ORNL/LTR-2022/11

Oak Ridge National Laboratory EPA Approval Letters and Historical Documentation for a Modification in Applying 40 CFR Part 61 Appendix D

William L. McCarter

February 2022

OAK RIDGE National Laboratory

ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY

ORNL/LTR-2022/11

Environmental Protection Services Division

EPA APPROVAL LETTERS AND HISTORICAL DOCUMENTATION FOR A MODIFICATION IN APPLYING 40 CFR PART 61 APPENDIX D

William L. McCarter

February 2022

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

INTRODUCTION

Appendix D of Title 40 Part 61, "Methods for Estimating Radionuclide Emissions," of the *Code of Federal Regulations* (CFR) provides a procedure that US Department of Energy (DOE) facility owners and operators can use to estimate radionuclide emissions to the atmosphere for dose calculations instead of measuring emissions for minor sources under 40 CFR Part 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities." The procedure assumes that any radioactive material heated above 100°C is completely vaporized and emitted to the atmosphere. In 1991, the DOE Oak Ridge Reservation (DOE-ORR) requested approval to use different release fractions (RFs) for uranium because of its high melting and boiling points (1,132°C and 3,818°C, respectively). In response to the request, Environmental Protection Agency (EPA) Region IV approved the use of modified RFs for elemental uranium provided no reaction had taken place to alter its chemical form. In 2015, DOE-ORR requested approval to use different RFs for radioactive tungsten, also because of its high melting and boiling points (3,410°C and 5,660°C, respectively). EPA Region IV approved the use of modified RFs for heated radioactive tungsten metal. In accordance with the two precedents set for heating uranium and radioactive tungsten metals, in 2016, DOE-ORR requested approval to use modified RFs in similar fashion for other radioactive solid metals and compounds with melting and boiling points above 500°C that might be heated above 100°C in future research projects and experiments, and again, the EPA Region IV granted approval to use modified RFs for the list of compounds.

This document contains the EPA approval letters and historical documentation used in the process to obtain approval for the use of alternative Appendix D emission factors. The approval to DOE-ORR allows modifying the existing regulatory RFs to 1 when radioactive solid metals and compounds are heated to temperatures greater than or equal to the boiling point of the solid, to 10^{-3} when radioactive solid metals and compounds are heated to temperatures greater than or equal to 90% of the melting point and less than the boiling point of the solid, and to 10^{-6} when radioactive solid materials are heated to temperatures above ambient air temperature but below 90% of the melting point of the solid.

APPENDIX A. EPA APPROVAL LETTERS AND HISTORICAL DOCUMENTATION FOR A MODIFICATION IN APPLYING APPENDIX D

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

FEB 23 2016

Mr. Johnny Moore
Manager
Oak Ridge National Laboratory Site Office
P.O. Box 2008
Oak Ridge, Tennessee 37831-6269

Dear Mr. Moore:

This is in response to your letter dated February 3, 2016, requesting approval for a modification in applying appendix D of 40 CFR Part 61 to heated radioactive solid materials with high melting and boiling points. A letter requesting approval for a modification in applying appendix D of 40 CFR Part 61 to heated radioactive tungsten metal and approval for surrogate for niobium dated June 25, 2015, was included as an enclosure. Your letter requested approval to use modified emission factors in a similar fashion for other radioactive solid metals and compounds whose melting and boiling points are significantly above 100 degrees Centigrade.

The U.S. Environmental Protection Agency has reviewed your enclosed Table 1 listing potential radioactive solid materials that Oak Ridge National Laboratory may heat above 100 degrees Centigrade in future research experiments and the list of references. The EPA approves your request to use modified emissions factors for the solids materials listed in Table 1. If you have any questions, please feel free to contact Lloyd Generette of my staff at (404) 562-9138 or generette.lloyd@epa.gov.

Sincerely,

Beverly H. Banister
Director
Air, Pesticides and Toxics Management Division

Department of Energy
ORNL Site Office
P.O. Box 2008
Oak Ridge, Tennessee 37831-6269

February 3, 2016

Mr. Gregg Worley, Chief
Air Analysis and Support Branch
Air, Pesticides and Toxics Management Division
United States Environmental Protection Agency
Region 4
61 Forsythe Street South West
Atlanta, Georgia 30303-3104

Dear Mr. Worley:

REQUEST FOR APPROVAL FOR A MODIFICATION IN APPLYING APPENDIX D OF 40 CODE OF FEDERAL REGULATIONS (CFR) PART 61 TO HEATED RADIOACTIVE SOLID MATERIALS WITH HIGH MELTING AND BOILING POINTS

Reference:
1. Letter from Winston A. Smith to Ronald R. Nelson, subject, *Request to Modify 40 CFR Part 61, Appendix D, Emission Factors For Uranium at the Department of Energy (DOE) Oak Ridge Reservation (ORR) and Paducah Gaseous Diffusion Plant (PGDP)*, dated December 2, 1991

2. Letter from Beverly H. Banister to Johnny O. Moore, no subject, responding to: Letter from Johnny O. Moore to Gregg Worley, subject *Request for Approval for a Modification in Applying Appendix D of 40 Code of Federal Regulations (CFR) Part 61 to Heated Radioactive Tungsten Metal and Approval for Surrogate for Niobium (NB)-91M*, dated June 25, 2015

Appendix D of 40 CFR Part 61 is a procedure that allows facility owners and operators to estimate radionuclide emissions to the atmosphere for dose calculations instead of measuring emissions for minor sources under the Radionuclide National Emission Standards for Hazardous Air Pollutants Regulation (40 CFR Part 61, Subpart H). The procedure assumes that any radioactive material heated above 100 °C is completely vaporized and emitted to the atmosphere (i.e., emission factor of 1.0). On August 1, 1991, the Department of Energy (DOE) Oak Ridge Reservation requested approval to use different emission factors for uranium since the melting and boiling points are 1,132 °C and 3,818 °C, respectively. United States Environmental Protection Agency (EPA) Region 4 granted approval on December 2, 1991, to use modified emission factors for elemental uranium provided that no reaction takes place to alter its chemical form. This approval letter is included as Enclosure 1. On June 3, 2015, DOE requested approval to use different emission factors for tungsten, again due to its high (significantly above 100 °C) melting and boiling points. EPA Region 4 granted approval on June 25, 2015, to use modified emission factors for heated radioactive tungsten metal. This approval letter is included as Enclosure 2.

REQUEST FOR APPROVAL FOR A MODIFICATION IN APPLYING APPENDIX D OF 40 CODE OF FEDERAL REGULATIONS (CFR) PART 61 TO HEATED RADIOACTIVE SOLID MATERIALS WITH HIGH MELTING AND BOILING POINTS

In line with these two precedents, DOE and Oak Ridge National Laboratory (ORNL) request approval to use modified emission factors in a similar fashion for other radioactive solid metals and compounds whose melting and boiling points are significantly above 100 °C (i.e., > 500 °C) in accordance with the following:

1) An emission factor of 1 will be applied to radioactive solid metals and compounds heated to temperatures greater than or equal to the boiling point of the solid.
2) An emission factor of 10^{-3} will be applied to radioactive solid metals and compounds heated to temperatures greater than or equal to 90 percent of the melting point[1] and less than the boiling point.
3) An emission factor of 10^{-6} will be applied to radioactive solid metals and compounds heated to temperatures above ambient temperature, but below 90 percent of the melting point[1].
4) Additional adjustments to emission factors for effluent controls will be allowed as presented in Table 1 of Appendix D.

Table 1 in Enclosure 3 is a listing of potential radioactive solid metals and compounds that ORNL may heat above 100 °C in future research experiments. Most of these compounds are materials associated with nuclear fuel rods, spent fuel, depleted uranium, and uranium enrichment processing.

Ms. Linda L. Smith of the environmental staff at ORNL spoke with Mr. Lloyd Generette of EPA Region 4 on October 7, 2015, requesting approval to use modified emission factors for other radioactive solid metals and compounds with high melting and boiling points similar to uranium and tungsten metal. He indicated that he foresaw no issues with the request, but asked that a formal written request for approval be submitted. On November 10, 2015, Ms. Smith emailed Mr. Generette with a draft listing of potential radioactive solid metals and compounds that ORNL may heat above 100 °C in future research experiments to clarify if EPA Region 4 would grant approval to use modified emission factors for radioactive solid compounds, as well as radioactive solid elemental metals with high melting and boiling points. On November 18, 2015, Mr. Generette responded by phone that approval would be granted for the heating of radioactive solid compounds with high melting and boiling points as well.

[1] Most pure solids typically melt at a sharply defined, single temperature value. However, impurities can cause the melting point to spread out over a range of several degrees and even lower the melting point of the substance. Therefore a conservative factor of 90% of the melting point is chosen to mitigate this effect. (Loudon, G. Marc (1988). *Organic Chemistry Third Edition* (p.70). Redwood City, CA: The Benjamin/Cummings Publishing Company, Inc.)

REQUEST FOR APPROVAL FOR A MODIFICATION IN APPLYING APPENDIX D OF 40 CODE OF FEDERAL REGULATIONS (CFR) PART 61 TO HEATED RADIOACTIVE SOLID MATERIALS WITH HIGH MELTING AND BOILING POINTS

DOE and ORNL appreciate your assistance. If there are any questions or additional information is required, please contact Eric Moore at (865) 576-7321, or either Linda L. Smith at (865) 241-3711 or Jim M. Eaton at (865) 576-8115, both of whom are with ORNL's Environmental Protection Air Quality group.

Sincerely,

Johnny O. Moore, Manager
ORNL Site Office

Enclosures

cc w/enclosures:
Lloyd Generette, EPA
Richard W. Martin, SC-OR
Mary R. Dunsmore, ORNL
Jim M. Eaton, ORNL
Brian Egle, ORNL
Mike B. Farrar, ORNL
Angel K. Kennedy, ORNL
R. Steve Owens, ORNL
Cecil V. Parks, ORNL
Michael J. Pierce, ORNL
John E. Powell, ORNL
Patricia A. Scofield, ORNL
David D. Skipper, ORNL
Linda L. Smith, ORNL
Raymond J. Vedder, ORNL
Michelle W. Owenby, TDEC
Hernan R. Flores, Jr., TDEC

ENCLOSURE 1

Letter from Winston A. Smith to Ronald R. Nelson, subject, *Request to Modify 40 CFR Part 61, Appendix D, Emission Factors For Uranium at the Department of Energy (DOE) Oak Ridge Reservation (ORR) and Paducah Gaseous Diffusion Plant (PGDP)*, dated December 2, 1991

Department of Energy
Field Office, Oak Ridge
P.O. Box 2001
Oak Ridge, Tennessee 37831— 8615

December 17, 1991

Mr. Frank Kornegay
Oak Ridge National Laboratory
Martin Marietta Energy Systems, Inc.
Post Office Box 2008
Oak Ridge, Tennessee 37831-6103

Dear Mr. Kornegay:

ENVIRONMENTAL PROTECTION AGENCY-IV (EPA-IV) RESPONSE TO THE DEPARTMENT OF ENERGY OAK RIDGE FIELD OFFICE REQUEST TO MODIFY 40 CFR 61, APPENDIX D, EMISSION FACTORS FOR URANIUM

Enclosed for your information is a letter from EPA-IV granting relief from the 40 CFR 61, Appendix D promulgated emission factors for uranium as a function of temperature. This is for your information only. If you have any questions, contact me at 576-7321.

Sincerely,

William Mark Belvin

W. Mark Belvin
Program Manager
Laboratory Operations Branch

Enclosure

cc w/enclosure:
C. Matthews, ER-114, OR
D. Buhaly, SE-311, OR
J. Murphy, ORNL
L. Hamilton, ORNL

WDD

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV

345 COURTLAND STREET, N.E.
ATLANTA, GEORGIA 30365

4APT-AEB

DEC - 2 1991

CRITICAL FILE COPY

ENVIRONMENTAL PROTECTION DIVISION

Log No. F 5061

Date Received DEC 05 1991

File Code 9255.9

Mr. R.R. Nelson, Assistant Manager of
Environment, Safety and Quality
Department of Energy
Oak Ridge Operations
P.O. Box 2001
Oak Ridge, Tennessee 37831-8739

RE: REQUEST TO MODIFY 40 CFR PART 61, APPENDIX D, EMISSION FACTORS FOR URANIUM AT THE DEPARTMENT OF ENERGY (DOE) OAK RIDGE RESERVATION (ORR) AND PADUCAH GASEOUS DIFFUSION PLANT (PGDP)

Dear Mr. Nelson:

References: 1. 8/1/91 letter, R.R. Nelson to W.A. Smith, subj: ORR Compliance Plan alternative monitoring methods.

2. 7/31/91 letter, D.C. Booher to W.A. Smith, subj: PGDP Compliance Plan alternative monitoring methods.

We have reviewed your Agency's request to use uranium emission factors different from those listed in 40 CFR Part 61, Appendix D, and have made the following determination:

1. An emission factor of 1 shall be applied to elemental uranium heated to temperatures greater than 3000°C.

2. Emission factors less than 1 may be considered for elemental uranium heated at temperatures less than 3000°C, provided no reaction takes place to alter its chemical form.

3. An emission factor of 10^{-3} may be applied to elemental uranium heated at temperatures greater than 1100°C but less than 3000°C.

4. An emission factor of 10^{-6} may be applied to elemental uranium heated at temperatures below 1100°C, provided the uranium is in solid form.

5. The exclusion for sealed radionuclides cannot be extended to radionuclides in solid form. Appendix D of 40 CFR Part 61, explicitly requires an emission factor of 10^{-6} for radionuclides in solid form. Depending on the degree of friability, dusting of radionuclides in solids will form airborne emissions.

If you should have any questions, please contact Mr. Brian L. Beals of my staff at FTS 257-5014.

Sincerely yours,

Winston A. Smith, Director
Air, Pesticides and Toxics
Management Division

cc: Mr. Harold Hodges, P.E., Director
Division of Air Pollution Control
Tennessee Department of Health and Environment
Customs House, 4th Floor
701 Broadway
Nashville, Tennessee 37219-5403

Mr. Michael Mobley, Director
Division of Radiological Health
Tennessee Department of Health and Environment
150 9th Avenue, North
Nashville, Tennessee 37219-5404

Mr. Weldon Dillow
U.S. Department of Energy
P.O. Box 2001
Oak Ridge, Tennessee 37831-8739

ENCLOSURE 2

Letter from Beverly H. Banister to Johnny O. Moore, no subject, dated June 25, 2015; responding to: Letter from Johnny O. Moore to Gregg Worley, *Request for Approval for a Modification in Applying Appendix D of 40 Code of Federal Regulations (CFR) Part 61 to Heated Radioactive Tungsten Metal and Approval for Surrogate for Niobium (NB)-91M*

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

JUN 25 2015

Mr. Johnny Moore
Manager
Oak Ridge National Laboratory Site Office
P.O. Box 2008
Oak Ridge, Tennessee 37831-6269

Dear Mr. Moore:

This is in response to your letter dated June 3, 2015, requesting approval for a modification in applying appendix D of 40CFR part 61 to heated radioactive tungsten metal. A letter from Winston Smith to Ronald R. Nelson was enclosed where approval was granted for the use of modified emission factors based on the high melting point of uranium and given that the physical state of the element would not be altered. Additionally, you requested that Niobium 95 be used as a surrogate for Niobium 91m in the CAP88PC v3 code, which is used to demonstrate compliance with the air dose to the maximally exposed member of the public. A second enclosure provided the technical justification for using Niobium 95 instead of Niobium 91m in RadNESHAPs dose calculations.

The U.S. Environmental Protection Agency approves your request to modify emissions factors in Appendix D of 40CFR part 61. Also the EPA approves your request to use Niobium 95 instead of Niobium 91m in RadNESHAPs calculations. If you have any questions, please feel free to contact Lloyd Generette of my staff at (404) 562-9138 or generette.lloyd@epa.gov.

Sincerely,

Carol L. Kemker for

Beverly H. Banister
Director
Air, Pesticides and Toxics Management Division

Department of Energy
ORNL Site Office
P.O. Box 2008
Oak Ridge, Tennessee 37831-6269

June 3, 2015

Mr. Gregg Worley, Chief
Air Analysis and Support Branch
Air, Pesticides and Toxics Management Division
United States Environmental Protection Agency
Region 4
61 Forsythe Street SW
Atlanta, Georgia 30303-3104

Dear Mr. Worley:

REQUEST FOR APPROVAL FOR A MODIFICATION IN APPLYING APPENDIX D OF 40 CODE OF FEDERAL REGULATIONS (CFR) PART 61 TO HEATED RADIOACTIVE TUNGSTEN METAL AND APPROVAL FOR SURROGATE FOR NIOBIUM (NB)-91M

Reference: Letter from Winston A. Smith to Ronald R. Nelson, subject, *Request to Modify 40 CFR Part 61, Appendix D, Emission Factors For Uranium at the Department of Energy (DOE) Oak Ridge Reservation (ORR) and Paducah Gaseous Diffusion Plant (PGDP)*, dated December 2, 1991

Appendix D of 40 CFR Part 61 allows facility owners and operators to estimate radionuclide emissions to the atmosphere for dose calculations instead of measuring emissions for minor sources under the Radionuclide National Emission Standards for Hazardous Air Pollutants (Rad NESHAPs) Regulation (40 CFR Part 61, Subpart H). The procedure assumes that any radioactive material heated above 100 degrees Celsius (°C) is completely vaporized and emitted to the atmosphere (i.e., emission factor of 1.0). On August 1, 1991, the Department of Energy (DOE) Oak Ridge Reservation requested approval to use different emission factors for uranium, since the melting and boiling points are 1,132 °C and 3,818 °C respectively. The Environmental Protection Agency (EPA) Region 4 granted approval on December 2, 1991, to use modified emission factors for elemental uranium provided that no reaction takes place to alter its chemical form. This approval letter is included as Enclosure 1. In line with this precedent, DOE and Oak Ridge National Laboratory (ORNL) request approval to use modified emission factors in similar fashion for elemental tungsten, since the melting and boiling points for this metal are 3,410 °C and 5,660 °C respectively. Under the same conditions as uranium, that no reaction takes place to alter its chemical form, we request approval to use the following modifications to Appendix D emission factors for tungsten:

REQUEST FOR APPROVAL FOR A MODIFICATION IN APPLYING APPENDIX D OF 40 CODE OF FEDERAL REGULATIONS (CFR) PART 61 TO HEATED RADIOACTIVE TUNGSTEN METAL AND APPROVAL FOR SURROGATE FOR NIOBIUM (NB)-91M

1. An emission factor of 1 will be applied to elemental tungsten heated to temperatures greater than 5000 °C.

2. An emission factor of 10^{-3} will be applied to elemental tungsten heated at temperatures greater than 3400 °C, but less than 5000 °C.

3. An emission factor of 10^{-6} will be applied to elemental tungsten heated at temperatures above ambient temperature, but below 3400 °C, provided the tungsten is in solid form.

4. Additional adjustments to emission factors for effluent controls will be allowed as presented in Table 1 of Appendix D.

Ms. Linda L. Smith of the environmental staff at ORNL spoke with Mr. Lloyd Generette of EPA Region 4 on May 7, 2015, and he indicated that he did not have a problem with the request to use modified emission factors for tungsten, but asked for a formal written request for approval.

In addition, we request approval to use Nb-95 as a surrogate for Nb-91m in Rad NESHAPs dose calculations. Mr. Keith Eckerman of the Human Health Risk and Environmental Analysis Section of the Environmental Sciences Division of ORNL has recommended the use of Nb-95 as a surrogate for Nb-91m. Ms. Patricia Scofield of the environmental staff at ORNL forwarded Mr. Eckerman's recommendation email to Mr. Generette on May 5, 2015, and requested approval to use Nb-95 as a surrogate for Nb-91m as Mr. Eckerman suggested. Mr. Generette corresponded back on May 7, 2015, indicating that he had no problem with the request, but also asked for a formal written request for approval. Enclosure 2 includes these email correspondences.

REQUEST FOR APPROVAL FOR A MODIFICATION IN APPLYING APPENDIX D OF 40 CODE OF FEDERAL REGULATIONS (CFR) PART 61 TO HEATED RADIOACTIVE TUNGSTEN METAL AND APPROVAL FOR SURROGATE FOR NIOBIUM (NB)-91M

DOE and ORNL appreciate your assistance. If there are any questions or additional information is required, please contact David Buhaly of my staff at (865) 576-1954 or Linda L. Smith at (865) 241-3711 or Jim M. Eaton at (865) 576-8115 with ORNL's Environmental Protection Air Quality group.

Sincerely,

Johnny O. Moore, Manager
ORNL Site Office

Enclosures

cc w/enclosures:
Lloyd Generette, EPA
Richard W. Martin, SC-OR
Vergil O. Murrell, TDEC
Barry Stephens, TDEC
David D. Drake, ORNL
Mary R. Dunsmore, ORNL
Jim M. Eaton, ORNL
Keith F. Eckerman, ORNL
Brian Egle, ORNL
Mike B. Farrar, ORNL
Cecil V. Parks, ORNL
Michael J. Pierce, ORNL
John E. Powell, ORNL
Patricia A. Scofield, ORNL
David D. Skipper, ORNL
Linda L. Smith, ORNL

ENCLOSURE 3

Listing of Potential Radioactive Solid Metals and Compounds that ORNL may Heat Above 100° in Future Research Experiments

Table 1. Listing of potential radioactive solid materials that ORNL may heat above 100 °C in future research experiments

Radioactive Compound	Melting Point (°C)	Boiling Point (°C)	Reference
TUNGSTEN METAL[2]	3,410	5,660	CRC Handbook of Chemistry and Physics
URANIUM METAL[†]	1,132	3,818	CRC Handbook of Chemistry and Physics
COMPOUNDS OF ACTINIUM			
Actinium Metal	1,050	3,200	CRC Handbook of Chemistry and Physics
Actinium Bromide	800 (sublimes)	NA	CRC Handbook of Chemistry and Physics
Actinium Iodide	700-800 (sublimes)	NA	CRC Handbook of Chemistry and Physics
Actinium Trichloride	960 (sublimes)	NA	CRC Handbook of Chemistry and Physics
COMPOUNDS OF BARIUM			
Barium Metal	725.0	1,640	CRC Handbook of Chemistry and Physics
Barium *ortho*Arsenate	1,605	Not Known	CRC Handbook of Chemistry and Physics
Barium Bromide	847	Not Known	CRC Handbook of Chemistry and Physics
Barium Bromide Dihydrate	880	Not Known	CRC Handbook of Chemistry and Physics
Barium Carbonate (α)	1,740	Decomposes	CRC Handbook of Chemistry and Physics
Barium Carbonate (β)	982 (transition point to α)	NA	CRC Handbook of Chemistry and Physics
Barium Carbonate (γ)	811 (transition point to β)	NA	CRC Handbook of Chemistry and Physics
Barium *per*chlorate	505	Not Known	CRC Handbook of Chemistry and Physics
Barium Chloride	963	1,560	CRC Handbook of Chemistry and Physics
Barium Fluoride	1,355	2,137	CRC Handbook of Chemistry and Physics
Barium Hydride	675 (decomposes)	1400(?)	CRC Handbook of Chemistry and Physics
Barium Hexaboride	2,270	Not Known	CRC Handbook of Chemistry and Physics
Barium Iodide	711	2027	Lange's Handbook of Chemistry
Barium Iodide Hydrate	539; 740 (decomposes)	NA	CRC Handbook of Chemistry and Physics
Barium Molybdate	1,480	Not Known	CRC Handbook of Chemistry and Physics
Barium Niobate	1,455	Not Known	Lange's Handbook of Chemistry
Barium Nitrate	592	Decomposes	CRC Handbook of Chemistry and Physics
Barium Nitride	Not Known	1,000 (decomposes)	CRC Handbook of Chemistry and Physics
Barium Oxide	1,973	3088	Lange's Handbook of Chemistry
Barium Selenide	1,780	Not Known	Lange's Handbook of Chemistry
Barium *meta*silicate	1,604	Not Known	CRC Handbook of Chemistry and Physics
Barium Sulphate	1,580	1,149 (transition point)	CRC Handbook of Chemistry and Physics
Barium Monosulphide	1,200	Not Known	CRC Handbook of Chemistry and Physics
Barium Trisulphide	554	Not Known	CRC Handbook of Chemistry and Physics
Barium Titanate	1,625	Not Known	Lange's Handbook of Chemistry
Barium *pyro*vanadate	863	Not Known	CRC Handbook of Chemistry and Physics
Barium Zirconate	2,500	Not Known	Lange's Handbook of Chemistry
COMPOUNDS OF NEPTUNIUM			
Neptunium Metal	644	>3,900	Lange's Handbook of Chemistry

[2] Already Approved

Neptunium Tribromide	800 (sublimes)	NA	CRC Handbook of Chemistry and Physics
Neptunium Tetrachloride	538	Not Known	CRC Handbook of Chemistry and Physics
Neptunium Trichloride	800 (sublimes)	NA	CRC Handbook of Chemistry and Physics
Neptunium Oxide	2,547	Not Known	Lange's Handbook of Chemistry
Neptunium Octatrioxide	500 (decomposes)	NA	CRC Handbook of Chemistry and Physics
COMPOUNDS OF PLUTONIUM			
Plutonium Metal	641	3,232	CRC Handbook of Chemistry and Physics
Diplutonium Trioxide	2,085 (in Helium)	Not Known	Lange's Handbook of Chemistry
Plutonium Dihyride	~727	Not Known	Lange's Handbook of Chemistry
Plutonium Dioxide	2,390	2,800 (decomposes)	Lange's Handbook of Chemistry
Plutonium Oxide	1,900	Not Known	Lange's Handbook of Chemistry
Plutonium Sulphide	1,727	Not Known	Lange's Handbook of Chemistry
Plutonium Tetrafluoride	1,037 (decomposes)	NA	Lange's Handbook of Chemistry
Plutonium Tribromide	681	>1,300 (decomposes)	Lange's Handbook of Chemistry
Plutonium Trichloride	760	1,767	Lange's Handbook of Chemistry
Plutonium Trifluoride	1,425	2,000 (decomposes)	Lange's Handbook of Chemistry
Plutonium Triiodide	777	Not Known	CRC Handbook of Chemistry and Physics
COMPOUNDS OF RADIUM			
Radium Metal	700.1	1737.0	Lange's Handbook of Chemistry
Radium Bromide	728	900 (sublimes)	Lange's Handbook of Chemistry
Radium Carbonate	>1,100	Not Known	CRC Handbook of Chemistry and Physics
Radium Chloride	1,000	Not Known	Lange's Handbook of Chemistry
COMPOUNDS OF THORIUM			
Thorium Metal	1,750	4,788	Lange's Handbook of Chemistry
Thorium Hexaboride	2,195	Not Known	CRC Handbook of Chemistry and Physics
Thorium Bromide	610 (sublimes)	NA	CRC Handbook of Chemistry and Physics
Thorium Carbide	2,655	5,000	CRC Handbook of Chemistry and Physics
Thorium Chloride	770	928 (decomposes)	CRC Handbook of Chemistry and Physics
Thorium Fluoride	1,110	1,680	Lange's Handbook of Chemistry
Thorium Iodide	570	837	Lange's Handbook of Chemistry
Thorium Nitrate	500 (decomposes)	NA	CRC Handbook of Chemistry and Physics
Thorium Oxide	3,320	4,400	CRC Handbook of Chemistry and Physics
Thorium Sulphide	1,925	Not Known	CRC Handbook of Chemistry and Physics
COMPOUNDS OF TUNGSTEN			
Ditungsten Carbide	2,860	6,000	CRC Handbook of Chemistry and Physics
Tungsten Carbide	2,870	6,000	CRC Handbook of Chemistry and Physics
Tungsten Diboride	2,900	Not Known	CRC Handbook of Chemistry and Physics
Tungsten Dioxide	1,550	1,724 (decomposes)	Lange's Handbook of Chemistry
Tungsten Pentoxide	800 (sublimes)	1,530 (decomposes)	CRC Handbook of Chemistry and Physics
Tungsten Trioxide	1,472	1,837	Lange's Handbook of Chemistry

Tungsten Silicide	>900	Not Known	CRC Handbook of Chemistry and Physics
Tungsten Sulfide	1,250 (decomposes)	NA	Lange's Handbook of Chemistry
COMPOUNDS OF URANIUM			
Uranium Diboride	2,365	Not Known	CRC Handbook of Chemistry and Physics
Uranium Dicarbide	2,350	4,370	CRC Handbook of Chemistry and Physics
Uranium Dioxide	2,827	Not Known	Lange's Handbook of Chemistry
Uranium Disulfide	>1,100	Not Known	CRC Handbook of Chemistry and Physics
Uranium Mononitride	2,630	Decomposes	CRC Handbook of Chemistry and Physics
Uranium Monosulphide	>2,000	Not Known	CRC Handbook of Chemistry and Physics
Uranium Tetrabromide	519	777	Lange's Handbook of Chemistry
Uranium Tetrachloride	590	790	Lange's Handbook of Chemistry
Uranium Tetrafluoride	1,036	1,414	Lange's Handbook of Chemistry
Uranium Tetraiodide	506	757	Lange's Handbook of Chemistry
Uranium Tribromide	730	Not Known	CRC Handbook of Chemistry and Physics
Uranium Trichloride	837	1,657	Lange's Handbook of Chemistry
Uranium Trifluoride	>1,000 (decomposes)	NA	CRC Handbook of Chemistry and Physics
Uranium Trioxide	1,300 (decomposes)	NA	Lange's Handbook of Chemistry
Uranyl Acetate Chloride	577	Not Known	Lange's Handbook of Chemistry
Triuranium Octaoxide	1300 (decomposes to UO_2)	NA	Lange's Handbook of Chemistry
COMPOUNDS OF ZIRCONIUM			
Zirconium Metal	1,852	3,577	Lange's Handbook of Chemistry
Zirconium Carbide	3,532	5,100	Lange's Handbook of Chemistry
Zirconium Chloride	727	1,292	Lange's Handbook of Chemistry
Zirconium Diboride	3,245	4,193 (decomposes)	Lange's Handbook of Chemistry
Zirconium Fluoride	932	912 (sublimes)	Lange's Handbook of Chemistry
Zirconium Nitride	2,980	Not Known	CRC Handbook of Chemistry and Physics
Zirconium Oxide	2,678	4,300	Lange's Handbook of Chemistry
Zirconium Silicate	1,540 (decomposes)	NA	Lange's Handbook of Chemistry
Zirconium Sulphide	~1,550	Not Known	CRC Handbook of Chemistry and Physics