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FOURIER-I, A COMPUTER PROGRAM FOR FUEL ELEMENT THERMAL DESIGN

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FOURIER-I, A COMPUTER PROGRAM FOR FUEL ELEMENT THERMAL DESIGN

by

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SUMMARY

Prediction of fuel element behavior in hot conditions is quite complicated, mainly because of the temperature dependence of the material properties. To carry out this type of calculation the FOURIER-I code was written in ICL-FORTRAN.

1. INTRODUCTION

The power output in nuclear reactors is limited by some characteristic temperatures in the system. The maximum temperatures in the core must be definitely established so that we can make sure that the cooling system will be adequate under steady state and transient conditions.

The most important parameters on a core's thermal performance are the fuel rod linear power, the fuel's specific power, the surface heat flux and the heat transfer rate. The maximum value of surface heat flux is determined by the heat transfer rate, which is limited by the boiling crisis. For a given surface heat flux, the fuel rod size /diameter/ is determined as a compromise between fuel center temperature and power density.

A high power density is required to minimize the fuel inventory. The center temperature is limited to avoid a significant meeting of fuel, clad swelling and a high release of fission gases.

Once the fuel element geometry has been determined, to calculate temperature distribution the conductance in the pellet-clad gap or at the contact surface has to be evaluated.

The FOURIER-I program calculates the hot diametral gaps between fuel and clad, thermal conductance in the gap, contact pressure between fuel and clad and the conductance and characteristic temperatures in the fuel element. The empirical relations cover UO_2 fuel of 95 % T.D., ZR-2 and stainless steel /SS-304/ clad. The gap gas can be air, helium or fission gas. Cold rod geometry and heat generation rate is to be entered as input.

2. CALCULATION METHOD

2.1. Clad

Knowing the clad surface temperature, the average temperature of the clad can be determined by

$$\bar{T}_c = T_{c,o} + \frac{q}{k_c} d_{c,o} \ln \frac{d_{c,o}}{d_{c,i}} \qquad /1/$$

The values of the average temperature $\bar{T}_c$ and the coefficients k_c, α_c, $d_{c,o}$ and $d_{c,i}$ can be calculated by an iteration procedure using empirical expressions for the temperature dependence of these parameters. Dependence of k_c and α_c on temperature /for both SS-304 and ZR-2/ is included in the code in polynomial form.

2.2 Gap and fuel

Temperature difference in the fuel clad gap is calculated by the following equation:

$$\Delta Tg = \frac{q.d_{c,o}}{2k_g} \cdot \ln \frac{d_{c,i}}{d_p} + \frac{q}{h} \quad , \qquad /2/$$

where $k_g = k_g/T/$; $\alpha_p = \alpha_p/T/$; and $d_p = d_p/\alpha_p/T//$. To start iteration we can get a value for ΔT_g according to

$$\Delta Tg = \frac{q}{h_t} \quad , \qquad /3/$$

where the total gap conductance is given by

$$h_t = \frac{h}{1 + \frac{h}{k_g}}$$

Temperature dependences of the gap conductance /for helium, air and fission gas/ and of the fuel expansion coefficient are accounted for, again in polynomial form.

2.3 Contact pressure and conductance

The iteration described in 2.2 may yield a value for d_p, exceeding the value of $d_{c,i}$, which means that the fuel and the clad have come into contact. As this results in a change in the heat transfer characteristics of the rod and in the mechanical stresses upon fuel and clad, the code calculates the contact pressure and conductance between the fuel and clad; the latter is evaluated as a function of the former according to the results obtained by Dean [1].

It is evident that if contact occurs, the above considerations must be taken into account when the iteration 2.2 is performed; h_t being replaced by h_c.

3. INPUT INSTRUCTIONS

Input data can be punched on paper tape or on card. The expression "card" is used for one record /one line/ of the paper tape.

Card No. 1. FORMAT /7I2/

char. 1- 2: IMR, cladding material indicator, dimensionless.
IMR = 0, if clad is of stainless steel;
IMR = +1, if clad is of zircaloy.

char. 3- 4: IGS, coolant indicator, dimensionless.
IGS = 0, if there is local boiling in coolant;
IGS = +1, if cooling is by forced convection.

char. 5- 6: INGP, number of gap gas types to be used by the program, dimensionless. /See Card No. 5/.
INGP $\leq$ 3

char. 7- 8: IQ1, number of linear heat flux values, dimensionless.
IQ1 $\leq$ 9

char. 9-10: IDP, number of pellet diameters, dimensionless.
IDP $\leq$ 9

char. 11-12: IDE, number of clad outer diameters, dimensionless.
IDE $\leq$ 9

char. 13-14: IPO, number of gap gas pressures.
IPO $\leq$ 9

Card No. 2. FORMAT /3E14.8/

char. 1-14: S, wall thickness of clad, inches.

char. 15-28: TS, clad surface temperature if there is local boiling in coolant;
coolant temperature if cooling is by forced convection; F^{o}.

char. 29-42: H, clad-coolant heat transfer coefficient, if cooling is by forced convenction;
$Btu/hr/ft^2/^{o}F$;
left blank if there is local boiling.

Card No. 3. FORMAT /3E14.8/

char. 1-14: RM1, surface roughness of pellet, minch.

char. 15-28: RM2, surface roughness of clad, minch.

char. 29-42: TUØ2, pellet surface temperature, ^{o}F .

Card No. 4. FORMAT /4E14.8/

char. 1-14: CNU, Poission modulus of clad, dimensionless.

char. 15-28: PNU, Poission modulus of pellet, dimensionless.

char. 29-42: EC, modulus of elasticity of clad, psi.

char. 43-56: EP, modulus of elasticity of pellet, psi.

Card No. 5. FORMAT /3I3/

NGAP/I/, I = 1, ... INGP, gap gas indicators, dimensionless. The following values should appear:

+1 for air,
+2 for helium,
+3 for fission gas in gap.

Card No. 6. FORMAT /5E14.8/

Q1/I/, I = 1, ... IQ1, values of linear heat flux, kW/ft.

Card No. 7. FORMAT /5E14.8/

DPF/I/, I = 1, ... IDP, values of pellet diameter, inch.

Card No. 8. FORMAT /5E14.8/

DEF/I/, I = 1, ... IDE, values of clad outer diameters, inch.

Card No. 9.

PO/I/, I = 1, ... IPO, values of gap gas pressure, psia.

OPERATING INSTRUCTIONS

The code uses one input and one output peripheral unit and requires 8K words in the core memory of an ICL 1905 computer.

NOMENCLATURE

- d - diameter
- h - joint heat transfer coefficient for pellet-gas and gas-clad interfaces. A value of $h = 1200$ Btu/hr/ft^2/^{o}F is assumed in the code.
- h_t - total heat transfer coefficient of gap. $/\frac{1}{h_t} = \frac{1}{h} + \frac{1}{k_g}/$
- h_c - heat transfer coefficient for the pellet-clad interface in case of contact.
- k - coefficient of thermal conductivity.
- q - heat flux on outer surface of clad.
- T - temperature
- α - thermal expansion coefficient.

Subscripts:

- c - clad
- c,i - inner surface of clad
- c,o - outer surface of clad
- g - gap
- p - pellet

REFERENCES

[1] R.A. Dean, Thermal contact conductance between UO_2 and Zircaloy-2, CVNA 127.

[2] L.S.Tong, Heat Transfer in Water-Cooled Nuclear Reactors. Nuclear Engineering and Design 6, /1967/ pp.301-324.

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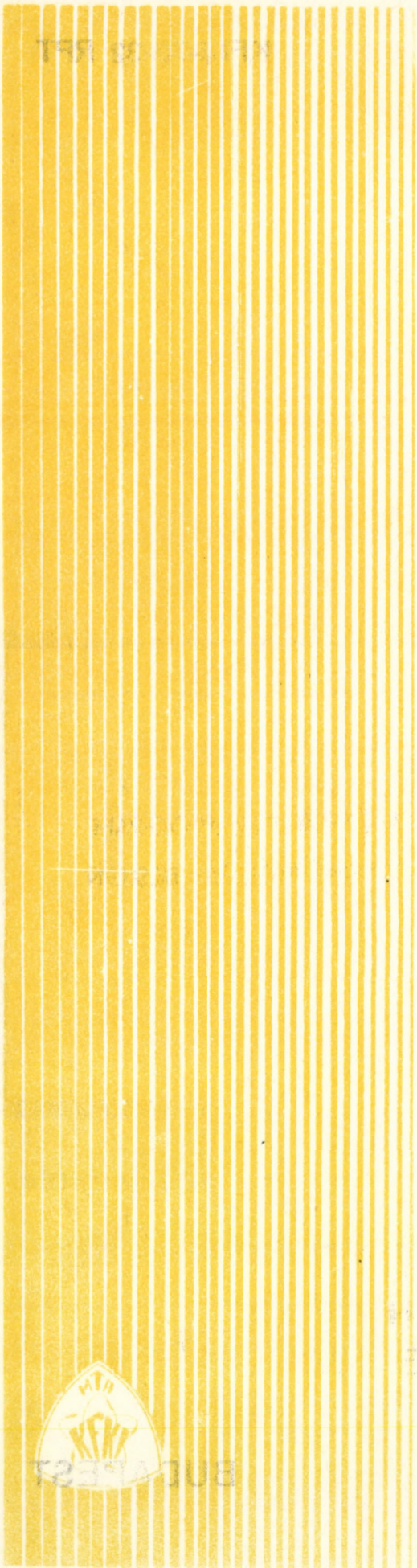

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