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CDAP-TR-78-039
for U. S. Nuclear Regulatory Commission

FUEL EMISSIVITY (FEMISS)

September 1978



EG&G Idaho, Inc.



IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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CODE DEVELOPMENT AND
ANALYSIS PROGRAM REPORT

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Report No. CDAP-TR-78-039

Date September 1978

Contract Program or Project Title: MATPRO (189 Number A 6096)

Subject of this Document: FUEL EMISSIVITY (FEMISS)

Type of Document: Interim Report

Author(s): R. E. Mason

Date of Document: September 1978

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for the
U.S. Department of Energy

Prepared for
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

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FUEL EMISSIVITY (FEMISS)

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CONTENTS

	<u>Page</u>
FORWARD	1
3. Fuel Emissivity (FEMISS)	2
3.1 Summary	2
3.2 Emissivity Data	3
3.3 Model Development	4
3.4 Fuel Emissivity Subcode Listing	5
3.5 References.	9

FIGURES

A-3.1 Emissivity data and corresponding FEMISS predictions. . . .	6
A-3.2 Comparison of the new FEMISS subcode predictions with those of MATPRO 10.	8

TABLES

A-3.1 Listing of the FEMISS subcode	7
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FOREWORD

This report describes work which is part of the fuel rod behavior modeling task performed at EG&G Idaho, Inc. It is an interim addition to work previously published in the Materials Properties (MATPRO) Handbook^[a] and will replace Section A-3 (Fuel Emissivity) of the MATPRO-11 handbook. This update of the fuel emissivity subcode includes new data and an estimate of the standard error to be expected with the subcode.

The material property correlations and computer subcodes described in MATPRO are developed for use in Light Water Reactor (LWR) analytical programs such as the Fuel Rod Analysis Program -- Steady-State (FRAPCON-1)^[b] code and the Fuel Rod Analysis Program -- Transient (FRAP-T4)^[c] code. This work is being performed as part of a broad effort to develop and verify analytical models capable of describing nuclear fuel rod behavior.

The format and numbering scheme used in this report is consistent with its intended use as a section of Appendix A of the MATPRO handbook. It is beyond the scope of this report to provide a complete description of MATPRO and its organization. Readers who require a description should consult the handbook.

[a] G. A. Reymann (Ed.) MATPRO Version 10 - A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior, TREE-NUREG-1180 (February 1978).

[b] G. A. Berna, et al., FRAPCON-1: A Computer Code for the Steady-State Analysis of Oxide Fuel Rods, CDAP-TR-78-032 (August 1978).

[c] J. A. Dearien, et al., FRAP-T4: A Computer Code for Transient Analysis of Oxide Fuel Rods - Vol 1 - Analytical Models and Input Manual, CDAP-TR-78-027 (July 1978).

3. FUEL EMISSIVITY (FEMISS)

The fuel emissivity subcode FEMISS calculates total UO_2 emissivity (emissivity integrated over all wavelengths) as a function of temperature. Fuel emissivity is defined as the ratio of radiant energy emitted from a material to that emitted by a black body at the same temperature.

The subcode is used to calculate radiant energy transfer from fuel to cladding in conjunction with thermal conduction. Radiant energy transfer can be a significant heat transfer mechanism depending on the gap size, temperature gradient across the gap and plenum gas.

3.1 Summary

The expression used in the FEMISS subcode to describe total emissivity is

$$e = 0.7856 + 1.5263 \times 10^{-5}T \quad (A-3.1)$$

where

e = total hemispherical emissivity (unitless)

T = fuel temperature (K)

The standard error of estimate of Equation (A-3.1) with respect to its own data base is $\pm 6.8\%$. The emissivity data was measured at temperatures up to approximately 2400 K. Use of FEMISS above this temperature is speculative because of possible high temperature effects which are not modeled. There was no data to develop a $(U,Pu)O_2$ emissivity equation so Equation (A-3.1) is recommended for $(U,Pu)O_2$ until such data are available.

Equation (A-3.1) is based on the data discussed in Section 3.2 and Section 3.3 is a discussion of the model development. The subcode listing and a comparison to earlier versions of FEMISS are provided in Section 3.4.

3.2 Emissivity Data

Emissivity data have been reported by Held and Wilder^[A-3.1], Cabannes et al^[A-3.2], Jones and Murchison^[A-3.3], Claudson^[A-3.4], Belle^[A-3.5] and Ehlert and Margrave^[A-3.6].

Held and Wilder reported hemispherical spectral emissivity data (emissivity at one wavelength) of UO_2 . These data are also documented by Touloukian and Dewitt^[A-3.7]. They determined emissivity of UO_2 having oxygen to metal ratios between 1.95 and 2.29 and bulk densities between 8×10^3 to 10.6×10^3 Kg/m^3 . The measurements were taken at wavelengths of 0.656 and 0.7 μm and at temperatures between 450 and 2400 K. The data show no observable emissivity trend as a function of the fuel oxygen to metal ratio or density but scatter of the data is large (+10%) and may obscure actual trends. Their data indicate that emissivity increases with temperature between 450 and 2200 K and drops a few percent at 2400 K. Whether or not the emissivity continues to drop at higher temperatures is uncertain because of lack of data. Since this high temperature decrease in emissivity is less than the scatter of the data, the trend cannot be considered to continue until more high temperature data are obtained.

Cabannes et al measured reflectance (1-emissivity) of UO_2 up to 2200 K as a function of wavelength and temperature. They found that the emissivity approaches 1.0 at wavelengths above 20 μm but remains between 0.9 and 0.8 for wavelengths below 10 μm . They also found that emissivity did not change with thermal cycling. Since a polished surface normally deteriorates during thermal cycling, their study implies little sensitivity of emissivity data to the surface polish of the UO_2 samples.

Jones and Murchison^[A-3.3] reported reflectivity of UO_2 at wavelengths between 0.4 and 0.7 μm . The emissivity of the samples varied between 0.81 to 0.84. They found emissivity to be smallest (0.81) at a wavelength of about 0.5 μm . It increased 1 to 3 percent as the wavelength decreased or increased beyond 0.5 μm . Emissivity also varied less than 3 percent for oxygen to metal ratios between 2.003 and 2.203.

Data reported by Claudson which were also reported by Belle indicate that emissivity decreases from 0.85 to 0.37 as temperature increases from 1000 to 2220 K. This is in direct contradiction to the Held and Wilder, Cabannes et al and Jones and Murchison data. Cabannes et al have reviewed Claudson's data and conclude that the discrepancy is possibly due to an error in Claudson's measurement technique.

Ehlert and Margrave reported two data from UO_2 pellets. They measured the emissivity of UO_2 at 2073 and approximately 3000 K and found the emissivity to be 0.416 and 0.40 respectively.

3.3 Model Development

The subcode FEMISS calculates total emissivity of fuel at a particular temperature. The hemispherical spectral data of Held and Wilder and the emissivity data of Cabannes et al and Jones and Murchison were used in developing the FEMISS model. Data of Claudson and Ehlert and Margrave were not used because of possible errors in measurement technique^[A-3.2].

Spectral emissivity data were used to develop the total emissivity subcode FEMISS. Use of spectral emissivity data as the data base of a total emissivity subcode is legitimate because of the following arguments. Jones and Murchison indicate that spectral emissivity does not vary more than 2 or 3 percent at wavelengths between 0.4 and 0.7 μm , well within the uncertainty of the data. The Cabannes et al data show that UO_2 emissivity is about 0.85 at all wavelengths below 10 μm . Since spectral data measured at wavelengths smaller than 10 μm does not vary more than a few percent as wavelength varies, spectral data can be used to develop a total emissivity correlation. This assumption is valid in general for FEMISS calculations since the radiation emitted from a black body or any material has maximum intensities at wavelengths smaller than 10 μm at temperatures where radiation energy transfer is important.

Besides the emitted wavelength, emissivity can be a function of material properties such as density, porosity, surface finish, oxygen to

metal ratio, and temperature. Analysis of the data showed no dependence of emissivity on any of the above properties except temperature. The Held and Wilder data and the Cabannes et al data were used in a linear regression program to obtain Equation (A-3.1). A standard error of estimate of $\pm 6.8\%$ was also determined using Equation (A-3.1) and the data base.

The emissivity data of Held and Wilder and Cabannes et al are shown in Figure A-3.1 as a function of temperature. The emissivity predictions of FEMISS for the same temperatures are shown as a solid line in the figure. The dashed lines in Figure A-3.1 represent predicted $\pm 1\sigma$ values. The decreasing emissivities of the Held and Wilder data at temperatures near 2400 K can be seen in Figure A-3.1. There is no data past this temperature to determine if the drop is a real affect or experimental error. If the trend is real, there is no data to indicate what happens to the emissivity beyond 2400 K, so until more data at higher temperatures are obtained the drop of the Held and Wilder data near 2400 K is assumed to be experimental error.

3.4 Fuel Emissivity Subcode Listing

A FORTRAN listing of the subcode FEMISS is presented in TABLE A-3.I and Figure A-3.2 shows a comparison of the MATPRO-10 FEMISS subcode and the new FEMISS subcode predictions. As can be seen in the figure, there is a significant difference between calculated emissivities of the two models. The old model predicts a decrease in emissivity around 1000 K where as the new model remains relatively constant as the data indicate.

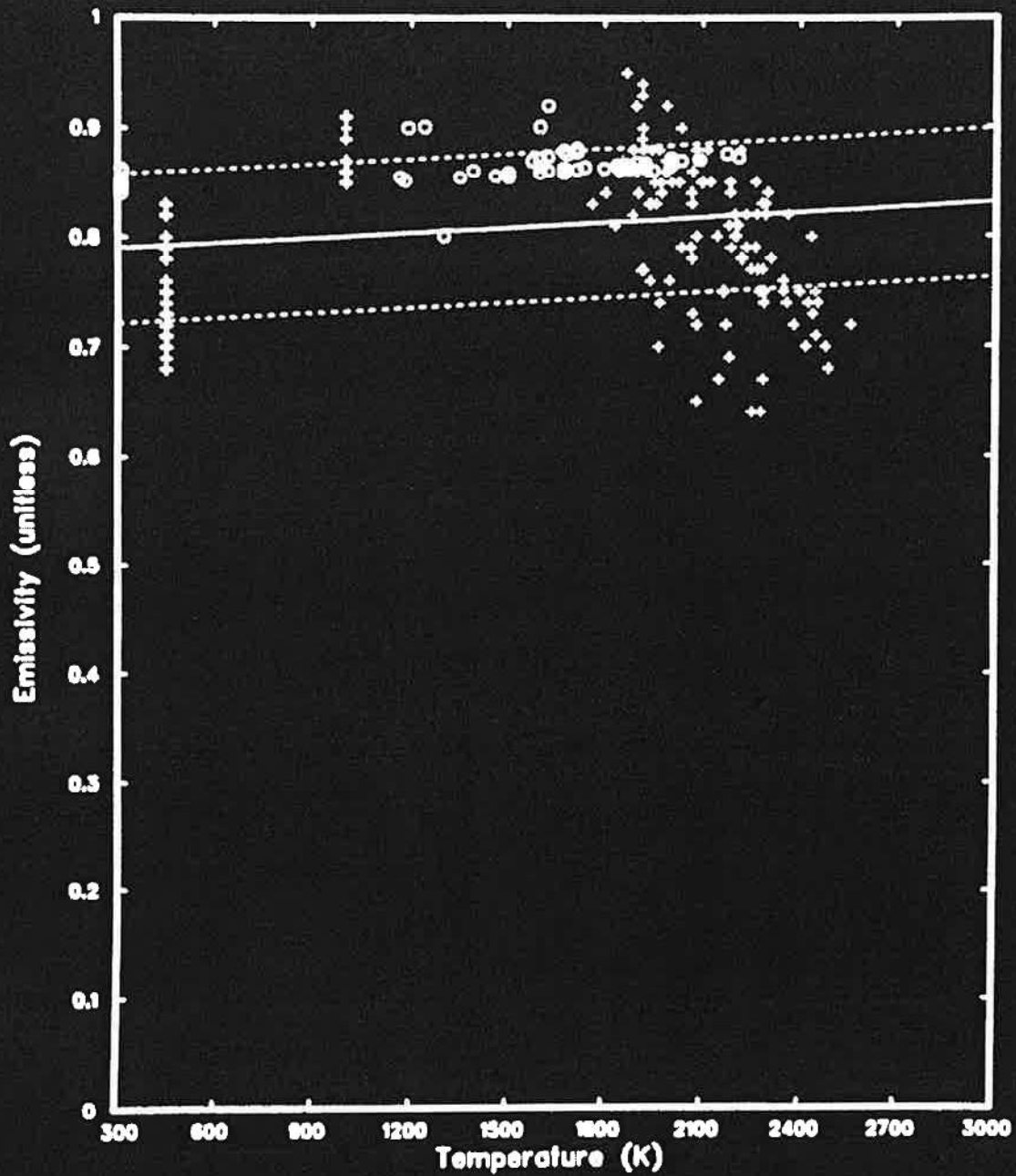


Fig. A-3.1 Emissivity data and corresponding FEMISS predictions. Data of Held and Wilder are shown as (+) and data of Cabannes et al are shown as (o).

TABLE A-3.I

LISTING OF THE FEMISS SUBCODE

FUNCTION FEMISS(FTEMP)

FEMISS CALCULATES FUEL EMISSIVITY AS A FUNCTION OF TEMPERATURE.

FTEMP = INPUT FUEL TEMPERATURE (K)
FEMISS = OUTPUT FUEL EMISSIVITY (UNITLESS)

DATA USED TO DEVELOP THE MODEL ARE
HELD AND WILDER, JOURN. AMER. CERAM. SOC.
VOL. 32, (1969)
CABANNES, ET AL, C. R. ACAD. SCI., PARIS, SER. B
(1967)

FEMISS WAS CODED BY R. E. MASON IN OCTOBER 1978.

$FEMISS = 0.78557 + 1.5263E-05 * FTEMP$

THE FOLLOWING CALCULATIONS PROVIDE THE UPPER AND LOWER BOUNDS.
THE UPPER AND LOWER BOUNDS ARE NOT AN OUTPUT UNLESS THE USER
DESIRES TO MODIFY THE SUBCODE APPROPRIATELY.

FEMISU IS THE UPPER BOUND
 $FEMISU = FEMISS * (1. + 0.06796)$
FEMISL IS THE LOWER BOUND
 $FEMISL = FEMISS * (1. - 0.06796)$

10

CONTINUE
RETURN
END

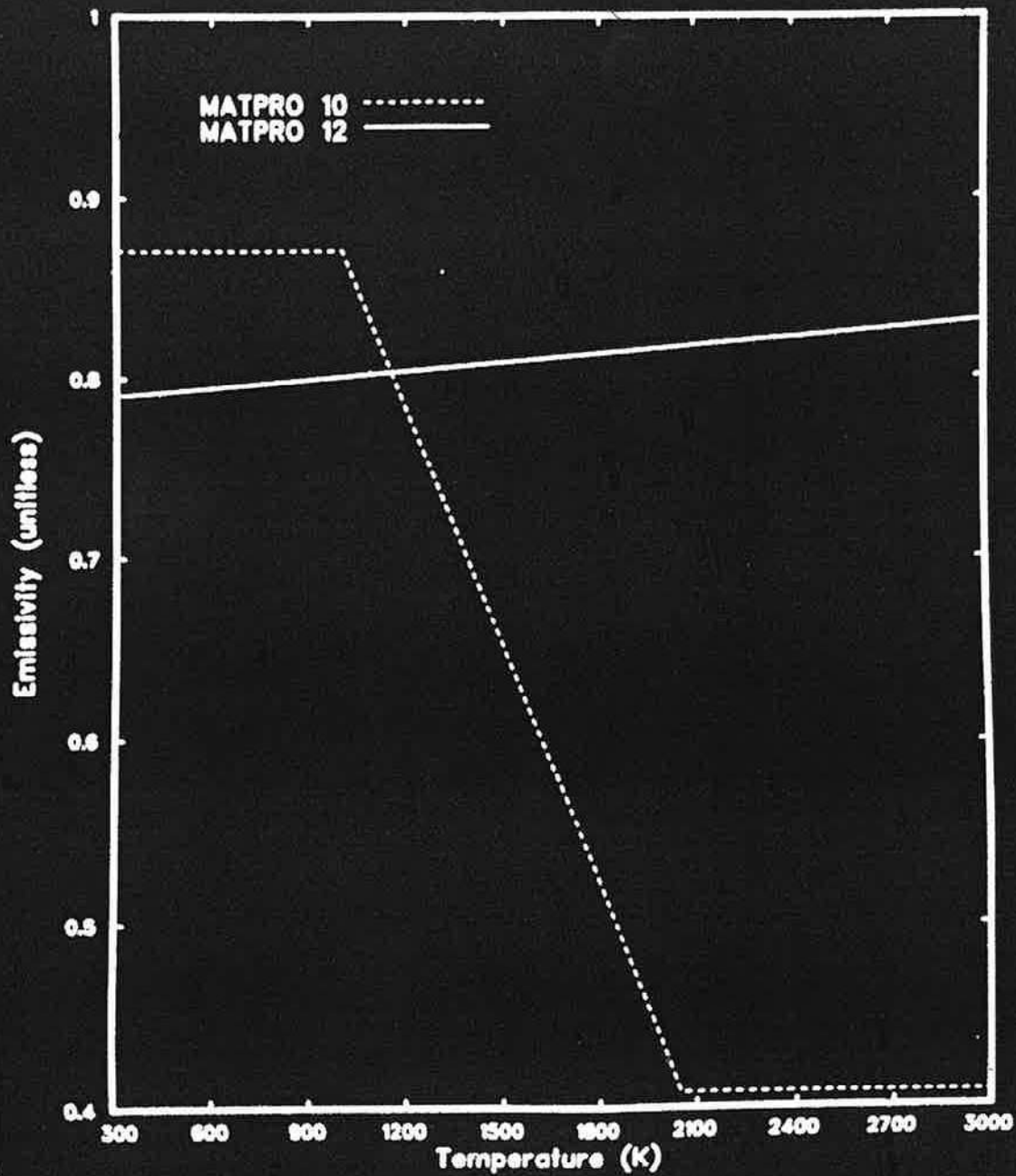


Figure A-3.2 Comparison of the new FEMISS subcode predictions with those of MATPRO 10.

3.5 REFERENCES

- A-3.1 P. C. Held and D. R. Wilder, "High Temperature Hemispherical Spectral Emittance of Uranium Oxides at 0.65 and 0.70 μm ," Journal of the American Ceramic Society, 52 (1969).
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- A-3.3 J. M. Jones and D. G. Murchison, "Optical Properties of Uranium Oxides," Nature 205 [4972] (1965) pp 663-665.
- A-3.4 T. T. Claudson, Emissivity Data for Uranium Dioxide, HM-55414 (November 5, 1958).
- A-3.5 J. Belle (ed.), Uranium Dioxide: Properties and Nuclear Applications, TID-7546, U. S. Government Printing Office, Washington, D.C. (1961).
- A-3.6 T. C. Ehlert and J. L. Margrave, "Melting Point and Spectral Emissivity of Uranium Dioxide," Journal of the American Ceramic Society, 41 (1958) p 330.
- A-3.7 Y. S. Touloukian and D. P. Dewitt, Thermal Radiative Properties of non metallic Solids, Thermophysical Properties of Materials Vol. 8 IFI/Plenung New York-Washington 1972.