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## computer program to determine single-phase interchannel mixing in reactor fuel rod bundles

*Hungarian Academy of Sciences*

CENTRAL RESEARCH INSTITUTE FOR PHYSICS



BUDAPEST

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# TURMIX - COMPUTER PROGRAM TO DETERMINE SINGLE-PHASE INTERCHANNEL MIXING IN REACTOR FUEL ROD BUNDLES

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## ABSTRACT

TURMIX is a digital computer program for ICL-1905 computer in FORTRAN language. The code considers a fuel rod bundle cooled by single-phase coolant, and the thermohydraulic characteristics of subchannels and fuel rods are calculated for steady-state conditions. The calculated parameters can be summarized as follows: pressure drop, axial distribution of coolant enthalpy, average mass velocity, average heat flux, and natural mixing effects between the interconnected subchannels. The code is a modified and single-phase version of the first COBRA code, and contains several semi-empirical equations for turbulent mixing parameter.



## РЕЗЮМЕ

Программа TURMIX представляет собой программу, разработанную для ЭВМ ICL-1905 и написанную на языке FORTRAN. Программа вычисляет самые важные теплогидравлические параметры пучков тепловыделяющих стержней в потоке однофазной среды при стационарном режиме. Вычисленные параметры следующие: напор, энтальпия охлаждающей среды, средняя массовая скорость, средний тепловой поток и характеристические параметры естественного турбулентного перемешивания, параметры перемешивания между соседними параллельными ячейками. Программа является видоизмененным однофазным вариантом оригинальной программы COBRA, которая использует полуэмпирические уравнения для турбулентного перемешивания.



## KIVONAT

A TURMIX-kód az ICL-1905 digitális számológépre kifejlesztett FORTRAN nyelvü program. A kód meghatározza az egyfázisu közeg által hütött üzemanyagköteg legfontosabb termohidraulikai paramétereit stacioner üzemállapot esetén. A számitott paraméterek az alábbiakban foglalhatók össze: nyomásesés, a hütőközeg entalpiaeloszlása, átlagos tömegáramlási sebesség, átlagos hőfluxus, és a szomszédos csatornák közötti természetes mixing jelenségekre jellemző paraméterek. A TURMIX-program az eredeti COBRA-kód módositott egyfázisu változata, amelyben figyelembe vettük a turbulens mixing paraméterre vonatkozó félempirikus egyenleteket is.

## I. INTRODUCTION

The well known subchannel analysis codes for single-phase flow - for example HECTIC-II [1] or MANTA [2] - are designed to consider the effect of turbulent interchange in a simple approximation. These codes do not contain the other natural mixing effect, namely the diversion crossflow.

The purpose of the present paper was to develop a flexible single--phase subchannel analysis code considering both turbulent interchange and diversion crossflow effects in a more exact way.

The TURMIX code is a revised and modified single-phase version of COBRA [3], [4] and contains several semi-empirical equations for turbulent mixing parameter [5].

The main features of the code can be summarized as follows:

a/ The program considers single-phase flow for steady-state conditions.

b/ It accounts for intersubchannel thermal mixing that results from both turbulent and diversion crossflow.

c/ It considers the momentum interchanges that result from both turbulent and diversion crossflow between adjacent subchannels.

d/ The code includes the effect of transverse resistance to diversion crossflow.

e/ It can consider an arbitrary layout of fuel rods and flow subchannels and thus allow the analysis of any rod bundle configuration.

f/ It can include arbitrary heat flux distribution by specifying the axial flux distribution, relative rod power, and the fraction of rod power to each adjacent subchannel.

g/ Input constants are provided to allow the user to select various empirical correlations for the calculation of the turbulent mixing parameter.

h/ The program uses a mathematical model that includes the effects of turbulent and diversion crossflow mixing between the adjacent subchannels.

i/ It solves the mathematical equations by using numerical methods similar to the modified Euler method, but incorporates an additional feature which ensures a stable solution in computing the diversion crossflow.

j/ The code can handle an input written in both metric and British unit system and can produce such an output if needed. In order to have consistency in the input the table of saturated water constants was incorporated into the program, so that the code TURMIX doesn't need this table as input.

k/ The program doesn't include the forced mixing effects - namely the flow scattering and flow sweeping -, and the pressure losses, which are induced by spacing devices.

## II. GENERAL DESCRIPTION OF THE CODE

### 1. Fundamental equations:

To develop a method for predicting the flow and enthalpy in selected regions of a rod bundle, a mathematical model is used that considers the important lateral transport processes. The approach used is essentially the same as in the COBRA, where the cross-section of the rod bundle is divided into discrete flow subchannels. By making suitable assumptions concerning the axial flow and cross-flow in these subchannels, the differential equations of continuity, energy and momentum can be derived for each subchannel. Numerical solution of this set of differential equations is treated as an initial value problem by integrating the equations in a stepwise manner starting at the inlet of the fuel bundle.

Continuity equation:

$$\frac{dm_i}{dx} = - \sum_{j=1}^{M} w_{ij} \qquad \text{where} \quad \begin{matrix} i = 1,2,\dots N \\ j = 1,2,\dots M \end{matrix} \qquad /1/$$

Energy equation:

$$m_i \frac{dh_i}{dx} = q_{total,i} + \sum_{j=1}^{M} w'_{ij}\left(h_j - h_i\right) - \sum_{j=1}^{M} \begin{bmatrix} 0 & \text{if} & w_{ij} \geq 0 \\ w_{ij}\left(h_i - h_j\right) & \text{if} & w_{ij} < 0 \end{bmatrix} \qquad /2/$$

where $i = 1,2,\dots N$
$j = 1,2,\dots M$

Axial momentum equation:

$$-\frac{dp_i}{dx} = \frac{1}{g_c} \cdot \left(\frac{m_i}{A_i}\right)^2 \cdot \frac{f_i}{2 \cdot \rho_{f,i} \cdot D_{hydr,i}} +$$

$$+ \rho_{f,i} \cdot \cos\Theta + \frac{1}{g_c \cdot A_i} \cdot \sum_{j=1}^{M} f_T \cdot w'_{ij} \left(u_i - u_j\right) +$$

$$+ \frac{1}{g_c \cdot A_i} \cdot \sum_{j=1}^{M} \begin{bmatrix} w_{ij} \cdot u_i \left(f_D - 2\right) & \text{if} & w_{ij} \geq 0 \\ w_{ij} \left(f_D \cdot u_j - 2 \cdot u_i\right) & \text{if} & w_{ij} < 0 \end{bmatrix} \qquad /3/$$

where $i = 1,2,\ldots N$
$j = 1,2,\ldots M$

Transverse momentum equation:

$$P_i - P_j = C_{ij} \cdot w_{ij} \cdot |w_{ij}| \qquad \text{where} \quad i = 1,2,\ldots N \quad j = 1,2,\ldots M \qquad /4/$$

Turbulent crossflow:

$$w'_{ij} = \beta_{ij} \cdot S_{ij} \cdot \frac{m_i + m_j}{A_i + A_j} \qquad \text{where} \quad i = 1,2,\ldots N \quad j = 1,2,\ldots M \qquad /5/$$

2. Computer program correlations

To carry out a solution, empirical and semiempirical correlations must be selected for input to the computer program. The following correlations are an example of what is available.

a/ Friction factor

The Darcy-Weisbach friction factor correlation in the $i^{th}$ subchannel is assumed to be of the form:

$$f_i = A \cdot Re_i^B + C \qquad /6/$$

where A,B and C are specified input constants.

b/ Single-phase turbulent mixing parameter

Several forms of equations for specifying the single-phase turbulent mixing parameter are included in the program [5]:

$$\beta_{ij} = a \qquad /7/$$

$$\beta_{ij} = a \cdot \overline{Re_{ij}}^{\,b} \qquad /8/$$

$$\beta_{ij} = a \cdot \overline{Re_{ij}}^{\,b} \cdot \frac{\overline{D_{hydr,ij}}}{S_{ij}} \qquad /9/$$

$$\beta_{ij} = a \cdot \overline{Re_{ij}}^{\,b} \cdot \frac{\overline{D_{hydr,ij}}}{Z_{ij}} \qquad /10/$$

where:

$$\overline{Re_{ij}} = \frac{\overline{G_{ij}} \cdot \overline{D_{hydr,ij}}}{\overline{\mu_{ij}}} \qquad /11/$$

$$\overline{D_{hydr,ij}} = 4 \cdot \frac{A_i + A_j}{P_{w,i} + P_{w,j}} \qquad /12/$$

$$\overline{G_{ij}} = \frac{m_i + m_j}{A_i + A_j} \qquad /13/$$

$$\overline{\mu_{ij}} = \frac{\mu_i + \mu_j}{2} \qquad /14/$$

The equations /7/, /8/, /9/ and /10/ are summarized in the program to a single equation having several input options:

$$\beta_{ij} = a \cdot \overline{Re_{ij}}^{\,b} \cdot \overline{D_{hydr,ij}}^{\,c} \cdot \frac{1}{S_{ij}^{d}} \cdot \frac{1}{Z_{ij}^{e}} \qquad /15/$$

where a, b, c, d and e are specified as input constants.

c/ Loss function for transverse momentum

To obtain an estimate of the transverse crossflow resistance, a simple friction model is used. The loss function for transverse momentum is supposed to have the analytical form

$$C_{ij} = \frac{f \cdot \ell}{4 \cdot g_c \cdot S_{ij}^3 \cdot \rho_{f,i}} \qquad /16/$$

where the product $f \cdot \ell$, called diversion cross flow resistance parameter, is an arbitrary constant that is input to the problem.

d/ Power distribution

The heat input per unit length of channel is the sum of all such inputs from fuel rods adjacent to the subchannel. The heat transfered from a rod /r/ to a subchannel /i/ is given by:

$$q'_{r,i}\left(\frac{X}{L}\right) = \bar{q}'' \cdot \pi \cdot D_{rod} \cdot f_{c,r,i} \cdot f_{R,i} \cdot f_{A,i}\left(\frac{X}{L}\right) \qquad /17/$$

where

$$\int_0^1 f_{A,i}\left(\frac{X}{L}\right) \cdot d\left(\frac{X}{L}\right) = 1 \qquad /18/$$

The sum of the heat inputs from all rods adjacent to subchannel /i/ gives the total heat transferred per unit length:

$$q_{total,i}\left(\frac{X}{L}\right) = \sum_{r=1}^{N_{rod}} q'_{r,i}\left(\frac{X}{L}\right) \qquad /19/$$

e/ Fluid properties

The table of saturated water constants is incorporated into the program, therefore the fluid properties are calculated automatically with linear interpolation by the code.

## III. USER'S MANUAL

INPUT preparation:

Input data are punched on paper tape or cards. The expression "card" will be used for one record /i.e. one line/ of the paper tape.

1/ Friction factor constants: FORMAT /12 F 5.0/

AA, BB, CC = Darcy - Weisbach friction factor constats in equation /6/.

2/ Control card for the case to be run: FORMAT /I3, 7I1, 11A4, I6, I1/

KASE = problem number /greater than zero/
J1 = control parameter for axial heat flux distribution.
J2 = control parameter for subchannel layout.
J3 = control parameter for subchannel gap and centroid distance dimensions.
J4 = control parameter for rod-subchannel layout.
J5 = control parameter for rod diameters and radial power distribution.
J6 = control parameter for calculation variables.
J7 = control parameter for operating conditions.
TEXT = identification title of the run is providing information for the user and machine operator.
IMETIN = metric input indicator.
IMET = metric output indicator.

N.B.: In columns 4 - 10 a zero or blank means that the corresponding card block will not be read. Any positive number requires data to be read. All data must be read for the first problem of a series. In columns 60 - 61 a zero or blank suggests to use British units, +1 metric units.

3/ Axial heat flux distribution table: /to be supplied only if J1 > 0/

FORMAT /I 5/(14 F 5.3)/

NAX = number of axial heat flux values in table. /NAX $\leq$ 15/
Y /I/ = relative distance from the inlet for the $I^{th}$ heated rod. $\left(\frac{X}{L}\right)$ /dimensionless/.
AXIAL /I/ = local to average axial power distribution in the $I^{th}$ heated rod. /dimensionless/.

N.B.: Up to seven pairs of values may be specified on each card. The values of the relative distance must be given in increasing order.

4/ Subchannel layout table: /to be supplied only if J2 > O/

FORMAT /I5/(5I5)/

NCHANL = number of subchannels. /NCHANL $\leq$ 17/
I = subchannel subscript.
LC /I,L/ = subscript of subchannels in increasing order surrounding the $I^{th}$ subchannel /up to four adjacent subchannels may be considered for each subchannel/.

N.B.: In the two-dimensional array LC/I,L/ a negative value must be substituted, if the gap between adjacent subchannels is divided by the boundary of the examined rod bundle sector. This negative sign tells the program to use half the full gap crossflow.

5/ Subchannel, gap and centroid distance dimensions
/to be supplied only if J3 > O/

FORMAT /I 5, 7 F 5.3/
FORMAT /I 5, 4 F 10.0/

I = subchannel subscript.
A/I/ = free flow area of the $I^{th}$ subchannel. /$inch^2$/ or /$cm^2$/.
PERIM/I/ = total wetted perimeter of the $I^{th}$ subchannel. /inch/ or /cm/.
HPERIM/I/ = total heated perimeter of the $I^{th}$ subchannel. /inch/ or /cm/.
S/I,L/,/L=1,4/ = full rod gap between adjacent subchannels in an arrangement as specified in the subchannel layout table LC/I,L/. /inch/ or /cm/.
I = subchannel subscript.
AL9L/I,L/,/L=1,4/ = effective centroid distance between adjacent subchannels in an arrangement as specified in the subchannel layout table LC/I,L/. /inch/ or /cm/.

6/ Rod-subchannel layout table: /to be supplied only if J4 > O/

FORMAT /I5/(7 I 5)/

NROD = number of heated rods. /NROD $\leq$ 12/.
NR = heated rod subscript.
LR/NR,L/,/L=1,6/ = subscript of adjacent subchannels in increasing order surrounding the $NR^{th}$ heated rod.

N.B.: Up to six adjacent subchannels may be considered for each rod.

7/ Rod diameters and radial power distribution table

/to be supplied only if J 5 > O/

FORMAT /I 5, 8 F 5.3/

| | |
|---|---|
| I | = heated rod subscript. |
| D/I/ | = outer diameter of the $I^{th}$ heated rod. /inch/ or /cm/. |
| RADIAL/I/ | = relative rod power distribution in the $I^{th}$ total heated rod. /local per average/. /dimensionless/. |
| PHI/I,L/ | = fraction of the $I^{th}$ rod power transferred to the $L^{th}$ adjacent subchannel in an arrangement, as specified in the rod-subchannel layout table LR/NR,L/. /dimensionless/. |

8/ Calculation variables: /to be supplied only if J6 > O/

FORMAT /3 F 5.3, 3 I 5, F 5.2, I 5, 2 F 10.0, 3 I 2/

| | |
|---|---|
| XMIX≡/f.l/ | = friction factor for diversion crossflow./ft/ or /m/. |
| FDIV≡$f_D$ | = correction term for diversion momentum. |
| FMIX≡$f_T$ | = correction term for turbulent momentum. |
| NPRINT | = number of axial locations for print-out. |
| NX | = number of axial subdivisions in print-out increment used for calculation. |
| KDEBUG | = Debug control parameter. /If 1 print out debug information at each iteration. If zero or blank, no debug information is printed./ |
| WERROR | = Allowable error in diversion crossflow. /If zero or blank, a value of 10.0 /lbm/hr.ft/ is used/ |

$$/ \frac{lbm}{hr.ft} / \quad \text{or} \quad / \frac{kg}{hr.m} /$$

| | |
|---|---|
| ITERAT | = maximum number of iterations. /If zero or blank, 25 is used/ |

A1A, B1B, N1C, N1D, N1E ≡ a, b, c, d, e = constants in the equation of the turbulent mixing parameter. /15/

9/ Operating conditions: /to be supplied if J7 > O/

FORMAT /7 F 10.0/

| | |
|---|---|
| POUT | = absolute pressure at the system outlet. /psia/ or /ata/. |
| HIN | = mixed-mean coolant enthalpy at inlet. /Btu/lbm/ or /kcal/kg/. |
| GIN | = average coolant mass velocity. |

$$10^{-6} \cdot / \frac{lbm}{hr \cdot ft^2} / \quad \text{or} \quad 10^{-6} \cdot / \frac{kg}{hr \cdot m^2} / .$$

Z = channel length. /inch/ or /cm/

THETA = channel orientation /deviation from vertical/. /radians/

10/ Different inlet enthalpy for each subchannel

/to be supplied only if HIN is specified < 0/

FORMAT /12 F 5.0/

H/J,1/, /J=1, NCHANL/ = Inlet enthalpy for the $J^{th}$ subchannel. Supply the subchannel subscripts in increasing order. /Btu/lbm/ or /kcal/kg/.

11/ Different inlet coolant flow rate for each subchannel

/to be supplied only if GIN is specified < 0/

FORMAT /6 F 10.0/

F/J,1/,/J=1, NCHANL/ = Inlet coolant flow rate for the $J^{th}$ subchannel. Supply the subchannel subscripts in increasing order. / $\frac{lbm}{hr}$ / or / $\frac{kg}{hr}$ /.

Remarks on input:

Card group 1 is read only once at the start of the calculations. Card group 2-9 must be specified initially /first case of the run/. Any group not changed by succeeding cases will remain the same as the previous case. A blank card at the end of the input data package will stop the calculations. TURMIX program is written for ICL-1905 computers. The code requires a memory capacity of 26750 words. The running time is determined by the complexity of the problem and the desired options, and is about 2-5 minutes.

Code OUTPUT:

First, the most important INPUT data are reproduced in the OUTPUT. Secondly, the calculated results are printed out for each subchannel at each printing point, as follows:

X = absolute distance of the printing points from the inlet of the system. /$0 \le X \le L$/. /inch/ or /cm/.

$\Delta p$/i/,/i=1,N/ = pressure drop in the $i^{th}$ subchannel at each axial printing point. /psia/ or /ata/.

$i_{coolant}$/i/,/i=1,N/ = coolant enthalpy in the $i^{th}$ subchannel at each axial printing point. /Btu/lbm/ or /kcal/kg/.

G/i/,/i=1,N/ = coolant mass velocity in the $i^{th}$ subchannel at each axial printing point.

where $G/i/ = \frac{m/i/}{A/i/}$ ; $10^6$/lbm/hr.$ft^2$/ or $10^6$/kg/hr.$m^2$/.

m/i/,/i=1,N/ = coolant mass flow rate in the $i^{th}$ subchannel at each axial printing point. /lbm/hr/ or /kg/hr/.

Q/i/,/i=1,N/ = average heat flux in the $i^{th}$ subchannel at each axial printing point;

where $$Q/i/ = \frac{q_{total,i}\left(\frac{X}{L}\right)}{P_{H,i}}$$

/total heat transferred per unit length to the $i^{th}$ subchannel per total heated perimeter of the $i^{th}$ subchannel/.

$10^6$/Btu/hr · $ft^2$/ or $10^6$/ $\frac{Watt}{m^2}$ / .

$W_{ij}$ = diversion crossflow between $i^{th}$ and $j^{th}$ subchannel at each axial printing point. /lbm/hr.ft/ or /kg/hr.m/.

$W'_{ij}$ = turbulent crossflow between $i^{th}$ and $j^{th}$ subchannel at each axial printing point. /lbm/hr.ft/ or /kg/hr.m/.

$\beta_{ij}$ = turbulent mixing parameter between $i^{th}$ and $j^{th}$ subchannel at each axial printing point. /dimensionless/

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NOMENCLATURE:

Dimensions are denoted by: L = length, T = time, M = mass,
Θ = temperature, $F = \frac{M.L}{T^2}$ = force,
$H = \frac{M \cdot L^2}{T^2}$ = energy, /n.d/ = dimensionless.

| | |
|---|---|
| $i$ | = subchannel subscript /n.d/ $/1 \leq i \leq N/$ |
| $j$ | = adjacent subchannel subscript of a subchannel. /n.d/ $/1 \leq j \leq M/$ |
| $N$ | = maximum number of subchannels /nd/ $/N \leq 17/$ |
| $M$ | = maximum adjacent subchannel number of a subchannel. /nd/ $/M \leq 4/$ |
| $r$ | = heated rod subscript /n.d/ $/1 \leq r \leq N_{rod}/$ |
| $N_{rod}$ | = maximum number of heated rods /nd/ $/N_{rod} \leq 12/$ |
| $X$ | = axial coordinate /L/ |
| $L$ | = channel length /L/ |
| $\frac{X}{L}$ | = non-dimensional axial parameter. /nd/ |
| A, B, C | = constants in the friction factor equation /6/. /nd/ |
| a,b,c,d,e | = constant in the summarized equation of the turbulent mixing parameter /15/. /nd/ |
| $g_c$ | = gravitational constant $/ \frac{M.L}{F.T^2} /$ |
| $A_i$ | = free flow area in the $i^{th}$ subchannel $/L^2/$ |
| $P_{w,i}$ | = total wetted perimeter in the $i^{th}$ subchannel /L/ |
| $P_{H,i}$ | = total heated perimeter in the $i^{th}$ subchannel /L/ |
| $D_{hydr,i}$ | = hydraulic diameter of the $i^{th}$ subchannel /L/ where: $D_{hydr,i} = 4 \cdot \frac{A_i}{P_{w,i}}$ |
| $D_{rod}$ | = outer diameter of the fuel rod /L/ |
| $Re_i$ | = Reynolds number in the $i^{th}$ subchannel /nd/ where: $Re_i = \frac{G_i \cdot D_{hydr,i}}{\mu_i}$ and $G_i = \frac{m_i}{A_i}$ |
| $m_i$ | = mass flow rate in the $i^{th}$ subchannel /M/T/ |
| $w_{ij}$ | = diversion crossflow between adjacent subchannels /i and j/ $/ \frac{M}{T.L} /$ |

$w'_{ij}$ = turbulent crossflow between adjacent subchannels /i and j/ / $\frac{M}{T.L}$ /

$h_i$ = coolant enthalpy in the $i^{th}$ subchannel / $\frac{H}{M}$ /

$\vartheta_{f,i}$ = liquid specific volume in the $i^{th}$ subchannel /$L^3/M$/

where $\vartheta_{f,i} = \frac{1}{\rho_{f,i}}$

$\rho_{f,i}$ = liquid density in the $i^{th}$ subchannel. /$M/L^3$/

$f_i$ = Darcy-Weisbach friction factor in the $i^{th}$ subchannel

$U_i$ = effective momentum velocity in the $i^{th}$ subchannel /L/T/

$$U_i = \frac{m_i \cdot \vartheta_{f,i}}{A_i}$$

$\Delta P_i$ = pressure drop in the $i^{th}$ subchannel /$F/L^2$/

$\mu_i$ = dynamic viscosity of the coolant in the $i^{th}$ subchannel. / $\frac{M}{L.T}$ /

$q'_{r,i}$ /$\frac{X}{L}$/ = heat transferred per unit length from a rod /r/ to a subchannel /i/ / $\frac{H}{L.T}$ /

$q_{total,i}$/$\frac{X}{L}$/ = total heat transferred per unit length to the $i^{th}$ subchannel from all adjacent fuel surface. / $\frac{H}{L.T}$ /.

$\bar{q}''$ = average heat flux /$\frac{H}{L^2.T}$ /

$z_{ij}$ = effective centroid distance between adjacent subchannels /i and j/ /L/

$s_{ij}$ = full rod gap between adjacent subchannels. /i and j/ /L/

$C_{ij}$ = loss coefficient for transverse crossflow. / $\frac{F}{M^2 \cdot T^2}$ /

$\beta_{ij}$ = turbulent mixing parameter between adjacent subchannels /i and j/. /nd/

$\overline{Re_{ij}}$ = average Reynolds number of the adjacent subchannels /i and j/ /nd/

$\overline{D_{hydr,ij}}$ = average equivalent hydraulic diameter of the adjacent subchannels /i and j/ /L/

$\overline{G_{ij}}$ = average mass velocity of the adjacent subchannels /i and j/. $/ \frac{M}{T.L^2} /$

$\overline{\mu_{ij}}$ = average dynamic viscosity of the adjacent subchannels /i and j/. $/ \frac{M}{L.T} /$

$f \cdot l$ = friction factor for diversion crossflow. /L/

$\Theta$ = orientation of subchannel /deviation from vertical/. /radians/

$f_T$ = correction term for turbulent momentum. /nd/

$f_D$ = correction term for diversion momentum. /nd/

$f_{c,r,i}$ = fraction of the $r^{th}$ rod power transferred to the $i^{th}$ adjacent subchannel. /nd/

$f_{R,i}$ = relative rod power distribution in the $i^{th}$ heated rod /local per average/ /nd/

$f_{A,i}\ /\frac{X}{L}/$ = local to average axial power distribution in the $i^{th}$ heated rod. /nd/

62.008

Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Szabó Ferenc, a KFKI Reaktorkutatási Tudományos Tanácsának elnöke
Szakmai lektor: Vigassy József
Nyelvi lektor: Tóth Iván
Példányszám: 70 Törzsszám: 73-8172
Készült a KFKI sokszorositó üzemében,
Budapest, 1973. április hó

MTA
KFKI