈-x oxygen-deficient species into the system. Therefore, the range 750 ± 25°C achieves all the desired stabilization conditions while avoiding undesirable conditions.
Fig. 2. Thermal profile of selected uranium oxides.

Above this temperature, all forms of UO$_3$ (higher uranium oxides) decompose to U$_3$O$_8$. U$_3$O$_8$ is stable up to 800, thereafter gradually losing oxygen favoring, U$_3$O$_8$-$Z$.

Studies show stoichiometric U$_2$O$_6$ formed from UO$_3$ at this range.

Above which, UO$_3$ begins to decompose to U$_3$O$_8$.

U$_3$O$_8$ begins to react with air to form monomeric gaseous UO$_3$.

U$_3$O$_8$ oxidizes in air to U$_3$O$_6$.
6. REFERENCES


Burney, G.A., 1966. *Cation Exchange Concentration of Aqueous* $^{233}\text{UO}_2\left(\text{NO}_3\right)_2$ *and Conversion to* $^{233}\text{UO}_3$. DP-1047. Savannah River Laboratory, Aiken, South Carolina.


INTERNAL DISTRIBUTION

1. C. W. Alexander 45. D. M. McGinty
2. J. M. Begovich 46. L. E. McNeese
3. B. B. Bevard 47. G. E. Michaels
5. R. A. Bond 49. H. J. Monroe
7. H. E. Clark 51. D. E. Mueller
8. E. D. Collins 52. D. G. O’Conner
9. S. O. Cox 53. C. V. Parks
10. A. G. Croff 54. B. D. Patton
11. M. D. DeHart 55. F. J. Peretz
12. W. D. Duerksen 56. L. M. Petrie
15. C. W. Forsberg 59. R. T. Primm, III
16. D. Foster, Jr. 60. D. W. Ramey
17. R. G. Gilliland 61. D. A. Reed
19. N. M. Greene 63. K. D. Rowley
20. S. R. Greene 64. J. E. Rushton
22. S. A. Hodge 66. J. Sinclair, III
23. E. M. Holdges 67. B. W. Starnes
24. R. F. Holdaway 68. S. N. Storch
25. C. M. Hopper 69. N. R. Sweat
26. M. J. Kass 70. G. W. West
27. J. M. Keller 71. R. M. Westfall
29. D. C. Kocher 73. K. A. Williams
30. M. W. Kohring 74. B. A. Worley
31-40. A. M. Krichinsky 75. R. Q. Wright
41. M. A. Kulinaha 76. Central Research Library
42. A. J. Lucero 77. Laboratory Records–RC
43. S. B. Ludwig 78. Document Reference Section
44. M. H. McBride

80. Guy Armantrout, Lawrence Livermore National Laboratory, MS-L394, P.O. Box 808, Livermore, CA 94551


82. M. W. Barlow, Westinghouse Savannah River Company, Savannah River Site, Bldg. 704-C, Aiken, SC 29808


84-88. Peter Bereolos, Advanced Integrated Management Services, 702 S. Illinois Avenue, Suite B-203, Oak Ridge, TN 37830

89. Ralph Best, SAIC, P. O. Box 2501, 800 Oak Ridge Turnpike, Oak Ridge, TN 37831-2501

90. Wade E. Bickford, Westinghouse Savannah River Company, Savannah River Site, Bldg. 773-41A, Aiken, SC 29808


92. Alenka Brown-Van Hoozer, Argonne National Laboratory, P. O. Box 1625, Idaho Falls, ID 83415-3750

93. Mathew Bunn, National Academy of Sciences, Founder's Bldg., 1055 Thomas Jefferson Street, N. W., Washington, DC 20007

94. Dr. Donald E. Carlson, Senior Criticality and Shielding Engineer, U.S. Nuclear Regulatory Commission, Spent Fuel Project Office, Nuclear Material Safety and Safeguards, MS 06-G22, 11555 Rockville Pike, Rockville, MD 20852

95. Nate Chipman, Idaho National Environmental and Engineering Laboratory, WCB, MS-3114, P. O. Box 1625, Idaho Falls, ID 83415-3114


97. Floyd L. Culler, Jr., Senior Technical Review Group, Mail Box 12098, Suite 800, 600 S. Tayler, Amarillo, TX 79101

98. Paul Cunningham, Los Alamos National Laboratory, MS-A102, P. O. Box 1663, Los Alamos, NM 87545


101. Tom Doering, Framatome Cogema Fuels, 1180 Town Center Dr., Las Vegas, NV 89134

102. John Duane, Westinghouse Savannah River Company, Savannah River Site, Bldg. 704-F, Aiken, SC 29808

103. C. Dunford, Brookhaven National Laboratory, National Nuclear Data Center, D. Bldg. 197D, Upton, NY 11973

104. Randy Erickson, Los Alamos National Laboratory, MS-F660, P. O. Box 1663, Los Alamos, NM 87545


106. Rowland Felt, 780 DOE Place, , Idaho Falls, ID 83415-1216


110. Peter Gottlieb, TESS, 1180 Town Center Dr., Las Vegas, NV 89134

111. Thomas Gould, Lawrence Livermore National Laboratory, MS-L186, P. O. Box 808, Livermore, CA 94551

112. Leonard W. Gray, Lawrence Livermore National Laboratory, MS-L394, P. O. Box 808, Livermore, CA 94551


114. M. Haas, U.S. Department of Energy, Rocky Flats Environmental Technology Site, P. O. Box 464, Golden, CO 80402


116-118. Reginald Hall, Advanced Integrated Management Services, 702 S. Illinois Avenue, Suite B-203, Oak Ridge, TN 37830
119. Bill Halsey, Lawrence Livermore National Laboratory, MS-L369, P. O. Box 808, Livermore, CA 94551
120. Roger Henry, P. O. Box 1625, Idaho Falls, ID 83415-3805
121. Laura Holgate, U.S. Department of Energy, Office of Fissile Material Disposition, 1000 Independence Ave., S.W., Washington, DC 20585
122. M. K. Holland, Westinghouse Savannah River Company, P. O. Box 616, Aiken, SC 29802
123. Frank Holmes, U.S. Department of Energy, Idaho Field Office, P. O. Box 1625, Idaho Falls, ID 83415-3805
124. Dave Huizenga, U.S. Department of Energy, DOE/EM-20, Forrestal Bldg., Rm.5B-086, 1000 Independence Ave., S.W., Washington, DC 20585
127. Carolyn Huntoon, U.S. Department of Energy, Assistant Secretary, Environmental Management, 1000 Independence Ave., S.W., Washington, DC 20585
128. Brent Ives, Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550
129. N. C. Iyer, Westinghouse Savannah River Company, Savannah River Site, Bldg. 773-A, Aiken, SC 29808
130. Leslie Jardine, Lawrence Livermore National Laboratory, MS-L186, P.O. Box 808, Livermore, CA 94551
131. Bill Jensen, U.S. Department of Energy, MS 1101, 850 Energy Dr., Idaho Falls, ID 38401-1563
132. Gregory V. Johnson, Savannah River Site, Bldg. 703-F, Room 26, Aiken, SC 29808
134. Ed Jones, Lawrence Livermore National Laboratory, 7000 East Ave., L-634, Livermore, CA 94550
135. William E. Kastenberg, University of California-Berkeley, Department of Nuclear Engineering, Berkeley, CA 94720-1730

18
137. J.F. Krupa, Westinghouse Savannah River Company, Savannah River Site, Bldg. 773-41A, Aiken, SC 29808
140. Leroy Lewis, Locked Martin Idaho Technologies Company, P.O. Box 1625, Idaho Falls, ID 83415
141. Cary Loflin, U.S. Department of Energy, P.O. Box 5400, Albuquerque, NM 87185-5400
145. T McLaughlin, Los Alamos National Laboratory, ESH-6, P.O. Box 1663, Los Alamos, NM 87545
146. Don McWhorter, Westinghouse Savannah River Company, Savannah River Site, Bldg. 704-F, Aiken, SC 29808
149. Ed Moore, Westinghouse Savannah River Company, Savannah River Site, Bldg. 773-41A, Rm. 125, P.O. Box 616, Aiken, SC 29808
150. Jim Nail, Lockheed Martin Idaho Technologies Company, P.O. Box 1625, Idaho Falls, ID 83415
151. Dave Neiswander, Advanced Integrated Management Services, 702 S. Illinois Avenue, Suite B-203, Oak Ridge, TN 37830
153. Jon Nielsen, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545
185. Bruce Twining, Manager, Albuquerque Operations Office, Kirkland Air Force Base, Pennsylvania & H Street, Albuquerque, NM 87116
186. Terry S. Vail, Westinghouse Hanford Company, R2-54, P.O. Box 1970, Richland, WA 99352
187. Richard VanKonynenburg, Lawrence Livermore National Laboratory, MS-L269, P.O. Box 808, Livermore, CA 94551
188. K.E. Waltzer, U.S. Department of Energy, Savannah River Site, Bldg. 703-F, Aiken, SC 29808
189. John Wilcynski, Manager, Idaho Operations Office, 765 Lindsay Blvd., Idaho Falls, ID 83401
190. Jeff Williams, Idaho National Environmental and Engineering Laboratory, P.O. Box 1625, Idaho Falls, ID 83415
191. M. Williams, Louisiana State University, Nuclear Science Center, Baton Rouge, LA 70803
192. C.R. Wolfe, Westinghouse Savannah River Company, Savannah River Site, Bldg. 773-A, Aiken, SC 29808
193. Jesse L. Yow, Lawrence Livermore National Laboratory, University of California, 7000 East Ave., Livermore, CA 94550
194. Loong Yong, Advanced Integrated Management Services, 702 S. Illinois Avenue, Suite B-203, Oak Ridge, TN 37830
195. Office of Assistant Manager of Energy Research and Development, P.O. Box 2008, DOE-ORO, Oak Ridge, TN 37831-6269
196. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831