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REACTION RATE CONSTANT FOR URANIUM IN WATER AND WATER VAPOR

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Abstract: The literature on uranium oxidation in water and oxygen free water vapor was reviewed. Arrhenius rate equations were developed from the review data. These data and equations will be used as a baseline from which to compare reaction rates measured for K Basin fuel.

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REACTION RATE CONSTANT FOR URANIUM IN WATER AND WATER VAPOR

1.0 PURPOSE

The purpose of this work is to review the literature on oxidation of uranium metal in water and oxygen free water vapor and to develop equations for reaction rate constant using the available data. The data and equations are compared to the equations in the Project Technical Databook (Reilly 1998).

The Technical Databook equations provide input parameters for calculation of the chemical reaction of K Basin fuel in Multi-Canister Overpacks (MCOs). These equations are from the literature and were developed from the data of a few investigators (Cooper 1997). When reaction rate data for K Basin fuel becomes available they will be compared to the Technical Databook equations and to the literature review data. If sufficient differences are seen revised equations will be developed for the Technical Databook as was done for the dry air oxidation equations (Trimble 1998).

2.0 SUMMARY

The reaction rate constant is defined in the following general equation.

$$R = A_s \times F_a \times k$$

where:

R = Reaction rate

A_s = Geometric fuel surface area

F_a = Enhancement factor to account for the following: (1) true reacting surface sometimes called a roughness factor, (2) uranium metal inclusions including hydrides from water exposure, and (3) other effects such as irradiation

k = Temperature and vapor pressure dependent reaction rate, typically an Arrhenius form.

The following equations were derived from literature data and define the reaction rate constant (k) for unirradiated uranium where k is weight gain in $\text{mg}/\text{cm}^2\text{-h}$, T is temperature in degrees Kelvin (K) and P is water vapor pressure in kPa. Since the data was for unirradiated material containing little or no hydride, in contrast to the irradiated K Basin fuel that contains substantial hydride, the equations may not represent oxidation of K Basin fuel.

2.1 IN OXYGEN FREE WATER VAPOR

At $T \leq 568$ K,

$$\text{Log } k = 4.947 - 2375/T + 0.5 * \text{Log}(P) \text{ for } P \leq 101 \text{ kPa}$$

and

$$\text{Log } k = 3.945 - 2375/T + 1 * \text{Log}(P) \text{ for } P > 101 \text{ kPa.}$$

At $568 < T \leq 852$ K ,

$$\text{Log } k = 0.7655 + 0.5 * \text{Log}(P) \text{ for } P \leq 101 \text{ kPa}$$

and

$$\text{Log } k = -0.2366 + 1 * \text{Log}(P) \text{ for } P > 101 \text{ kPa}$$

At $T > 852$ K,

$$\text{Log } k = 3.454 - 2290/T + 0.5 * \text{Log}(P) \text{ for } P \leq 101 \text{ kPa}$$

and

$$\text{Log } k = 2.452 - 2290/T + 1 * \text{Log}(P) \text{ for } P > 101 \text{ kPa}$$

2.2 IN LIQUID WATER

$$\text{Log } k = 8.956 - 3516/T \text{ for } T \leq 573 \text{ K}$$

3.0 ASSUMPTIONS

Linear oxidation is assumed for all conditions according to the following equation:

$$W = k \times t \quad (3.1)$$

where:

W is weight gain per unit surface area, t is time, and k is the rate constant.

It is assumed that the initial oxidation of clean, unoxidized uranium surfaces exposed to water and oxygen free inert gas occurs in a linear manner. Linear oxidation is also assumed for oxidized surfaces that have developed from exposure to the oxidizing atmosphere as well as from long term water storage. Oxidation at all stages will therefore be linear and progress according to Equation (3.1), and the rate constant at a given temperature and vapor pressure will be the same for unoxidized as well as oxidized surfaces.

4.0 SOURCES OF INFORMATION

Data for oxidation of unirradiated uranium in oxygen free water vapor were extracted from the literature and are listed in Appendix A. Ritchie (1981) and Pearce (1989) reviewed current reaction rate data for uranium in various environments including oxygen free water vapor and provided rate law equations. Ritchie (1981) lists data from several sources (Besson and Santon 1963; Corcoran et al., 1965; Magnani 1974; Grimes and Morris 1965; Jackson and Condon 1977; Kondo et al., 1974; Kondo et al., 1964; Orman 1963, 1964; Waber 1958). Ritchie (1981) also provides data from previously unpublished sources (Baker et al., 1981; Orman 1962; Orman and Walker 1964). Pearce (1989) plots many of the data in Ritchie (1981) as well as data from additional sources (Baker 1964; Colmenares 1984; Hopkinson 1959; Huddle 1953; Pearce and Kay 1987; Ritchie 1984; Ritchie 1986; Scott 1959; Wathen 1943; Weirick 1984). In addition data were also extracted from other sources (Hayward 1994; Lemmon 1957; Troutner 1960).

Oxidation rate data for uranium in liquid water are listed in Appendix A. Reviews by Waber (1952) and McWhirter and Draley (1952) provided data by Benson et al. (1945), Draley and English (1945), Colbeck et al. (1945), Greninger et al. (1945), and Mollison et al. (1945). Other data were obtained from Baker et al. (1966), Orman (1963), Schroeder (1959), Troutner (1960), and Waber (1958).

5.0 REACTION RATES

The issue is the number of corrosion events that occur in a given time at a given temperature. This is the product of the reactive fuel surface area and the corresponding rate constant. In actual practice it may not be necessary to know each of these two parameters if measurements of reaction products such as hydrogen are conducted. However, for modeling calculations specific values for each of these parameters are necessary. The Project Technical Databook (Reilly 1998) provides fuel surface area values and reaction rate equations for applicable environments for use in design and safety evaluations. The reaction rate equations presented here are consistent with the terms defined and used in the Databook.

5.1 DEFINITION OF TERMS

The primary interest in estimating oxidation rates of K Basin fuel in an MCO originates with the need to define the rate of potential chemical reactions. These reactions are exothermic and can result in the net production of gaseous products. Therefore, the reaction rates become important factors for predicting thermal transients in an MCO and the potential for over pressurization.

The reaction of uranium metal fuel in an MCO with a number of different reactants will occur as an MCO is loaded at the basins, transferred, dried, staged, conditioned, and stored. The reactants of interest can vary with the

type of analysis under consideration (e.g., prediction of routine processing, analysis of accident conditions, etc.), however, the main reactants of interest include water, oxygen, and hydrogen. The general form of the relationship used to predict reaction rates is as follows.

$$R = A_s \times F_a \times k \quad (5.1)$$

where:

R = Uranium reaction rate, mg of weight gain/hour

A_s = Geometric surface area of uranium exposed to reactants, cm^2

F_a = Reactivity factor, to account for the true reacting surface sometimes called a roughness factor, dimension less

k = Reaction rate constant, $\text{mg of weight gain/h-cm}^2$

These terms are defined in more detail as follows.

Reaction Rate (R)--The reaction rate describes the mass of oxygen reacted per unit of time.

Geometric Surface Area (A_s)--The area of uranium exposed to reactants estimated by geometric dimensions assuming a smooth surface.

Reactivity Factor F_a --This enhancement factor accounts for the following: (1) the true reacting surface which can conceptually be thought of as the roughness of the actual uranium metal surface, increasing the smooth surface area associated with the geometric dimensions, (2) alloy inclusions including hydride, and (3) characteristics of the native oxide present on the reacting surface.

Reaction Rate Constant (k)--The reaction rate constant is an exponential function of water vapor pressure and inverse absolute temperature (Arrhenius relationship).

Reaction rate data are typically generated in the laboratory under controlled conditions and, for solid/gas or solid/liquid reactions, reported as a function of reactant concentration, temperature, and surface area. Placing the reaction rate data on a unit surface area basis allows use of the laboratory data for a variety of different configurations that may be encountered in practice. Specimens used to obtain laboratory data have some undefined degree of surface roughness which is ignored in this document. Laboratory observations typically focus on determining the reaction rate dependence on temperature and reactant concentration.

5.2 OXIDATION OF URANIUM IN WATER AND OXYGEN FREE WATER VAPOR

The reaction of uranium with water and water vapor is

with $x < 0.25$ at temperatures up to about 250 °C (Colmenares 1984; Baker et al., 1966; Pearce 1989). There is some evidence that U_3O_8 becomes increasingly important at temperatures in excess of roughly 300 °C. Other species such as hydroxides, hydrated oxides and UH_3 are probably also involved at various temperatures. The release of non-stoichiometric hydrogen has been observed indicating the formation of uranium hydride as an intermediate in a sequence of reactions

(Baker et al., 1966).

The reaction kinetics are generally observed to be essentially linear below about 800 °C (Colmenares 1984; Pearce 1989; Ritchie 1981). Above 800 °C rates that decrease with time have been usually observed during initial testing (Pearce 1989). The linear rates that are reported and used in this work were either final rates after about one to two hours of exposure or were the average rates at the end of the test assuming linear kinetics.

5.3 WATER VAPOR DATA AND ANALYSIS

The data base for oxidation in oxygen free water vapor is a collection of linear rate data for unirradiated uranium from a number of authors. These data are tabulated in Appendix A.

5.3.1 Vapor Pressure Dependence

The dependence of reaction rate constant (k) on water vapor pressure (P) has been studied by several investigators (Colmenares, 1984; Ritchie, 1983, 1986; Pearce and Kay, 1987). The dependency is generally agreed to be approximately equal to the square root of the pressure such that at constant temperature

$$\frac{k_1}{k_2} = \left(\frac{P_1}{P_2} \right)^{0.5}$$

Assuming this dependency holds over a large range of temperature the literature data were normalized for pressure by dividing the rate by $P^{0.5}$ and are shown on an Arrhenius plot (Figure 1). This plot shows data breaks at two temperatures (about 300 °C and 600 °C), and three groups of data appear

Figure 1. Literature Oxidation Rate Data for Uranium in Oxygen Free Water Vapor. (Data is normalized to 1 kPa water vapor pressure.)

exceptional when compared to the remaining data within the bounds of the temperature breaks. At 300 °C to 600 °C the data at pressure greater than 101 kPa (Troutner 1960) lie significantly above the data in this range. Above 600 °C a subset of data by Hopkinson (1959) lie below the remaining data and the data at 343 kPa (Lemmon 1957) are in the lower region of the data, excluding the noted Hopkinson data.

Multiple linear regression analyses were performed for the data in each of the three temperature regions. Inverse temperature (K^{-1}) and log (pressure, kPa) were the independent variables and log(rate, mg/cm²-h) was the dependent variable in the analyses of the temperature-pressure model

$$\log(k) = a + b/T + n * \log(P)$$

The results of these regressions are given in Table 1.

The regression results for the data at $T < 300$ °C gave a pressure dependence coefficient of 0.469 ± 0.046 which is in good agreement with the literature value of 0.5. The pressure in this temperature range varied from less than 0.01 kPa to 101 kPa plus one datum at 1377 kPa. When the regression was performed excluding the 1377 kPa datum, the results were essentially unchanged.

Pressure dependence was also evaluated at constant temperatures of 40 °C, 70 °C, 100 °C and 150 °C. A plot of these data and the linear regressions of log k versus log P are shown on Figure 2a. The pressure dependency coefficient, n, ranged from 0.44 to 0.81. The 0.81 value was from the data set (40 °C) having the least pressure range (1.2 kPa to 7.3 kPa) and having the lowest correlation coefficient (R^2). The regression statistics on the 40 °C data allow for a possible value of $n = 0.5$.

The data in the temperature range 300 °C to 600 °C includes vapor pressures at primarily 101 kPa pressure with a few points in the range of 1377 kPa to 13770 kPa. Regression analysis gave a coefficient of 1.00 for pressure dependence and a small, positive and not highly significant coefficient for reciprocal temperature ($1/T$) dependence. When no temperature dependence ($b = 0$) was assumed regression analysis again yielded a pressure dependency coefficient of $1.00 (0.997 \pm 0.13)$ with an R^2 of 0.79 (Figure 2b). The line for $n = 0.5$, also on Figure 2b, falls well below the high pressure data but approaches the datum for $P < 100$ kPa. Insufficient data was available to determine pressure dependence at pressure less than 101 kPa. An assumption of $n = 0.5$ at $P < 101$ kPa provides higher rate values than $n = 1$ and would, therefore, be conservative and is consistent with the lower temperature results.

At temperature greater than 600 °C the data includes two pressures: 101 kPa and 344 kPa. Regression analysis of these data indicates a negative pressure dependence with no statistical significance. The 344 kPa data (Lemmon 1957) were obtained from hydrogen evolution data and were converted to weight gain data assuming stoichiometric generation of hydrogen. Thus, there may be some uncertainty regarding these data. The literature gives no guidance here, so the following conservative assumptions were used to be consistent with the other temperature ranges: at $P \leq 101$ kPa, $n = 0.5$, and at $P > 101$ kPa, $n = 1.0$.

Table 1. Results from Linear Regressions of Literature Data for Oxidation of Uranium in Oxygen Free Water Vapor.¹

Temperature Range (°C)	N	R ²	std error ²	Intercept		X Coefficients				Comment
				a		b		n		
				Value	2 x std error ³	Value	2 x std error ³	Value	2 x std error ³	
T<299	242	0.958	0.238	5.110	0.290	-2423	96.1	0.469	0.046	
299<T<599	62	0.817	0.278	-1.232	0.658	699	396.5	1.00	0.123	
299<T<599	62	0.789	0.301	-0.227	0.152	0	NA	1.00	0.133	Assumes no temperature dependence
T>599	100	0.341	0.492	4.766	1.080	-2197	603.1	-0.30	0.408	All data including Lemmon and Hopkinson
T>599	100	0.340	0.495	4.073	0.499	-2130	599.4	0	NA	All data, no pressure dependence
T>599	90	0.607	0.310	4.260	0.315	-2200	377.0	0	NA	No pressure dependence, w/o Hopkinson 10 data
T>599	60	0.736	0.270	4.456	0.306	-2290	356.2	0	NA	No pressure dependence, w/o Hopkinson 10 data or Lemmon data

¹Regressions used the model $\log k = a + b/T + n \log P$
 where T = Temperature (K)
 P = Vapor Pressure (kPa).

²Standard error on the regression.

³Two times the standard error on the parameter.

NA = Not applicable.

Figure 2. Effect of Water Vapor Pressure on Oxidation of Uranium in Oxygen Free Water Vapor at (a) 40 °C to 150 °C and (b) at 300 °C to 600 °C.

A plot of the data (Figure 3) normalized to 1 atmosphere (101 kPa) vapor pressure using pressure dependency assumptions of $n = 0.5$ at $P \leq 101$ kPa and $n = 1.0$ at $P > 101$ kPa shows consistency of the data within the following three temperature regimes: $T < 295$ °C, 295 °C $< T < 579$ °C and $T > 579$ °C. Figure 3 includes the data by Troutner (1960), but it does not include the data by Lemmon (1957) nor the offending subset of data by Hopkinson (1959).

5.3.2 Temperature Dependence

Using the pressure dependency assumptions discussed above, coefficients for temperature dependence were derived from regression analysis of the reaction rate (k) data normalized to a pressure of 1 atmosphere (101 kPa) and using the model

$$\log k' = a + b/T$$

where $k' = k (101/P)^n$, k is weight gain in $\text{mg}/\text{cm}^2\text{-h}$, T is temperature in degrees Kelvin (K), P is water vapor pressure in kPa, $n = 0.5$ at $P \leq 101$ kPa and $n = 1.0$ at $P > 101$ kPa (Figure 3). The regressions were performed in each of the three temperature regimes indicated in Figure 3. The temperature limits for each equation were determined by the intercepts of the regression lines.

At $T \leq 568$ K (295 °C)

$$\log k = 5.949 - n * \log(101) - 2375/T + n * \log P \quad (5.3)$$

thus for $P \leq 101$ kPa

$$\log k = 4.947 - 2375/T + 0.5 * \log P \quad (5.4)$$

and for $P > 101$ kPa

$$\log k = 3.945 - 2375/T + 1.0 * \log P \quad (5.5)$$

At $T > 852$ K (579 °C)

$$\log k = 4.456 - n * \log(101) - 2290/T + n * \log P \quad (5.6)$$

thus for $P \leq 101$ kPa

$$\log k = 3.454 - 2290/T + 0.5 * \log P \quad (5.7)$$

and for $P > 101$ kPa

$$\log k = 2.452 - 2290/T + 1.0 * \log P \quad (5.8)$$

In the range 568 K $< T \leq 852$ K the rate constant data indicated no significant temperature dependence (as discussed in Section 5.4.1), and the average for $\log k'$ was used to derive the following equation:

$$\log k = 1.7677 - n * \log (101) + n * \log P \quad (5.9)$$

Figure 3. Reaction Rate Data for Uranium in Oxygen Free Water Vapor.
Data is normalized to 101 kPa.

for $P \leq 101$ kPa

$$\log k = 0.7655 + 0.5 * \log P \quad (5.10)$$

and for $P > 101$ kPa

$$\log k = -0.2366 + 1.0 * \log P \quad (5.11)$$

The lines for the above equation are shown on Figure 3 with the 95% confidence interval lines.

5.3.3 Irradiation and Water Storage Effects

A limited amount of oxidation data for irradiated uranium oxidized in oxygen free water vapor was available (Scott 1959). These data, listed in Appendix A and plotted in Figures 1 and 3, are for high temperature (730 °C to 1215 °C) and low irradiation (10^{14} nvt, less than 0.1 MWD/MTU). No effect of this level of irradiation on oxidation rate was measured (Figure 4). The irradiation exposure of the N Reactor fuel stored in the K Basins averages about 2500 MWD/MTU and ranges up to 5000 MWD/MTU. While tests in dry air did not indicate an effect of the N Reactor irradiation (Abrefah et al. 1998), testing of the K Basin fuel in water vapor would be prudent.

Figure 4. Effect of Low Irradiation (<0.1 MWD/MTU) on Oxidation of Uranium in Oxygen Free Water Vapor.

Water storage of exposed metallic fuel corrodes the uranium and can create uranium hydride particulate in the fuel matrix at and near the exposed surfaces. Such inclusions have been observed in K Basin fuel (Marschman, Pyecha, and Abrefah 1997). It has been proposed that these hydrides contributed to the measured increase in dry air reaction rate of the K Basin fuel compared to the literature data for unirradiated uranium (Abrefah et al. 1998).

Only one known data point exists for uranium hydride in water or water vapor, and it indicates that the rate of oxidation is less than for uranium metal (Baker et al. 1966). This however, is inadequate for making conclusions on the effect of hydride particulate on the reaction rate of K Basin fuel. Measurements are planned for K Basin fuel in oxygen free water vapor. When these data become available the Technical Databook (Reilly 1998) rate law equations and/or enhancement factors will be reevaluated.

5.4 WATER IMMERSION DATA AND ANALYSIS

Oxidation rate data for uranium in deaerated water at temperature up to 300 °C was found in several literature sources. They are listed in Appendix A and plotted on Figure 5a. The linear regression fit to the water immersion data is

$$\text{Log } k = 8.956 - 3516/T \quad (5.12)$$

Data by Waber (1958) do not fit with the remaining data and were not used in this correlation. Corrosion rates of uranium in water are inhibited by dissolved oxygen (Orman, 1963; Waber, 1952). This is illustrated (Figure 5a) by rate data for air saturated water. Hydrogen saturated water data indicate no effect relative to oxygen free water and were used with gas free, helium saturated, and nitrogen saturated water data to derive Equation (5.11).

Water vapor data at saturation pressures and the lines for Equations (5.4) and (5.5) at saturated water vapor are shown on Figure 5b. Data at 225 °C and 300 °C were adjusted to the saturation pressure according to the ratio of the saturation pressure, and the test pressure. Below 100 °C the water immersion data line falls on the line for saturated water vapor. Above 100 °C and one atmosphere vapor pressure the pressure dependency for water vapor increases and the slope of the saturated water vapor line increases.

Water corrosion rates for K Basin fuel were derived from hydrogen generation data collected from shipping container storage of the fuel in preparation for shipment to the 300 Area hot cells (Pajunen 1998). These data, plotted on Figure 5a, are in good agreement with the literature data.

The present Databook equation for liquid water is in good agreement with the equations of this document for water and water vapor (Figure 5b).

Figure 5. Oxidation of Uranium in (a) Liquid Water and (b) Saturated Water Vapor.

5.5 COMPARISON WITH LITERATURE EQUATIONS

Reaction rate constant equations for oxidation of uranium in liquid water and oxygen free water vapor in Revision 6 of the Technical Databook (Reilly 1998) were obtained from the literature (Ritchie 1981, Pearce 1989, Hayward 1994). These equations include the following:

for liquid water at temperature (T) <373 K

$$\text{Log } K = 7.634 - 3016/T$$

for water vapor at T < 523 K

$$\text{Log } K = 4.33 - 2144/T + 0.5\text{Log}(P)$$

for water vapor at 523 < T < 735 K and 43 kPa to 93 kPa

$$\text{Log } K = -22.915 + 30,066/T - 9,119,078/T^2$$

for water vapor at 735 < T < 923 K and 43 kPa to 93 kPa

$$\text{Log } K = -23.905 + 42,718/T - 17,875,810/T^2$$

where K is reaction rate constant in units of mg/cm²-h, T is temperature in degrees K and P is water vapor pressure in kPa.

The Databook equation for liquid water reaction rate constant is compared to the literature review data and data fit on Figure 5b.

The Databook equations for water vapor reaction rate constant are compared to the literature review data on Figure 6a. The equation for T < 523 K was evaluated at 43 kPa and at 93 kPa to be consistent with the range of pressures represented by the equations for T > 523 K. The literature review data on Figure 6a were normalized to a pressure of 70 kPa as follows: $k' = k(70/P)^{0.5}$. Also shown for reference on Figure 6a are the regression lines from the review data (Equations 5.3, 5.7, and 5.9) evaluated at 70 kPa.

Figure 6b shows the Databook and the review data equation lines (Equation 5.3) for 12 kPa water vapor, saturation at 50 °C. Also shown are the literature review data in the range of 7 kPa to 20 kPa.

6.0 CONCLUSIONS

The literature review data for uranium reaction rate constant in liquid water and oxygen free water vapor over a wide range of temperature and pressure can be represented by Equations 5.4, 5.5, 5.7, 5.9, 5.10, and 5.11. At temperature below about 200 °C these recommended equations are in good agreement with the literature equations in Revision 6 of the Technical Databook (Reilly 1998).

Figure 6. Comparison of Literature Equations Used in the Technical Databook, Literature Review Data, and the Line Fit to the Review Data.
(a) At high vapor pressures and (b) at low vapor pressure.

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APPENDIX A

DATA BASE FOR OXIDATION OF URANIUM IN WATER AND OXYGEN FREE WATER VAPOR

Table A1 contains the data for oxidation of uranium in oxygen free water vapor.

Table A2 contains the data for oxidation of uranium in liquid water.

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Table A1. Oxidation of Uranium in Oxygen Free Water Vapor.

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
65	338	0.00296	25.0	0.091	Baker et al. (1964)
80	353	0.00283	47.3	0.233	Baker et al. (1964)
100	373	0.00268	3.32	0.059	Baker et al. (1964)
100	373	0.00268	6.64	0.086	Baker et al. (1964)
100	373	0.00268	13.3	0.11	Baker et al. (1964)
100	373	0.00268	26.6	0.15	Baker et al. (1964)
100	373	0.00268	53.2	0.2	Baker et al. (1964)
100	373	0.00268	80	0.349	Baker et al. (1964)
100	373	0.00268	93	0.341	Baker et al. (1964)
100	373	0.00268	101	0.638	Baker et al. (1964)
80	353	0.00283	47.2	0.12773	Baker et al. (1965)
100	373	0.00268	0.61	0.01345	Besson and Santon (1963)
62	335	0.00299	7.97	0.024	Colmenares (1984)
80	353	0.00283	7.97	0.045	Colmenares (1984)
100	373	0.00268	0.0065	0.0055	Colmenares (1984)
100	373	0.00268	0.012	0.007	Colmenares (1984)
100	373	0.00268	0.07	0.0075	Colmenares (1984)
100	373	0.00268	0.30	0.03	Colmenares (1984)
100	373	0.00268	1.50	0.055	Colmenares (1984)
100	373	0.00268	3.00	0.085	Colmenares (1984)
100	373	0.00268	5.00	0.12	Colmenares (1984)
100	373	0.00268	8.5	0.14	Colmenares (1984)
100	373	0.00268	8.5	0.16	Colmenares (1984)
100	373	0.00268	13.3	0.167	Colmenares (1984)
100	373	0.00268	13.3	0.217	Colmenares (1984)
100	373	0.00268	13.3	0.225	Colmenares (1984)
100	373	0.00268	13.3	0.23	Colmenares (1984)
100	373	0.00268	13.3	0.24	Colmenares (1984)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
25	298	0.00336	4.52	0.00323	Corcoran et al. (1965)
40	313	0.00319	3.19	0.00578	Corcoran et al. (1965)
40	313	0.00319	2.33	0.00457	Grimes and Morris (1965)
199	472	0.00212	101	3.42	Hayward et al. (1994)
199	472	0.00212	101	4.87	Hayward et al. (1994)
200	473	0.00211	101	4.96	Hayward et al. (1994)
201	474	0.00211	101	2.99	Hayward et al. (1994)
201	474	0.00211	101	3.07	Hayward et al. (1994)
201	474	0.00211	101	3.23	Hayward et al. (1994)
250	523	0.00191	101	20.3	Hayward et al. (1994)
250	523	0.00191	101	23.8	Hayward et al. (1994)
252	525	0.0019	101	10.1	Hayward et al. (1994)
252	525	0.0019	101	10.7	Hayward et al. (1994)
285	558	0.00179	101	38.2	Hayward et al. (1994)
285	558	0.00179	101	42.0	Hayward et al. (1994)
301	574	0.00174	101	32.2	Hayward et al. (1994)
301	574	0.00174	101	64.5	Hayward et al. (1994)
301	574	0.00174	101	70.7	Hayward et al. (1994)
302	575	0.00174	101	30.3	Hayward et al. (1994)
325	598	0.00167	101	64.6	Hayward et al. (1994)
327	600	0.00167	101	59.9	Hayward et al. (1994)
349	622	0.00161	101	87.1	Hayward et al. (1994)
350	623	0.00161	101	78.9	Hayward et al. (1994)
351	624	0.00160	101	63.0	Hayward et al. (1994)
352	625	0.00160	101	50.4	Hayward et al. (1994)
352	625	0.00160	101	59.9	Hayward et al. (1994)
353	626	0.00160	101	55.5	Hayward et al. (1994)
400	673	0.00149	101	43.4	Hayward et al. (1994)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
400	673	0.00149	101	54.5	Hayward et al. (1994)
400	673	0.00149	101	65.4	Hayward et al. (1994)
447	720	0.00139	101	32.5	Hayward et al. (1994)
450	723	0.00138	101	25.7	Hayward et al. (1994)
451	724	0.00138	101	9.28	Hayward et al. (1994)
451	724	0.00138	101	16.9	Hayward et al. (1994)
499	772	0.0013	101	6.92	Hayward et al. (1994)
500	773	0.00129	101	8.42	Hayward et al. (1994)
501	774	0.00129	101	24.5	Hayward et al. (1994)
501	774	0.00129	101	27.1	Hayward et al. (1994)
502	775	0.00129	101	36.8	Hayward et al. (1994)
552	825	0.00121	101	49.0	Hayward et al. (1994)
600	873	0.00115	101	29.7	Hayward et al. (1994)
602	875	0.00114	101	57.8	Hayward et al. (1994)
603	876	0.00114	101	31.7	Hayward et al. (1994)
650	923	0.00108	101	29.7	Hayward et al. (1994)
160	433	0.00231	101	1.20	Hopkinson (1959)
200	473	0.00211	101	4.80	Hopkinson (1959)
200	473	0.00211	101	6.00	Hopkinson (1959)
200	473	0.00211	101	6.00	Hopkinson (1959)
230	503	0.00199	101	18	Hopkinson (1959)
230	503	0.00199	101	18	Hopkinson (1959)
230	503	0.00199	101	96	Hopkinson (1959)
250	523	0.00191	101	54	Hopkinson (1959)
250	523	0.00191	101	96	Hopkinson (1959)
250	523	0.00191	101	96	Hopkinson (1959)
270	543	0.00184	101	102	Hopkinson (1959)
270	543	0.00184	101	114	Hopkinson (1959)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
270	543	0.00184	101	114	Hopkinson (1959)
300	573	0.00175	101	120	Hopkinson (1959)
300	573	0.00175	101	144	Hopkinson (1959)
300	573	0.00175	101	162	Hopkinson (1959)
330	603	0.00166	101	126	Hopkinson (1959)
350	623	0.00161	101	96	Hopkinson (1959)
370	643	0.00156	101	114	Hopkinson (1959)
380	653	0.00153	101	96	Hopkinson (1959)
400	673	0.00149	101	108	Hopkinson (1959)
420	693	0.00144	101	72	Hopkinson (1959)
420	693	0.00144	101	84	Hopkinson (1959)
420	693	0.00144	101	108	Hopkinson (1959)
450	723	0.00138	101	66	Hopkinson (1959)
450	723	0.00138	101	102	Hopkinson (1959)
500	773	0.00129	101	54	Hopkinson (1959)
500	773	0.00129	101	60	Hopkinson (1959)
500	773	0.00129	101	78	Hopkinson (1959)
520	793	0.00126	101	36	Hopkinson (1959)
520	793	0.00126	101	60	Hopkinson (1959)
550	823	0.00122	101	42	Hopkinson (1959)
550	823	0.00122	101	48	Hopkinson (1959)
550	823	0.00122	101	60	Hopkinson (1959)
550	823	0.00122	101	66	Hopkinson (1959)
600	873	0.00115	101	78	Hopkinson (1959)
600	873	0.00115	101	90	Hopkinson (1959)
600	873	0.00115	101	102	Hopkinson (1959)
650	923	0.00108	101	84	Hopkinson (1959)
650	923	0.00108	101	90	Hopkinson (1959)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
700	973	0.00103	101	78	Hopkinson (1959)
700	973	0.00103	101	360	Hopkinson (1959)
730	1003	0.00100	101	360	Hopkinson (1959)
780	1053	0.00095	101	240	Hopkinson (1959)
820	1093	0.00091	101	180	Hopkinson (1959)
840	1113	0.0009	101	180	Hopkinson (1959)
880	1153	0.00087	101	12	Hopkinson (1959)
890	1163	0.00086	101	18	Hopkinson (1959)
930	1203	0.00083	101	18	Hopkinson (1959)
970	1243	0.00080	101	12	Hopkinson (1959)
970	1243	0.00080	101	18	Hopkinson (1959)
1000	1273	0.00079	101	12	Hopkinson (1959)
1000	1273	0.00079	101	18	Hopkinson (1959)
1020	1293	0.00077	101	12	Hopkinson (1959)
1020	1293	0.00077	101	18	Hopkinson (1959)
1060	1333	0.00075	101	18	Hopkinson (1959)
1200	1473	0.00068	101	228	Hopkinson (1959)
1400	1673	0.00060	101	288	Hopkinson (1959)
200	473	0.00211	101	14.0	Huddle (1953)
250	523	0.00191	101	79.8	Huddle (1953)
300	573	0.00175	101	70.2	Huddle (1953)
350	623	0.00161	101	119	Huddle (1953)
400	673	0.00149	101	106	Huddle (1953)
450	723	0.00138	101	68.1	Huddle (1953)
500	773	0.00129	101	68.1	Huddle (1953)
600	873	0.00115	101	59.6	Huddle (1953)
100	373	0.00268	1.59	0.176	Jackson and Condon (1977)
100	373	0.00268	2.86	0.211	Jackson and Condon (1977)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
150	423	0.00236	0.40	0.0779	Jackson and Condon (1977)
150	423	0.00236	1.59	0.325	Jackson and Condon (1977)
150	423	0.00236	2.86	0.406	Jackson and Condon (1977)
75	348	0.00287	4.39	0.0226	Kondo (1964)
75	348	0.00287	5.32	0.0175	Kondo (1964)
75	348	0.00287	7.97	0.0255	Kondo (1964)
75	348	0.00287	10.63	0.0350	Kondo (1964)
75	348	0.00287	13.29	0.0430	Kondo (1964)
80	353	0.00283	0.40	0.0336	Kondo (1964)
80	353	0.00283	1.59	0.0740	Kondo (1964)
80	353	0.00283	2.86	0.0928	Kondo (1964)
98	371	0.0027	0.40	0.0484	Kondo (1964)
60	333	0.00300	11.03	0.0207	Kondo (1974)
800	1073	0.00093	344	29.0	Lemmon (1957)
800	1073	0.00093	344	41.8	Lemmon (1957)
800	1073	0.00093	344	57.8	Lemmon (1957)
800	1073	0.00093	344	78.0	Lemmon (1957)
800	1073	0.00093	344	98.6	Lemmon (1957)
800	1073	0.00093	344	101	Lemmon (1957)
900	1173	0.00085	344	71	Lemmon (1957)
900	1173	0.00085	344	98	Lemmon (1957)
900	1173	0.00085	344	137	Lemmon (1957)
900	1173	0.00085	344	214	Lemmon (1957)
900	1173	0.00085	344	287	Lemmon (1957)
900	1173	0.00085	344	411	Lemmon (1957)
1000	1273	0.00079	344	68	Lemmon (1957)
1000	1273	0.00079	344	101	Lemmon (1957)
1000	1273	0.00079	344	146	Lemmon (1957)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
1000	1273	0.00079	344	238	Lemmon (1957)
1000	1273	0.00079	344	347	Lemmon (1957)
1125	1398	0.00072	344	398	Lemmon (1957)
1125	1398	0.00072	344	488	Lemmon (1957)
1125	1398	0.00072	344	514	Lemmon (1957)
1230	1503	0.00067	344	283	Lemmon (1957)
1230	1503	0.00067	344	386	Lemmon (1957)
1230	1503	0.00067	344	471	Lemmon (1957)
1230	1503	0.00067	344	535	Lemmon (1957)
1230	1503	0.00067	344	535	Lemmon (1957)
1280	1553	0.00064	344	246	Lemmon (1957)
1280	1553	0.00064	344	343	Lemmon (1957)
1280	1553	0.00064	344	394	Lemmon (1957)
1280	1553	0.00064	344	579	Lemmon (1957)
1280	1553	0.00064	344	600	Lemmon (1957)
75	348	0.00287	38.41	0.0114	Magnani (1974)
35	308	0.00325	5.58	0.00807	Orman (1963)
50	323	0.00310	12.36	0.0282	Orman (1963)
65	338	0.00296	24.98	0.0914	Orman (1963)
70	343	0.00292	31.06	0.0417	Orman (1963)
70	343	0.00292	31.06	0.0457	Orman (1963)
80	353	0.00283	47	0.234	Orman (1963)
100	373	0.00268	101	0.639	Orman (1963)
100	373	0.00268	0.94	0.0229	Orman (1964)
100	373	0.00268	1.30	0.0578	Orman (1964)
100	373	0.00268	2.22	0.0659	Orman (1964)
100	373	0.00268	2.78	0.0645	Orman (1964)
100	373	0.00268	3.16	0.0981	Orman (1964)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
100	373	0.00268	23	0.234	Orman (1964)
100	373	0.00268	42	0.269	Orman (1964)
100	373	0.00268	50.9	0.211	Orman (1964)
100	373	0.00268	57	0.308	Orman (1964)
100	373	0.00268	66	0.352	Orman (1964)
100	373	0.00268	70	0.468	Orman (1964)
100	373	0.00268	74	0.427	Orman (1964)
100	373	0.00268	81	0.462	Orman (1964)
100	373	0.00268	87	0.505	Orman (1964)
100	373	0.00268	92	0.432	Orman (1964)
100	373	0.00268	98	0.531	Orman (1964)
100	373	0.00268	99	0.578	Orman (1964)
100	373	0.00268	100	0.583	Orman (1964)
100	373	0.00268	100	0.562	Orman (1964)
100	373	0.00268	101	0.639	Orman (1964)
20	293	0.00341	2.39	0.00242	Orman and Walker (1964)
22	295	0.00339	2.66	0.00215	Orman and Walker (1964)
22	295	0.00339	2.66	0.00403	Orman and Walker (1964)
40	313	0.00319	7.31	0.00605	Orman and Walker (1964)
40	313	0.00319	7.31	0.0121	Orman and Walker (1964)
50	323	0.0031	12.36	0.0134	Orman and Walker (1964)
50	323	0.0031	12.36	0.0148	Orman and Walker (1964)
60	333	0.00300	19.80	0.0242	Orman and Walker (1964)
70	343	0.00292	31.10	0.0417	Orman and Walker (1964)
70	343	0.00292	31.10	0.0417	Orman and Walker (1964)
74	347	0.00288	36.81	0.0511	Orman and Walker (1964)
74	347	0.00288	36.81	0.0511	Orman and Walker (1964)
105	378	0.00265	20.80	0.015	Pearce and Kay (1987)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
105	378	0.00265	79	0.238	Pearce and Kay (1987)
105	378	0.00265	100	0.40	Pearce and Kay (1987)
150	423	0.00236	5.10	0.28	Pearce and Kay (1987)
150	423	0.00236	21	0.44	Pearce and Kay (1987)
150	423	0.00236	21	0.51	Pearce and Kay (1987)
150	423	0.00236	49	0.72	Pearce and Kay (1987)
150	423	0.00236	49	0.75	Pearce and Kay (1987)
150	423	0.00236	49	0.77	Pearce and Kay (1987)
150	423	0.00236	79	1.26	Pearce and Kay (1987)
180	453	0.00221	49	1.82	Pearce and Kay (1987)
180	453	0.00221	49	1.87	Pearce and Kay (1987)
180	453	0.00221	79	1.90	Pearce and Kay (1987)
200	473	0.00211	21	2.13	Pearce and Kay (1987)
200	473	0.00211	49	3.00	Pearce and Kay (1987)
200	473	0.00211	79	5.05	Pearce and Kay (1987)
200	473	0.00211	100	5.85	Pearce and Kay (1987)
240	513	0.00195	49	17.1	Pearce and Kay (1987)
250	523	0.00191	49	17.0	Pearce and Kay (1987)
250	523	0.00191	49	19.5	Pearce and Kay (1987)
250	523	0.00191	79	33.7	Pearce and Kay (1987)
325	598	0.00167	49	52.4	Pearce and Kay (1987)
34.2	307.2	0.00326	2.67	0.00309	Ritchie (1984)
40	313	0.00319	2.67	0.00417	Ritchie (1984)
50	323	0.00310	2.67	0.00605	Ritchie (1984)
50	323	0.00310	2.67	0.00672	Ritchie (1984)
60	333	0.00300	2.67	0.0103	Ritchie (1984)
60	333	0.00300	2.67	0.0105	Ritchie (1984)
70	343	0.00292	2.67	0.0138	Ritchie (1984)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
70	343	0.00292	2.67	0.0165	Ritchie (1984)
80	353	0.00283	2.67	0.0206	Ritchie (1984)
80	353	0.00283	2.67	0.0208	Ritchie (1984)
30	303	0.00330	3.19	0.00296	Ritchie (1986)
30.1	303.1	0.00330	1.22	0.00134	Ritchie (1986)
30.1	303.1	0.00330	2.29	0.00242	Ritchie (1986)
40	313	0.00319	1.21	0.00148	Ritchie (1986)
40	313	0.00319	1.31	0.00175	Ritchie (1986)
40	313	0.00319	2.84	0.00417	Ritchie (1986)
40	313	0.00319	4.24	0.00417	Ritchie (1986)
40	313	0.00319	4.24	0.0043	Ritchie (1986)
40	313	0.00319	4.24	0.00457	Ritchie (1986)
40	313	0.00319	5.53	0.00497	Ritchie (1986)
49.5	322.5	0.00310	1.22	0.00444	Ritchie (1986)
49.9	322.9	0.00310	7.65	0.0116	Ritchie (1986)
50	323	0.00310	7.37	0.00998	Ritchie (1986)
50	323	0.00310	9.38	0.00874	Ritchie (1986)
50.1	323.1	0.00310	1.23	0.00471	Ritchie (1986)
50.1	323.1	0.00310	4.34	0.00789	Ritchie (1986)
50.3	323.3	0.00309	4.32	0.00554	Ritchie (1986)
50.9	323.9	0.00309	4.47	0.00801	Ritchie (1986)
59.9	332.9	0.00300	7.65	0.0133	Ritchie (1986)
59.9	332.9	0.00300	12.61	0.0175	Ritchie (1986)
60	333	0.00300	1.25	0.0103	Ritchie (1986)
60	333	0.00300	3.19	0.00859	Ritchie (1986)
60	333	0.00300	7.45	0.0105	Ritchie (1986)
60	333	0.00300	9.64	0.0149	Ritchie (1986)
60	333	0.00300	12.33	0.0331	Ritchie (1986)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
60.1	333.1	0.00300	2.40	0.00856	Ritchie (1986)
60.5	333.5	0.00300	12.47	0.0276	Ritchie (1986)
60.9	333.9	0.00299	4.24	0.0110	Ritchie (1986)
61.9	334.9	0.00299	15.52	0.0215	Ritchie (1986)
69.4	342.4	0.00292	12.02	0.0250	Ritchie (1986)
70	343	0.00292	7.79	0.0242	Ritchie (1986)
70	343	0.00292	12.34	0.0332	Ritchie (1986)
70.1	343.1	0.00291	1.25	0.0125	Ritchie (1986)
70.1	343.1	0.00291	2.35	0.0175	Ritchie (1986)
70.1	343.1	0.00291	2.38	0.0168	Ritchie (1986)
70.1	343.1	0.00291	2.50	0.0149	Ritchie (1986)
70.1	343.1	0.00291	4.26	0.0164	Ritchie (1986)
70.1	343.1	0.00291	4.32	0.0194	Ritchie (1986)
70.1	343.1	0.00291	5.66	0.0208	Ritchie (1986)
70.1	343.1	0.00291	5.76	0.0222	Ritchie (1986)
70.1	343.1	0.00291	5.76	0.0290	Ritchie (1986)
70.1	343.1	0.00291	7.45	0.0185	Ritchie (1986)
70.1	343.1	0.00291	7.51	0.0263	Ritchie (1986)
70.1	343.1	0.00291	7.51	0.0277	Ritchie (1986)
70.1	343.1	0.00291	9.67	0.0305	Ritchie (1986)
70.1	343.1	0.00291	9.79	0.0263	Ritchie (1986)
70.1	343.1	0.00291	12.45	0.0471	Ritchie (1986)
70.1	343.1	0.00291	12.52	0.0372	Ritchie (1986)
70.1	343.1	0.00291	15.96	0.0332	Ritchie (1986)
70.1	343.1	0.00291	19.93	0.0471	Ritchie (1986)
70.1	343.1	0.00291	20.37	0.0389	Ritchie (1986)
70.6	343.6	0.00291	20.45	0.0554	Ritchie (1986)
70.9	343.9	0.00291	6.30	0.0175	Ritchie (1986)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
71.2	344.2	0.00291	12.76	0.0288	Ritchie (1986)
71.4	344.4	0.00290	24.02	0.0375	Ritchie (1986)
80	353	0.00283	4.26	0.0239	Ritchie (1986)
80	353	0.00283	8.10	0.0376	Ritchie (1986)
80	353	0.00283	12.36	0.0512	Ritchie (1986)
80	353	0.00283	19.93	0.0566	Ritchie (1986)
80	353	0.00283	19.93	0.0590	Ritchie (1986)
80	353	0.00283	35.41	0.0699	Ritchie (1986)
80.1	353.1	0.00283	20.10	0.0721	Ritchie (1986)
80.2	353.2	0.00283	20.38	0.0514	Ritchie (1986)
80.2	353.2	0.00283	31.83	0.1026	Ritchie (1986)
80.3	353.3	0.00283	4.36	0.0324	Ritchie (1986)
80.4	353.4	0.00283	1.25	0.0167	Ritchie (1986)
80.4	353.4	0.00283	1.40	0.0211	Ritchie (1986)
80.4	353.4	0.00283	2.50	0.0222	Ritchie (1986)
80.5	353.5	0.00283	2.41	0.0263	Ritchie (1986)
80.5	353.5	0.00283	4.24	0.0327	Ritchie (1986)
80.5	353.5	0.00283	7.36	0.0374	Ritchie (1986)
80.5	353.5	0.00283	12.56	0.0485	Ritchie (1986)
80.5	353.5	0.00283	19.83	0.0737	Ritchie (1986)
80.5	353.5	0.00283	31.38	0.0969	Ritchie (1986)
80.6	353.6	0.00283	7.42	0.0394	Ritchie (1986)
81.2	354.2	0.00282	12.27	0.0504	Ritchie (1986)
81.4	354.4	0.00282	19.68	0.0655	Ritchie (1986)
620	893	0.00112	101	56.2	Scott (1959)
620	893	0.00112	101	93.4	Scott (1959)
620	893	0.00112	101	102	Scott (1959)
730	1003	0.00100	101	138	Scott (1959)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
730	1003	0.00100	101	210	Scott (1959)
730	1003	0.00100	101	211	Scott (1959)
730	1003	0.00100	101	347	Scott (1959)
780	1053	0.00095	101	236	Scott (1959)
780	1053	0.00095	101	455	Scott (1959)
990	1263	0.00079	101	271	Scott (1959)
990	1263	0.00079	101	346	Scott (1959)
990	1263	0.00079	101	465	Scott (1959)
990	1263	0.00079	101	508	Scott (1959)
1100	1373	0.00073	101	196	Scott (1959)
1100	1373	0.00073	101	299	Scott (1959)
1100	1373	0.00073	101	326	Scott (1959)
1100	1373	0.00073	101	380	Scott (1959)
1100	1373	0.00073	101	393	Scott (1959)
1100	1373	0.00073	101	402	Scott (1959)
1100	1373	0.00073	101	475	Scott (1959)
1100	1373	0.00073	101	780	Scott (1959)
1100	1373	0.00073	101	1068	Scott (1959)
1215	1488	0.00067	101	463	Scott (1959)
1215	1488	0.00067	101	480	Scott (1959)
1215	1488	0.00067	101	556	Scott (1959)
1215	1488	0.00067	101	780	Scott (1959)
1215	1488	0.00067	101	833	Scott (1959)
1215	1488	0.00067	101	929	Scott (1959)
1215	1488	0.00067	101	1203	Scott (1959)
1215	1488	0.00067	101	1214	Scott (1959)
1215	1488	0.00067	101	1254	Scott (1959)
1215	1488	0.00067	101	1532	Scott (1959)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
1215	1488	0.00067	101	1604	Scott (1959)
1215	1488	0.00067	101	2340	Scott (1959)
1215	1488	0.00067	101	2412	Scott (1959)
1215	1488	0.00067	101	4356	Scott (1959)
1440	1713	0.00058	101	895	Scott (1959)
1440	1713	0.00058	101	985	Scott (1959)
1440	1713	0.00058	101	1179	Scott (1959)
1440	1713	0.00058	101	1500	Scott (1959)
1440	1713	0.00058	101	2183	Scott (1959)
1440	1713	0.00058	101	2273	Scott (1959)
225	498	0.00201	1377	491	Troutner (1960)
300	573	0.00175	1377	1400	Troutner (1960)
300	573	0.00175	6884	2545	Troutner (1960)
400	673	0.00149	1377	2727	Troutner (1960)
400	673	0.00149	6884	4000	Troutner (1960)
400	673	0.00149	13769	6000	Troutner (1960)
500	773	0.00129	1377	2182	Troutner (1960)
500	773	0.00129	6884	2909	Troutner (1960)
500	773	0.00129	13769	4909	Troutner (1960)
57	330	0.00303	1.73	0.00592	Waber (1958)
75	348	0.00287	19.27	0.02017	Waber (1958)
150	423	0.00236	101	2.16	Wathen (1943)
200	473	0.00211	101	16.0	Wathen (1943)
250	523	0.00191	101	161	Wathen (1943)
300	573	0.00175	101	193	Wathen (1943)
100	373	0.00268	0.27	0.022	Weirick (1984)
100	373	0.00268	0.27	0.0225	Weirick (1984)
100	373	0.00268	0.27	0.023	Weirick (1984)

Table A1. Oxidation of Uranium in Oxygen Free Water Vapor. (Continued)

Temperature			Water Vapor Pressure (kPa)	Oxidation Rate (mg/cm ² -h)	Reference
(°C)	(K)	(K ⁻¹)			
100	373	0.00268	0.50	0.029	Weirick (1984)
100	373	0.00268	0.67	0.034	Weirick (1984)
100	373	0.00268	0.67	0.035	Weirick (1984)
100	373	0.00268	0.67	0.042	Weirick (1984)
100	373	0.00268	1.33	0.048	Weirick (1984)
100	373	0.00268	1.33	0.050	Weirick (1984)
100	373	0.00268	2.00	0.056	Weirick (1984)

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Table A2. Oxidation of Uranium in Liquid Water.

Temperature			Oxidation Rate		Reference
(C)	(K)	(K ⁻¹)	mg/cm ² -h	Comment	
35	308	3.25e-03	7.68e-03	Degassed water(4)	Baker et al. (1966)
50	323	3.10e-03	2.55e-02	Degassed water(4)	Baker et al. (1966)
65	338	2.96e-03	8.95e-02	Degassed water(4)	Baker et al. (1966)
80	353	2.83e-03	2.19e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	4.91e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	5.38e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	5.65e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	5.71e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	5.58e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	5.85e-01	Degassed water(4)	Baker et al. (1966)
100	373	2.68e-03	5.65e-01	Degassed water(4)	Baker et al. (1966)
183	456	2.19e-03	1.87e+01	Hydrogen saturated water(4)	Bensen et al. (1945)*
226	499	2.00e-03	9.55e+01	Hydrogen saturated water(4)	Bensen et al. (1945)*
100	373	2.68e-03	1.21e-01	Hydrogen saturated water(4)	Colbeck et al. (1945)*
50	323	3.10e-03	2.42e-04	Air saturated water(4)	Draley and English (1945)**
60	333	3.00e-03	9.55e-04	Air saturated water(4)	Draley and English (1945)**
70	343	2.92e-03	1.83e-03	Air saturated water(4)	Draley and English (1945)**
80	353	2.83e-03	7.73e-02	Air saturated water(4)	Draley and English (1945)**
90	363	2.75e-03	6.74e-02	Air saturated water(4)	Draley and English (1945)**
50	323	3.10e-03	8.90e-03	Hydrogen saturated water(4)	Draley and English (1945)**
70	343	2.92e-03	6.23e-02	Hydrogen saturated water(4)	Draley and English (1945)**
90	363	2.75e-03	1.36e-01	Hydrogen saturated water(4)	Draley and English (1945)**
100	373	2.68e-03	1.05e-01	Distilled water(4,6)	Greninger et al. (1945)*
100	373	2.68e-03	1.56e-01	Distilled water(4,6)	Greninger et al. (1945)*
100	373	2.68e-03	1.04e-01	Distilled water(4,6)	Greninger et al. (1945)*
70	343	2.92e-03	2.82e-02	Helium sat. water(4)	Mollison et al.(1945)*
50	323	3.10e-03	8.34e-03	Hydrogen saturated water(4)	Mollison et al.(1945)*

Table A2. Oxidation of Uranium in Liquid Water. (Continued)

Temperature			Oxidation Rate		Reference
(C)	(K)	(K ⁻¹)	mg/cm ² -h	Comment	
70	343	2.92e-03	4.71e-02	Hydrogen saturated water(4)	Mollison et al.(1945)*
90	363	2.75e-03	1.61e-01	Hydrogen saturated water(4)	Mollison et al.(1945)*
100	373	2.68e-03	3.63e-01	Hydrogen saturated water(4)	Mollison et al.(1945)*
70	343	2.92e-03	3.36e-02	Nitrogen sat. water(4)	Mollison et al.(1945)*
100	373	2.68e-03	3.63e-01	Distilled water(4,5)	Mollison et al.(1945)*
100	373	2.68e-03	1.48e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	2.08e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	2.74e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	2.42e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	2.92e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	1.57e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	1.26e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	1.48e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	2.26e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	2.86e-01	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	8.87e-02	Distilled water(4,6)	Mollison et al.(1945)*
100	373	2.68e-03	3.28e-01	Distilled water(4,6)	Mollison et al.(1945)*
35	308	3.25e-03	9.55e-03	Gas-free water(4)	Orman(1963)
65	338	2.96e-03	8.47e-02	Gas-free water(4)	Orman(1963)
80	353	2.83e-03	2.35e-01	Gas-free water(4)	Orman(1963)
21	294	3.40e-03	8.00e-03	K West Basin water***	Pajunen(1998)
21	294	3.40e-03	1.20e-03	K West Basin water***	Pajunen(1998)
21	294	3.40e-03	1.00e-03	K West Basin water***	Pajunen(1998)
21	294	3.40e-03	1.30e-02	K West Basin water***	Pajunen(1998)
100	373	2.68e-03	3.94e-01	Boiled, deionized water(4)	Schroeder(1959)
100	373	2.68e-03	4.09e-01	Boiled, deionized water(4)	Schroeder(1959)
100	373	2.68e-03	4.38e-01	Boiled, deionized water(4)	Schroeder(1959)

Table A2. Oxidation of Uranium in Liquid Water. (Continued)

Temperature			Oxidation Rate		Reference
(C)	(K)	(K ⁻¹)	mg/cm ² -h	Comment	
100	373	2.68e-03	3.74e-01	Boiled, deionized water(4)	Schroeder(1959)
100	373	2.68e-03	4.41e-01	Boiled, deionized water(4)	Schroeder(1959)
200	473	2.11e-03	3.54e+01	Surface penetration data	Troutner (1960)
200	473	2.11e-03	4.28e+01	Surface penetration data	Troutner (1960)
200	473	2.11e-03	3.85e+01	Surface penetration data	Troutner (1960)
225	498	2.01e-03	1.01e+02	Surface penetration data	Troutner (1960)
225	498	2.01e-03	1.17e+02	Surface penetration data	Troutner (1960)
250	523	1.91e-03	2.49e+02	Surface penetration data	Troutner (1960)
250	523	1.91e-03	2.37e+02	Surface penetration data	Troutner (1960)
250	523	1.91e-03	2.22e+02	Surface penetration data	Troutner (1960)
300	573	1.75e-03	7.24e+02	Surface penetration data	Troutner (1960)
300	573	1.75e-03	6.19e+02	Surface penetration data	Troutner (1960)
50	323	3.10e-03	1.32e-06	Purified water***	Waber(1958)
50	323	3.10e-03	5.19e-06	Purified water	Waber(1958)
50	323	3.10e-03	8.62e-06	Purified water	Waber(1958)
50	323	3.10e-03	1.64e-05	Purified water	Waber(1958)
50	323	3.10e-03	2.17e-05	Purified water	Waber(1958)
50	323	3.10e-03	3.43e-05	Purified water	Waber(1958)
50	323	3.10e-03	4.91e-05	Purified water	Waber(1958)
50	323	3.10e-03	5.79e-05	Purified water	Waber(1958)
50	323	3.10e-03	7.75e-05	Purified water***	Waber(1958)

*As reported by McWhirter and Draley (1952).

**As reported by Waber (1952).

***Hydrogen generation data.

(4)Weight loss data.

(5)As-cast uranium.

(6)Heat treated uranium.

DISTRIBUTION SHEET

To	From	Page 1 of 2
Distribution	SNF Characterization Project	Date November 1998
Project Title/Work Order		EDT No. 620819
Reaction Rate Constant for Uranium in Water and Water Vapor HNF-2853, Rev. 0		ECN No.

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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