MASTER

EXTERNAL TRANSMITTAL AUTHORIZED

X-822

OAK RIDGE NATIONAL LABORATORY

Operated by

UNION CARBIDE NUCLEAR COMPANY

Division of Union Carbide Corporation

Post Office Box X
Oak Ridge, Tennessee

ORNL
CENTRAL FILES NUMBER

59-8-33

COPY NO. 44

DATE: August 5, 1959

SUBJECT: Temperature and Rate of Heat Removal of
UO₂ Test Elements

TO: A. M. Perry

FROM: J. R. Nix

Abstract

The method of calculation of various quantities relating the temperature and the rate of heat removal of UO₂ test elements is presented. Graphs of the appropriate quantities as a function of the rate of heat removal are included.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report. The information is not to be abstracted, reprinted or otherwise given public dissemination without the approval of the ORNL patent branch, Legal and Information Control Department.

RELEASE APPROVED
BY PATENT BRANCH

8/18/59 *William J. Davis*
DATE SIGNATURE

5-1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TEMPERATURE AND RATE OF HEAT REMOVAL OF UO_2 TEST ELEMENTS

I. Problem

To compute various quantities relating the temperature and the rate of heat removal of UO_2 test element, specifically:

A. $\int_{T_1}^{T_2} k d\theta$ vs q .

B. T_2 vs q for $T_1 = 600^\circ\text{C}, 750^\circ\text{C}, 900^\circ\text{C}$.

C. Fraction of UO_2 at a temperature above T_3 vs q for the five combinations:

$$T_1 = 900^\circ\text{C}, T_3 = 1500^\circ\text{C};$$

$$T_1 = 600^\circ\text{C}, T_3 = 1500^\circ\text{C};$$

$$T_1 = 750^\circ\text{C}, T_3 = 1500^\circ\text{C};$$

$$T_1 = 750^\circ\text{C}, T_3 = 1750^\circ\text{C};$$

$$T_1 = 750^\circ\text{C}, T_3 = 2000^\circ\text{C}.$$

D. Temperature vs radius for a surface temperature of 750°C , for the four combinations:

$$q = 20,000 \text{ Btu/hr-ft, cored rod};$$

$$q = 20,000 \text{ Btu/hr-ft, solid rod};$$

$$q = 40,000 \text{ Btu/hr-ft, cored rod};$$

$$q = 40,000 \text{ Btu/hr-ft, solid rod}.$$

T_1 is the temperature on the outer surface of the test element; while T_2 , representing the maximum UO_2 temperature, is the temperature on the inner surface; k is the thermal conductivity of the UO_2 ; θ is simply the temperature variable in the integral.

The quantity q , heat removal per unit length, is considered in this problem to lie within the range 15,000 Btu/hr-ft to 50,000 Btu/hr-ft.

The hollow cylindrical test elements considered are of 95% dense UO_2 , 1% enriched in U^{235} , with an outside diameter of 0.705 in. and an inside diameter of 0.323 in. At this enrichment, the neutron flux variation within the element is slight, and the heat generation may be considered to be uniform.

II. Solution of Problem

The formula for a hollow cylindrical rod of outer radius a and inner radius b , cooled on the outer surface only, relating the rate of heat removal to the surface temperature T_1 and the temperature T_r at radius r is:

$$\int_{T_1}^{T_r} kd\theta = \frac{q}{4\pi} \left\{ \frac{a^2 - r^2}{a^2 - b^2} - \frac{2b^2 \ln a/r}{a^2 - b^2} \right\}. \quad (1)$$

Evaluating this expression at $r = b$, we obtain, for the geometry specified above ($b/a = 0.458$),

$$\int_{T_1}^{T_2} kd\theta = 0.04657 q \quad (2)$$

as the solution to part (A).

In order to determine T_2 for a given T_1 and q , we note that

$$\int_0^{T_2} kd\theta = \int_0^{T_1} kd\theta + \int_{T_1}^{T_2} kd\theta. \quad (3)$$

The value of $\int_0^{T_1} kd\theta$ for a particular T_1 is obtained from a graph of

$\int_0^T kd\theta$ vs T ,⁽¹⁾ while $\int_{T_1}^{T_2} kd\theta$ is given by Eq. (2) above. From the

⁽¹⁾J.A.L. Robertson, $\int_0^T kd\theta$ in Fuel Irradiations, CRFD-835 (April 1959).

computed value of $\int_0^{T_2} k d\theta$, one can determine T_2 from the graph of $\int_0^T k d\theta$ vs T .

The fraction of UO_2 at a temperature above T_3 is given by

$$\frac{r^2 - b^2}{a^2 - b^2},$$

where r is the radius at which the temperature is T_3 . In order to determine this radius, Eq. (1) is transformed to

$$\ln r^2 = \frac{r^2}{b^2} + 2 \ln a - \frac{a^2}{b^2} + \frac{4\pi(a^2 - b^2)}{b^2 q} \int_{T_1}^{T_3} k d\theta, \quad (4)$$

which gives upon substitution of the values for a and b

$$\ln r^2 = 38.34025 r^2 - 6.84942 + \frac{47.3000}{q} \int_{T_1}^{T_3} k d\theta. \quad (4')$$

A graphical solution may be employed to find r^2 and hence the fraction of UO_2 at a temperature above T_3 for given values of T_1 , T_3 , and q .

Equation (4') is also suitable for calculating temperature vs radius for the two cored rod combinations listed in part (D). For a solid rod ($b = 0$), Eq. (1) may be solved for

$$r^2 = a^2 \left(1 - \frac{4\pi}{q} \int_{T_1}^{T_r} k d\theta \right). \quad (5)$$

The radius r corresponding to a particular temperature T_r may be determined from this expression for both $q = 20,000$ Btu/hr-ft and $q = 40,000$ Btu/hr-ft.

III. Results

As can be seen from Eq. (2), $\int_{T_1}^{T_2} k d\theta$ is directly proportional to q ; the linear graph of $\int_{T_1}^{T_2} k d\theta$ vs q is included.

The maximum UO_2 temperature T_2 is plotted vs q for $T_1 = 600^\circ\text{C}$, 750°C , and 900°C , and shows a very slight increase in slope with an increase in q . This non-linearity is due to a small variation of the thermal conductivity k with temperature.

For the five combinations of T_1 and T_3 listed in part (C) of the problem, the fraction of UO_2 at a temperature above T_3 is plotted vs q . This fraction increases very rapidly with an increase in q in the neighborhood of the critical value of q , with a decrease in the slope being observed for larger values of q .

A graph of temperature vs radius is included for the four combinations specified in part (D). The temperature at a particular radius in the cored rod is seen to be considerably less than the corresponding temperature at the same radius in a solid rod, with this temperature difference increasing from zero at the outer surface to a maximum value at the inner surface of the cored rod.

It is to be noted that these results depend only on the ratio b/a , and are valid for any annular UO_2 element having the inside diameter to outside diameter ratio of 0.458.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5
TEMPERATURE vs. RADIUS
95% DENSE UO_2

SURFACE TEMP. = $750^{\circ}C$

TEMPERATURE ($^{\circ}C$)

$q = 40,000$ BTU/HR. FT.
(SOLID ROD)

$q = 40,000$ BTU/HR. FT.
(CORED ROD)

$q = 20,000$ BTU/HR. FT.
(SOLID ROD)

$q = 20,000$ BTU/HR. FT.
(CORED ROD)

$b = 0.458 a$

RADIUS (UNITS OF a = OUTSIDE RADIUS)

DISTRIBUTION

1. M. Bender	29. F. H. Neill
2. R. S. Carlsmith	30. E. A. Nephew
3. R. A. Charpie	31. J. R. Nix
4-6. J. H. Coobs	32-33. A. M. Perry
7-9. W. B. Cottrell	34. P. H. Pitkanen
10. H. N. Culver	35. C. A. Preskitt
11. T. K. DeBoer	36. M. W. Rosenthal
12. J. G. Delene	37. T. H. Row
13. L. G. Epel	38-40. G. Samuels
14. J. Foster	41-43. O. Sisman
15-17. A. P. Fraas	44. M. J. Skinner
18. D. R. Gilfillan	45-49. D. B. Trauger
19-21. B. L. Greenstreet	50. M. Yarosh
22. E. C. Halbert	51. Laboratory Records, ORNL-RC
23. R. S. Holcomb	52-53. Laboratory Records
24. R. B. Korsmeyer	54. Central Research Library
25. M. E. Lackey	55. ORNL-Y-12 Document
Reference Section
26-28. W. D. Manly	

**DO NOT
PHOTOSTAT**