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AN ICL VERSION OF THE 05R PROGRAMM SYSTEM

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ABSTRACT

The well-known O5R /Oak Ridge Random Research Reactor Routine/ code has been adapted for the computer ICL-1905 of the Central Research Institute for Physics, Budapest. The code is divided into 3 individual parts. This report contains short descriptions and user's manuals of all the three programs.

РЕЗЮМЕ

В настоящей статье описывается вариант признанной во всем мире программы O5R /Oak Ridge Random Research Reactor Routine/ , разработанный для ЭВМ ICL-1905 , эксплуатируемой в ЦИФИ. Исходная система программ была разделена на три отдельные программы, которые тоже кратко описываются вместе с информацией, необходимой для их применения.

KIVONAT

A jelen riportban a világszerte jól ismert O5R /Oak Ridge Random Research Reactor Routine/ programnak a KFKI ICL-1905 tipusu számitógépére készitett verzióját ismertetjük. Az eredeti programrendszert három külön programmá bontottuk, ezek rövid ismertetését és a felhasználáshoz szükséges információkat közöljük.

CONTENTS

CONTENTS

1. INTRODUCTION

The O5R Monte Carlo code, developed by R.R. Coveyou, J.G. Sulliven, H.P. Carter and D.C. Irving [1], was sent to our Institute from the ENEA Computer Programme Library, ISPRA with the permission of the ORNL-RSIC. Because of the limited storage capacity of our computer ICL-1905, the original program had to be divided into 3 individual codes. The first two are the cross section library handling codes. DKPC replaces CODE 1, 2 and 3 of the original XSECT routine and DK5R refers to CODE 6 and 8; the other codes of XSECT are omitted.

The third code, RX5R, contains the actual Monte Carlo computations, extended with a source and a collision band analysing routine.

Being a general purpose code, the original O5R code gives us a possibility to add any source and/or analysing routines. The routines presently included have been written for special problems.

The source routine written by the user has to replace the presently existing one, but the analysing program may be a separate code, which utilizes the collision tape created by RX5R.

The whole code is written in FORTRAN IV, and some parts are added in PLAN, the assembly language of the ICL computer /see Section 3.5./.

2. GENERAL FEATURES OF THE PROGRAM SYSTEM

The MC calculation which is essentially free from geometrical limitations may be looked on as a simulation of an idealized experiment. Histories of neutrons are followed step by step.

The user has to give the spatial and energy distribution of the source neutrons, as well as the geometry of the system in which the neutrons are followed. This system can be built up from different materials whose elemental compositions are also defined in the input.

The code XSECT calculates the mean free flight times in the

different media from the cross section data. The site of the following collision is determined so, that a random number having exponential distribution is chosen and is multiplied by the mean free flight time and the speed of the neutron.

In the O5R Monte Carlo transport code the neutrons are grouped in so called batches, and the neutrons of one batch are processed together from beginning to end. The study of a new batch begins when the process of the previous batch is terminated. A new batch may consist of either the fission neutrons produced in the previous batch or newly chosen source neutrons. In the first case the weights of the fission neutrons are renormalized so as to get the same total weight as in the first batch.

The code covers the energy range from 77.13 MeV to 0.07×10^{-3} eV. This energy range is divided into 40 supergroups, whose boundaries are successive powers of 2 in speed squared /in cm^2/sec^2/. Each supergroup can be divided into 2^n equally wide subgroups, where n can be chosen arbitrarily between 0 and 9. Cross-section data are assumed to be constant within each subgroup. Only the cross sections for a single supergroup are stored in the core memory at one time and all neutrons having an energy lying in this supergroup are processed together until they leave this energy range. Cross sections for the next lower supergroup are then read in from tape and the process repeated.

A very general geometry routine permits the treatment of complicated configurations. 8 media, each of which can contain 8 scatterers, are permitted and boundaries may be either planes or quadratic surfaces. For quick finding of the site of a neutron the system is divided into zones by planes, parallel to the coordinate plans. /For simple cases the use of one zone is sufficient./ Moreover, each zone is cut into blocks in the same manner, independently from one another. These blocks are divided into sectors by quadratic surfaces. The sectors are either closed surfaces /e.g. spheres/ or extend from one block boundary to another.

Absorption of neutrons is replaced by reduction of the statistical weight of the neutrons by multiplying with the nonabsorption probability. Both splitting and Russian roulette are allowed, at the option of the user, for handling neutrons having extremely large or small statistical weights. So the user can define spatial regions and weight standards for each region. If the weight of a neutron entering a given region is greater than the upper weight standard then the neutron is split into two equally weighted parts, till the neutron's weights are less than the standard. On the other hand if a neutron's

weight /w/ falls below the lower standard of the given region /as a consequence of the collisions/, then the neutron is killed by a probability of 1 - w/V. If the neutron survives this so called Russian roulette then it gets a weight of V, defined among the input data. For this treatment the geometrical subroutine allows a system of regions for the application of weight standards to distinguish the most important places. The term "region" for the division for application of weight standards is analogous with the term "medium" in the spatial division. The zone and block system for the region geometry must coincide with those for the material geometry, but an entirely independent division of blocks into sectors is permitted.

For an example of a real system divided as mentioned above see Appendix D.

The user can stop the calculation when the neutrons reach the thermal energy /arbitrarily chosen/, or can treat them in one group approximation.

The original code permits taking into account the inelastic scattering, with a routine written by the user. At this time we have no such routine. Therefore the INPUT requirements for this treatment are not included in this report.

Fissioning and anisotropic scattering are permitted. For selecting from anisotropic distribution a special technique of Coveyou is used, which gives the same accuracy as a straightforward selection from a Legendre expansion but requires considerably less computer time /see Reference [1], Appendix I/. Moreover the angular distribution can be modified by biasing the discrete directions selected by the Coveyou technique.

Some of the random number generators were replaced by the standard generators of our program library, some were written by the senior author of this report /see Section 3.4./.

2.1. THE SOURCE ROUTINE

The original O5R code does not contain source routine. We have adapted a source routine [2]/also from Oak Ridge/ for determining the energy, the speed and the initial spatial distribution of neutrons arising from fission. The energy distribution is obtained by sampling a Maxwellian fission spectrum which depends upon the energy of neutrons producing fission. The program locates the neutrons at a point or distributes them spatially, either uniformly or according to a cosine function.

2.2 GENERATION OF NEUTRON HISTORIES

The procedure followed by RX5R for the production of a neutron history is the following.

1/ The neutron gets a name /an integer number/, which distinguishes it from the other neutrons of the batch.

2/ Initial speed, direction of flight, weight and coordinates of birth position are chosen. /These data may be set by the user, or, may result from the distribution of fissions from the previous batch in fissioning systems.

3/ Determination of the medium in which the source neutron lies.

4/ In the case of application of weight standards the neutron is tested for splitting and Russian roulette.

5/ A tentative position for the next collision is chosen. If the flight path lies entirely within the original medium, the tentative position is adapted as the collision site. If the flight path crosses a medium boundary, the distance to this crossing point is subtracted from the length of the flight path and this point becomes the starting point for the continuation of the flight in the new medium. The process continues until the flight path lies entirely within a single medium or the neutron escapes from the system.

6/ A new weight is computed by multiplying the old weight by the survival probability.

7/ The nuclide from which the neutron is to scatter is chosen.

8/ The new velocity, after collision, is calculated.

9/ The new energy of the neutron is compared to an arbitrary cutoff energy. If the energy is greater than the cutoff, the process is continued by returning to step 4, above. In the other case the neutron enters the thermal group.

2.3 THE COLLISION TAPE

Each neutron collision results in the determination of 34 parameters characteristic for the neutron before and after the collision. The data pertinent to the analysis are selected by the user in the RX5R input, and only these selected parameters are written on the so called collision tape.

This tape is used by the analysis routine.

2.4 THE ANALYSIS ROUTINE

For collision tape analysis we have two routines - till now.

The first is the SPCTRM code, written in Oak Ridge [3]. We have joined this code to the O5R set. This code can be used for computing the energy spectrum of neutrons crossing a boundary, of neutrons in the medium and of source neutrons using equal energy intervals or equal lethargy intervals, as the user likes it. It also computes the fraction of neutrons leaking from the system and the average number of collisions before the neutrons are lost.

The second analysing code, the general AGBC routine is under adaptation.

3. USER'S MANUAL

3.1 THE DKPC CODE

The DKPC code contains CODE 1, 2 and 3 of the original XSECT code.

CODE 1 initializes the master cross section tape and writes point cross sections on master tape.

CODE 2 adds cross sections to an existing master tape. Because of the special features of magnetic tape handling of our computer, in case of CODE 2 the existing cross sections have to be copied on a scratch tape. In the second step both the earlier existing and the newly added cross sections are written on the original tape.

CODE 3 prints out contents of master cross section tape.

3.1.1 DKPC input

The first record is the "code" record designating what code is to be used:

Format (A4, I2, I4, I4)
a b c d

a. The word CODE

b. The code number /1, 2 or 3/

c. MTAPE, the logical tape number for the master cross section tape

d. NTAPE, the logical tape number for the scratch tape.

In our representation the logical tape number MTAPE has to be the same as the code number. NTAPE has to be 4, even if there is no need for scratch tape /only CODE 2 uses it/. The name of the master cross section tape is XSECTION.

The following records required for employment of Codes 1 and 2 are as follows:

Record A: Format (I5, I5, I5, I5, E10.5, 8A4)

a b c d e f

a. The element indentifier /> 0/ (see Appendix A)

b. The cross section identifier, according to the following list:

1 = total

2 = elastic scattering

3 = inelastic scattering

4 = fission

5 = ν x fission

6 = ν, the average number of neutrons per fission

7 - 69 = other scattering

70 + k = f_k

The f_k-s are the coefficients of the expansion of the angular scattering distribution in Legendre polynomials. As many as 16 f's are permitted.

c. An integer designating the interpolating scheme, assuming that
8: cross section is linear in lethargy
0: Logarithm of cross section is linear in lethargy
-8: Cross section is linear in energy.

d. Left blank in input

e. A decimal number /suggested use: mass, is not used by the code/

f. Thirty two Hollerith characters

A blank record signals the end of the CODE's input.

Record B: Format (E15.5, E15.5)
a b

a. U: The energy in eV

b. S: The cross section, in barns, or the f values or ν values, as appropriate.

The records B have to be in the order of monotonously decreasing energy.

A blank record signals the end of the list of cross sections for a particular element /for a record A/. The loading sequence: code record, A,B,B...B, blank, A,B,B...B, blank,...A,B,...B, blank, blank.

The CODE 3 needs no other input than the code record.

The last record of the DKPC code is again a "code" record, but instead of the word CODE the word ENDX has to be written and the three numbers are arbitrary.

CODE 1 and 2 print out the contents of records A.

3.2 THE DK5R CODE

The DK5R code contains CODE 6 and 8 of the original XSECT code. CODE 6 prepares the O5R System Data Tape, which contains the mean-free-flight time for each subgroup, the nonabsorption probabilities and the f_1 values /if f_1 approximation is used/ and the fission probabilities for each medium having fissioning.

CODE 8 prepares the so-called "Phi Tape", which contains the data necessary to the employment of the Coveyou technique. Using this method the cosine of a scattering angle is selected from a discrete distribution function instead of the continuous Legendre expansion. The selection rule gives an unbiased estimation for the angle.

The codes 6 and 8 can be used either separately or together. If both codes are called during one run, the order of the codes can be arbitrary.

3.2.1 DK5R input

The first record is the "code" record, the same as for DKPC.

MTAPE has always to be 1. /This is the tape XSECTION/

NTAPE is the logical number of the System Data Tape or Phi Tape created by CODE 6 or 8, respectively. If new tapes are created then NTAPE is 7 or 8; if existing tapes are over-written then NTAPE is 2 or 3, for CODE 6 or 8, respectively. The names of the System Data Tape and Phi Tape are CROSSS and PHITAPE, respectively.

The following records of CODE 6:

Record A: Format (18A4)

72 Hollerith characters

Record B: Format (I5, E10.5, E10.5)
a b c

a. NMED: The number of media in the system /$\leq$8/

b. ETOP: The highest energy of cross sections needed, in eV /< 77 MeV/.

c. ECUT: The lowest energy of cross sections needed, in eV /$>1.8 \times 10^{-5}$ eV/.

The first supergroup on the System Data Tape starts at 2^k, where $2^k >$ ETOP /cm^2/sec^2/ $\geq 2^{k-1}$. The last supergroup ends at 2^L, where $2^{L+1} >$ ECUT $\geq 2^L$.

Record C: Format (I5, I5)
a b

a. NOELM:/ $\leq$ 8/ The number of scatters in medium M.

b. NPOINT: The number of subgroups per supergroup in medium M. NPOINT = 2^j, $0 \leq j \leq 9$. NPOINT may be different for different media.

A record C is required for each medium of the system.

Record D: Format (I5, 5I5, E10.5)
a b c

a. IDELM: element identifier

b. IDSIG: cross section identifiers for element IDELM /see b. of record A in CODE 1 and 2/.

CODE 6 ignores identifiers 4, 6 and $\geq$ 70.

If less than 5 kinds of cross sections are needed fill out with blanks or zeros.

c. Atom density of the element IDELM, in 10^{+24} atoms/cm^3.

A record D is required for each scatter for each medium.

Record E: Format (I5)

NF1: /$\leq$ 8/ The number of scatters giving f_1 scattering

Record F: Format (I5, I5)

a b

/Omit this record if NF1 = 0/

a. NFONE: The element identifier of an f_1 scatterer

b. NPTF1: The number of subgroup per supergroup for this f_1 scatterer.

A record F is required for each f_1 scatterer.

The order of loading the INPUT for CODE 6.

Code record, A, B, C, D, D....C, D, D .... D, E, F, F....F.

In case of CODE 8 the records after the code record are the following:

Record A: Format (18A4)

72 Hollerith characters.

Record B: Format (I5, I5, 12I5)

a b c

a. NEL: /$\leq$ 8/ The number of anisotropic scatterers.

b. MX: /$\leq$16/ The index of the P approximation desired.

c. NP(I), I = 1, NEL: The number of Legendre coefficients available for each scatterer.

NP(I) $\leq$ MX.

Record C: Format (E10.5, E10.5, 10I5)
a b c

a. ETOP: The highest energy of cross-sections needed, in eV.

b. ECUT: The lowest energy, in eV.

c. NPTS(I), I = 1, NEL: The number of subgroups per supergroup for each scatterer. NPTS(I)= 2^j, $0 \leq j \leq 9$.

Record D: Format (I5, 13I5)
a b

a. IDL: Element identifier

b. IDSG: Cross section identifier for f_L, L = 1, NP(I).

A Record D is required for each Legendre coefficient.

The last record of the DK5R code is again a "code" record but instead of the word CODE the word ENDX has to be written and the three numbers are arbitrary.

3.2.2 Restrictions on variables, core store used, use of program switches

The cross sections referring to a single supergroup are stored in the unlabelled common field.

The number of cross sections of one supergroup must not exceed 5200 and the upper limit for the angular distribution data is 2600.

But, as these data are a part of the O5R data, the sum of the numbers of the cross sections and angular distribution data of one supergroup has to be less than 4700 in every circumstances, but generally the upper limit is somewhere about 3000 /see Section 3.3.8./.

Code 6 writes NLAST words per supergroups:

$$NLAST = \sum_{M=1}^{NMED} NPOINT(M) \times (NOELM(M) + IF(M)) + \sum_{M=1}^{NF1} NPTF1(M),$$

where IF/M/ = 2, if there is fissioning element in the Mth medium

= 1, if there is no fissioning element in the Mth medium.

For the other variables see the input of DK5R, Code 6.

The Code 8 writes

$$LZ = (MX + 2) \sum_{M=1}^{NEL} NPTS(M)$$

words per supergroups /see the input of DK5R, Code 8/.

See Chapter 4. about the possibility offered by the use of switch No.2.

3.3 THE RX5R CODE

The "package" required to run a problem with RX5R consists of a System Data Tape and a Phi Tape, which are both made by the DK5R code, and the RX5R input. This RX5R input contains the input data for the substantial part of the code /the so-called 05R Input/, for subroutines GEOM, SOURCE and SPCTRM, in this order.

3.3.1 05R Input

Record A: Format (20A4)

80 arbitrary Hollerith characters for identification.

Record B: Format (I5, I5, I5, I5, E10.5, I5)
a b c d e f

a. NSTRT: The number of neutrons with which to start off each batch; $0 < NSTRT \leq NMOST$

b. NMOST: The maximum number of neutrons permitted to appear during the run of one batch. $NMOST < 4096$

c. NITS: The number of batches in one run.

d. NQUIT: The number of runs.

e. EBOT: The upper limit of thermal group /in eV/.

f. NTHRML: if 0 - no thermal group
if 1 - one velocity thermal group is used.

/A subroutine SNAFU can be added to the code for handling thermal neutrons in other way, in this case NTHRML = 2/

Record C: Format (I5, I5, I5, I5)
a b c d

a. MEDIA: The total number of media, exclusive of voids, appearing in the system. $MEDIA \leq 8$.

b. NCONT1: The logical number of the System Data Tape.

In a problem involving only thermal neutrons, set 0, otherwise 3.

c. NCONT2: May be blank or set equal to NCONT1.

d. NSTAPE: The logical number of the data tape for the thermal-neutron subroutine SNAFU. At this stage leave it blank.

Record D: Format (8I5)

LF1: Designates the type of scattering to be used for each scatterer. The order of the scatterers must be the same as their order on the System Data Tape, as specified by records D of CODE 6.

LF1 = 0: isotopic scattering distribution

= + N: anisotropic distribution function

$P(\mu) = (1 + 3f_1\mu)/2$ in the centre of mass system and use the Nth set of f_1's on the data tape /see Record E, CODE 6/

= - N: anisotropic distribution. The angle is selected by the Coveyou technique. Use the Nth scatterer appearing on the Phi Tape, as determined by the order of record D of CODE 8.

In problems involving thermal neutrons only this record should be omitted.

Record E: Format (7E10.5)

ASSES: Atomic masses, in a.m.u., of each scatterer of a given medium. If there are more than 7 scatterers, a second card is used. The order of scatterers must be the same as the order on the System Data Tape.

For problems involving only thermal neutrons record E is omitted.

Record F: Format (E10.5, E10.5, E10.5)

a b c

This record carries the one-velocity thermal-neutron parameters. It is omitted if a thermal-neutron treatment other than one-velocity is selected.

a. SLOTH: The thermal mean free path for the medium, in cm.

b. SLOTS: The thermal nonabsorption probability for the medium.

c. SLOFS: The average number of fission neutrons produced by a collision at thermal energies in the medium,

$$\nu\Sigma_f/\Sigma_t.$$

Individual records D, E, F must be furnished for each medium, in the same order as they are listed on the System Data Tape.

Record G: Format (E10.4, E10.4, E10.4, E10.4, E10.4)
a b c d e

a. ESOUR: The source energy in eV. /In one-velocity thermal treatment set O and RX5R will set all source velocity square to 1 cm^2/sec^2/

b. UINP
c. VINP
d. WINP

The source neutron direction cosines. The sum of $UINP^2 + VINP^2 + WINP^2$ must be equal to 1. If this sum is equal to zero, RX5R will chose source directions isotropically.

e. WTSTRT: The initial statistical weight of each source neutron.

Parameters computed by SOURCE /if it is used/ will supersede these values.

Record H: Format (E10.4, E10.4, E10.4, I5, I5)
a b c d e

a. XSTRT
b. YSTRT
c. ZSTRT

The coordinates of the initial position of all neutrons /in cm/.

d. NMED: The number of the medium where the initial position lies.

e. NREG: The region where the initial position lies.

Parameters computed by subroutine SOURCE will supersede those given in this record.

Record I: Format (I5, I5, 5X, 36I1, 5X, 9I1)
a b c d

a. NHISTR: The logical number of the first collision tape. A collision tape must always be specified and at least one collision parameter requested. If the internal analysing routine is used, i.e. the data do not have to be preserved, or if no collision tape is desired, then a scratch tape has to be taken on and NHISTR = 1. In the latter case all types of collisions may be omitted under NCOLLS, item d, below. If collision tape has to be created, then NHISTR = 7. The name of the newly created tape: HISTAPE.

b. NHISMX: The highest logical number of the collision tapes. NHISTR $\leq$ NHISMX. At this time the program does not use more collision tapes, so NHISMX = 1. If the user would like to use more than one collision tape then the program has to be recompiled adding a new program description segment. In this case the tapes noted in the program description segment with logical numbers from NHISTR + 1 upto NHISMX can be used.

c. NBIND: An index which designates the collision parameters to be recorded on the collision tape, according to the list in Appendix B. A "1" selects a parameter, a "0" rejects a parameter. For each parameter a "1" or "0" must be punched.

d. NCOLLS: Designates the types of collision to be put on the tape. /In the same manner as c., above/
The indices of the different types of collision are the same as the respective values of NCOLL - the first element in Appendix B.

Record K: Format (I5, I5, I5, I5)
a b c d

a. NSPLT = 1 if splitting of neutrons is to be allowed;
= 0 if splitting is not used

b. NKILL = 1 if neutrons are to be subjected to Russian roulette;
= 0 if not.

c. MXREG: The maximum number of regions in the system.

d. MAXGP: The number of energy groups for the application of weight standards. See next record.

Record L: Format (7E10.5)

EWT: Energy values, in eV, used to divide the energy range of the problem into groups for the application of weight standards. There will be a total of /MAXGP - 1/ values of EWT, listed in descending order. The first group of weight standards then will be applied to neutrons having energies greater than EWT /1/, and so on. The last group of weight standards refers to all neutrons having energies less than EWT /MAXGP - 1/. As many records L as are needed may be used. Record L is omitted if the number of energy groups is 1 or 0 or if NSPLT and NKILL are both equal to 0.

Record M: Format (I5, I5, I5, I5, I5, I5, E10.5, E10.5, E10.5)
a b c d e f g h i

a. NGP1
b. NDG
c. NGP2
d. NRG1
e. NDRG
f. NRG2

These parameters designate particular groups and regions within which the weight standards given by items g, h, i, are to be applied. From energy group NGP1 to energy group NGP2, inclusive, in steps of NDG; and from region NRG1 to NRG2, inclusive, in steps of NDRG the weight standards to be applied are the values given by g, h, i. If NGP1/or NRG1/ is set to 0, all groups /or regions/ will be given the weights specified by g, h and i.

g. WTHIH: Neutrons having weights above this value in the groups and regions indicated will be split.

h. WTLOW: Neutrons having weights below this value in the groups and regions indicated will be subjected to Russian roulette.

i. WTAVE: If a neutron is not killed by Russian roulette it will be assigned a new weight equal to WTAVE.

As many records M as are required may be used. The end of the loading of all weight standards is signalled by a separate record M, with NGP1 = -1.

If neither splitting nor Russian roulette are permitted record M is omitted.

Record N: Format (I5, I5)
a b

a. NSOUR: If NSOUR $\leq$ 0, the original source will be used for every batch of neutrons. If NSOUR $\geq$ 1, the source for the second and succeeding batches will be the neutrons resulting from fissions taking place during the transport of the preceeding batch.

b. MFISTP: The logical number of a scratch tape available for storing intermediate fission data. If no fission occurs in the system, MFISTP = 0 or blank, else 2.

Record O: Format (7E10.5)

FWLOW: The weight to be assigned to neutrons produced by fission. Usually it will be 1.0. A value of FWLOW must be specified for each region. As many records O as are required may be used. This record is omitted if no fissioning occurs in the system.

Record P: Format (I5, I5)
a b

a. NPTAPE: The logical number of the Phi Tape. If no Phi Tape is needed NPTAPE = 0 or blank, else 4.

b. NTYPE: If NTYPE > 0 a biasing of angular scattering is to be done in the problem. NTYPE $\leq$ 0 directs no biasing.

Record Q: Format (7E10.5)

BIAS: The arbitrarily chosen numbers controlling the biasing of the angular scattering. Each root of the Legendre polynomial $P_{n+1}(\mu)$ corresponds to a discrete angle of scattering. A BIAS, which must lie within the range 0.0 to 1.0, must be assigned to each angle in decreasing order, that is from forward scattering to backward scattering. If there is no biasing record Q is omitted.

3.3.2 The geometry routine

The package of subroutines which accomplish the tracing and tallying of neutron paths through such systems is called GEOM.

The entire system is enclosed in a rectangular parallelepiped whose faces are parallel with the coordinate planes. This parallelepiped is then divided into several smaller parallelepipeds, called zones, by planes parallel to the coordinate planes and extending entirely across the system.

The zones are then divided into smaller parallelepipeds, called blocks, by planes again parallel to the coordinate axes but extending only across an individual zone. The planes used as zone and block boundaries need not necessarily be boundaries between media, however, if a boundary between two media is a plane parallel to a coordinate plane it is

advantageous to make it a block or zone boundary.

Boundaries between media which are not also block boundaries may be any quadric surface. A quadric surface is defined by the quadric equation reduced to zero, and it divides the whole space into two regions. In one of the regions the function defining the surface will be positive, in the other it will be negative. Each block may contain a maximum of 18 such surfaces as medium boundaries. The surfaces will divide the block into sectors. A sector is defined as a volume positive to one set of quadratic surfaces but negative to another set. Each sector must contain only one medium, which, however may be the same as the medium in another sector.

It is more efficient to include in a sector definition only those surfaces, which actually form the boundary of the sector. Sectors containing the same medium may overlap.

In addition to the real material media two more material media may be specified: interior void /denoted by medium number 1000/ and exterior void /medium number 0/. This latter is the void between the real reactor and the covering parallelepiped.

Any neutron flight entering an interior void is extended, until it leaves the interior void, and the path length through the void is taken as zero mean free path.

In addition, GEOM also allows a system of regions for the application of weight standards. The zone and block systems for the region geometry must coincide with those for the material geometry but an entirely independent division of blocks into sectors is permitted. The region geometry may be omitted, if no weight standards are used.

3.3.3 Input to GEOM

Record A: Format (I5, 5X, A6, 1X, A7)
a b c

a. NSTAT: if NSTAT = 1, then both material media and statistical region geometry are considered,
if NSTAT = 2, than only material media are pertinent.

b. SEX: Sex of the programmer (MALE or FEMALE).

c. STATUS: Marital status of the programmer /may be omitted if item b is "MALE"/
b. and c. are used only in error messages.

Record B: Format (A11, 5(E10.5, A1))

This record lists the zone boundaries in increasing order along the X axis, including the boundaries of the parallelepiped enclosing the entire system. If in the A1 field there is a comma the list continues, the absence of a comma following the last boundary indicates that the list has ended. The A11 field will be ignored by the code.

Record B': Format (6(E10.5, A1))

If the number of boundaries exceeds the five allowed by the format of Record B, the list is continued on as many records B' as are required.

Record C: Format (A11, 5(E10.5, A1))

Identical with Record B except that the listing is of the zone boundaries along the y axis.

Record C': Format (6(E10.5, A1))

Identical with Record B' but for the y axis.

Record D: Format (A11, 5(E10.5, A1))

Identical with Record B but for the z axis.

Record D': Format (6(E10.5, A1))

Identical with Record B' but for the z axis.

Records from E to P: Constitute a complete zone description.

This set of records must be included once for each zone.

Record E: Format (A6, I5, I5, I5))
a b c d

a. The word ZONE

b,c,d. These integers specify the zone as being the lth, mth, and nth in the x, y and z directions, respectively.

Records from F to H' are the same as records from B to D', but for block boundaries /the Formats are the same/.

Record J is the same as Record E, but for blocks /a - the word BLOCK/.

Record K: Format (A12, 10(I5, A1))
a b

a. The word MEDIA

b. A list of the media, sector by sector, in the block.

A comma in the A1 field indicates that the list continues, its termination is indicated by the abscence of the comma.

Record K': Format (12(I5, A1))

The continuation, if required, of the medium list.

Record L: Format (A12, 10(I5, A1))
a b

a. The word SURFACES

b. A list of quadric surfaces appearing in the block. Commas in the A1 field indicate that the list continues, a blank indicates the end of the list. The numbers derive from the order in which the surfaces are mathematically described in Record R, see below.
/The boundaries of the block must not be mentioned/

Record L': Format (8(I5, A1))

The continuation, if needed, of the surface list.

Record M: Format (A6, 24I3/(6X, 24I3))
a b b

a. The word SECTOR.

b. For every sector in the block there must be a Record M, which will have as many references as there are surfaces in the block. The status of the sector is listed according to the following key:

+ 1: The sector is on the positive side of the surface

- 1: The sector is on the negative side of the surface

0: The surface is not needed in the definition of the sector.

The order of the surfaces in Records L and M must be the same.

If there is only one sector in a block, Records L and M should be omitted.

Records N, O and P specify the region geometry in the block. If there is no region geometry or there is only one region these records are omitted.

Record N: Format (A12, 10(I5, A1))
a b

a. The word REGIONS.

b. A list of the regions, sector by sector in each block.

The role of the A1 field is the same as it was in the previous records.

Record N': Format (12(I5, A1))

A continuation, if required, of the region list.
Record O, and O' have the same format and structure as records L and L' above, but for the region division.

Record P is the same as Record M but for the region division.

Record Q: Format (I5, 11A6)
a b

a. The total number of quadric surfaces in the entire system.

b. For the user's convenience, it is ignored by the code.

Record R: Format (4(E10.5, A4, 1X, A1))
a b c

Each quadric surface is described by writing the quadric function in a fixed field format:

a. The coefficient of the term.

b. May be XSQ, YSQ, ZSQ /for x^2 etc./
XY, XZ, YZ, YX, ZX, ZY, X, Y, Z, or blank. The first letter has to be written into the first position of the A4 field.

c. A non-blank character in this field indicates the end of the function. The next function must start in a new record.

It will be noted that the function is written in such a fashion, that the exterior of the quadric surface is positive in agreement with the sector designation of Records M and P.

3.3.4 The analysing routine

As the original O5R program has neither source nor analyser routine, these codes have to be written by the user. The so-called SPCTRM routine written by G.W. Morrison, J.T. Mihalczo and D.C. Irving [2] is included in our RX5R package.

This subroutine analyses the Collision Tape to obtain the energy spectrum of neutrons crossing a boundary, leaking from the system, having a real collision, or the spectrum of the source neutrons, using maximum 100 equal energy intervals or logarithmic energy intervals.

It also computes the fraction of neutrons leaking from the system and the average number of collisions before the neutrons are lost. The standard deviation of the spectra is also determined.

The code offers a possibility for ignoring the results of some first and last batches.

3.3.5 SPCTRM Input

Record A: Format (I3)

NOPT: = 0, if equidistant energy intervals are used
= 1, if equidistant lethargy intervals are used
= 2, if SPCTRM code is not used, at all.

Record B: Format (I3, I3, I3, 3X, 9I1)
a b c d

a. NBOX: The number of energy intervals between ETOP1 and ELOW1 /see Record C, below/.

b. NTHROW: The index of the last batch, yet ignored.

c. NTOBCH: The index of the last batch to be analysed.

d. ILK: Indicates, what collisions are to be analysed, according to the list in Appendix B. The 1st, 2nd, 4th and 7th types may be used, separately, or together. If a collision type is selected, then punch 1, if rejected, punch 0.

Record C: Format (E10.5, E10.5)
a b

a. ETOP1: The upper limit of energy groups. Neutrons having energy greater than ETOP1 are handled in one group.

b. ELOW1: The lower limit of energy groups. Neutrons having less energy, are handled in one group.

If NOPT in Record A is 2, than Records B and C should be omitted.

3.3.6 The SOURCE routine

The SOURCE routine of J.T. Mihalczo, G.W. Morrison and D. Irving [3], which is included in RX5R, is a program for determining the energy, the speed and the initial spatial distribution of neutrons arising from fission. The energy distribution within the batch of neutrons is obtained by sampling a Maxwellian fission spectrum, which depends upon the energy of the neutrons producing fission. If this source routine is not used, then the RX5R code chooses the energy automatically from the Watt-fission spectrum /modified by Cranberg et al. [4]/.

3.3.7 Input to SOURCE

Record A: Format (E5.2)

UNU = 0. SOURCE is not used
> 0. SOURCE is used

Record B: Format (E10.5, I5)
a b

a. TEMPER: The temperature of the first batch in the Maxwellian distribution.

b. NSORCE: Determines the spatial distribution of the first generation neutrons.

NSORCE = 1, point source is desired, the values of XSTRT, YSTRT and ZSTRT of Record H of 05R input are used as coordinates,

= 2, uniform distribution is to be sampled,
= 3,cosine distribution along each of the coordinate axes is to be sampled.

Record C: Format (E10.5, E10.5, E10.5, E10.5, E10.5, E10.5)
a b c d e f

a. XZERO: The X coordinate corresponding to the center of the cosine or of the uniform distribution.

b. XLENTH: The X coordinate at which the source spatial distribution becomes zero. For the cosine distribution XLENTH corresponds to L in the relationship

$$S/X/ = \cos \frac{\pi}{2L} X$$

c. YZERO
d. YLENTH
e. ZZERO
f. ZLENTH

} The same for the Y and Z axis.

Record D: Format (E10.5, E10.5)

a b

a. E: The energy in eV, in decreasing order

b. TBAR: The nuclear temperature corresponding to the energy specified in /a/ for the Maxwellian distribution.

As many as 100 values of E and TBAR pairs may be used.

Record E: A blank record.

Record D is ignored by the program in the solution of one velocity problems.

Records B - E have to be omitted if UNU = 0.

3.3.8 Additional information /memory, switch/

The RX5R code is an overlay program with one area /plus the permanent area/ of six units. The whole program needs 27712 words of memory.

There is the common field labelled "N" in which the input data and the intermediate results are stored. The dimension of this block is 4700.

After having read in the input data the code computes the size of the unused part of this common block in words and writes it out. If this number is negative /i.e. more than 4700 words would be needed/ the program terminates.

The core store required for this common block may be estimated as follows:

A. MAXGP words for the energy boundaries of the weight standards /see: Record K of O5R Input/

B. 3 * MAXGP * MXREG words for the weight standards /see: as above/

C. $\lesssim$ 500 words for geometry input data

D. 11 * NMOST words for the neutron bank containing the current variables for each neutron in the batch /see Record B of O5R Input/

E. NLAST words for the cross section data from the System Data Tape /see: Section 3.2.2./

F. LZ words for the angular distribution data from the Phi Tape /see: Section 3.2.2./.

As it can be seen from this list the great flexibility and ability of the O5R code cannot be exploited in our 32K computer, therefore problems of relatively little volume are only solvable.

See Section 3.4 about the possibility offered by the use of switch No.2.

3.4 RANDOM NUMBER GENERATORS

The RX5R random number package contains several subprograms which can be used to obtain various types of pseudorandom numbers. The first five of these subprograms only call the standard generators of our program library [5], the last two use the standard generator RDMUNI2. The fission spectrum generator uses the method described in ref.[6] The generation of random numbers with Maxwellian distribution is described in Appendix C.

As the sequence of the random numbers is the same for all the runs, for avoiding this repetition the RX5R code calls the basic random number generator /RDMUNI2/ N - times before the beginning of every run. N is randomly chosen so, that the code calls the ITIME routine, which gives the actual time in seconds, and last three decimal figures of this number are used as N.

If the user wants to get reproducible results, then this process can be omitted by switching on the switch No.2.

List of routines:

Fortran Calling Statement	Library Routines Called
R = FLTRNF(DUMMY)[1]	RDMUNI2 (DUMMY)
R = EXPRNF(1.)	RDMEXP1(1.)
R = SFLRANF(DUMMY)	RDMUNI2SG(DUMMY)
CALL GTISO(X,Y,Z)	RDMDRCOS3DM(X,Y,Z)
CALL AZIRN(X, Y)	RDMDRCOS2DM(X,Y)
	Distribution of the random number generated
R = FISRNF(DUMMY)	Watt fission spectrum $P/R/dR = c.e^{-R/T}.\mathrm{sh}\sqrt{2.29R}$, where T = 0.965 /see [4]/
R = RNMAXF(T)	Maxwellian energy distribution: $P/R/dR = \sqrt{\frac{4R}{T^3\pi}}\ e^{-R/T}\ dR$, where T = the nuclear temperature

[1] A DUMMY argument not used by the code

The SCATR routine, which computes the scattering angle uses a very interesting procedure not described in the original report for determining this angle in the linear anisotropic case. This procedure is described in Appendix C.

3.5 AUXILIARY ROUTINES WRITTEN IN PLAN

There are three routines /OR, AND and COMPL/ for handling the contents of storage bit by bit.

As their names indicate the subroutines OR and AND create the logical sum and product, respectively, of the contents of two storages locations, while the routine COMPL creates the complementer of the content of the storage location.

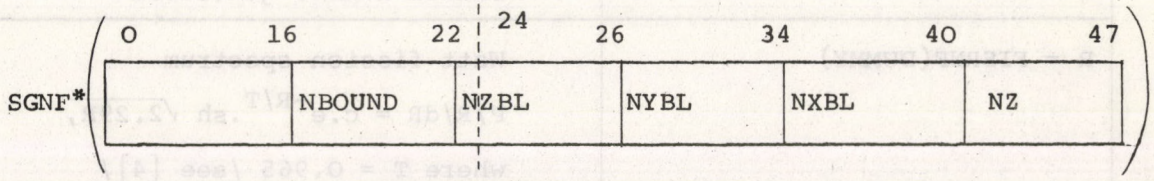
Fortran calling statements:

```
I = OR(K,L)
I = AND(K,L)
I = COMPL(K)
```

The JOM15 routine makes a packed word which gives the block and zone location of the actual collision site. /This word and the same word for the previous collision can be stored on the collision tape under items 29 and 28, respectively, see Appendix B./

The JOM14 routine unpacks the words having packed by JOM15, and calculates NBL.

The structure of this packed word named BLZON:



where SGNF for boundary crossing pseudo collisions, the signum, allocated by the surface crossed, to the space from where the neutron arrives at the surface /see Record M, of GEOM input/.

NBOUND: The number of the surface crossed /see Record L, of GEOM/

NXBL
NYBL
NZBL — The indices of the block along with the coordinata axis.

NBL The number of the block where the collision site lies.

NZ The number of the zone in which this block lies.

The first two quantities are not equal to zero only if the collision is a boundary crossing pseudo collision.

As it can be seen from the scheme NZ has to be less than 2^7 = = 128, and the number of surfaces appearing in the system must not exceed 2^6 = 64, but these limitations have no importance because of the small memory of our computer. There is a limitation, similarly not too important, for NMOST /the maximum number of neutrons existing in the system/, as it must be less than 4096.

3.6 SUMMARY OF PERIPHERIALS, SWITCHES USED AND CORE REQUIREMENTS

program	TR	LP	MT	CORE	SWITCH can be used
DKPC	1	1	1 or 2	9183	——
DK5R	1	1	2 or 3	27649	No.2
DX5R	1	1	usually 4	27712	No.2

NB. The codes contain many error messages, but these are all detailed and clear error descriptions, no additional comment is necessary.

4. OUTPUT OF THE CODES

The main output of the DKPC code in modes CODE 1 and 2 is the new or modified XSECTION tape. Short indications of the operations are printed out on the line printer. The output of the CODE 3 is the whole content of the cross section tape, printed on the line printer.

The DK5R code writes the System Data Tape and/or the Phi Tape. The input data and /after the successful completion of the data tape/ the "A-OK" message are printed out on the line printer.

If the switch No.2. is on, then the CODE 6 prints out all the data written on the System Data Tape. The data of a new supergroup are written on a new page, but there is no indication of the kind of cross sections.

The primary output of RX5R is the collision tape. The input to RX5R is printed out as it is read, and, in addition, several quantities which were input to Codes 6 and 8 are obtained from the system data and phi tapes and printed out. /ELEMENTS: the number of scatterers on the phi tape. COEFF: the number of discrete angles allowed for scattering. This will exceed the index of the approximation by one. POINTS: the number of subgroups per supergroup for each scatterer.

$$Q(I),\ I = 1,\ COEFF:$$

the cosines of allowed scattering angles./

Following the printing of the input, a line of occasionally useful data is printed three times during each batch: after all source neutrons have been generated; after slowing down has been completed and

before treatment of the thermal group has begun; and at the end of the batch. If there is no thermal group the second printing is omitted. The quantities printed are:

WEIGHT: The total neutron weight remaining. Neutrons that have escaped or have been killed by Russian roulette will have weight zero but neutrons degraded below the energy cutoff will have their non-zero weights.

X, Y and Z averages: the weighted coordinates averaged for all neutrons.

FTOTL: The sum of weights produced in the fissions.

FWATE: The sum of weight of neutrons stored in the fission bank.

These two latest quantities are not equal to each other, as in case of weights which are not integer times the fission weight given in the input, the fission created neutrons undergo a splitting and/or Russian roulette, before being stored in fission bank.

At the end of the run the multiplication coefficients of every batch and their average /for all the batches/ with its standard deviation are printed out.

If the internal analysing routine is used then the collision tape would not be preserved, and this routine has the printed output of its own, which contains the energy spectra of collisions /and/or pseudo collisions/ requested in the input, together with their standard deviations and the average number of collisions is also included in the output.

ACKNOWLEDGMENTS

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APPENDIX A

THE CONTENT OF THE CROSS SECTION LIBRARY

The name of the tape: XSECTION

The identification number of the tape: 1656/1

Only the cross sections marked with an "x" can be used by the DK5R code. The remainders can be used by other programs.

The cross section identifiers are commented where they differ from the numbers given in Section 3.1.1, Record A.

Element identifier	Element	Cross section identifier	Cross section
26000	Fe	x 1	
		x 2	
		9	/N-X/
		20	/N,G/
		21	/N,P/
		30	/N,NxG/
		31-37	1st-7th level
		46	/N,2N/
		x71-78	
		701-708	inelastic f1-f8
29000	Cu	x 1	
		x 2	
		9	nonelastic
92235	U-235	x 1	
		x 2	
		x 3	
		4	
		x 5	
		6	
		x71-84	
92238	U-238	x 1	
		x 2	
		x 3	
		4	
		x 5	
		6	
		x71-84	

Element identifier	Element	Cross section identifier	Cross section
94239	Pu-239	x 1	
		x 2	
		4	
94241	Pu-241	x 1	
		x 2	
		4	
28000	Ni	x 1	
		x 2	
		30	/N,NxG/
		31-32	1st-2nd level
		x71-78	
40000	Zr	x 1	
		x 2	
		x 3	
		30	/N,NxG/
		46	/N,2N/
		x71-76	
42000	Mo	x 1	
		x 2	
		30	inelastic
		x71-78	
1001	H	x 1	
		x 2	
		20	/N,G/
1002	D	x 1	
		x 2	
		46	/N,2N/
		x71-76	
3006	Li-6	x 1	
		x 2	
		30	/N,NxG/
		31	1st level
		21	/N,P/
		51	/N,ND/
		52	/N,NT/
		x71-78	
3007	Li-7	x 1	
		x 2	
		30	/N,NxG/
		31	1st level
		52	/N,NT/
		x71-78	

Element identifier	Element	Cross section identifier	Cross section
4000	BeO	x 1	
		x 2	
		46	/N,2N/
		31	1st level
		x71-78	
		701	inelastic f1
5000	B /nat./	x 1	
		10	scatter
5010	B-10	x 1	
		10	scatter
6000	C	x 1	
		x 2	
		9	non-elastic
		13	assorted non-elastic
		22	/N,ALPHA/
		30	/N,NxG/
		53	/N,Nx3A/
		x71-76	
		701-708	/N,NxG/ f1-f8
7000	N	x 1	
		x 2	
		9	non-elastic
		30	/N,NxG/
		31	1st level
		x71-78	
		300	/N,NxZ/
		310...400	1st-10th level
8000	O	x 1	
		x 2	
		9	non-elastic
		30	/N,NxG/
		31-32	1st-2nd level
		x71-78	
9000	F	x 1	
		10	scatter-total
11000	Na	x 1	
		x 2	
		9	/N,X/
		20	/N,G/
		31-35	1st-5th level
		x71-78	

Element identifier	Element	Cross section identifier	Cross section
12000	Mg	x 1	
		x 2	
		20	/N,G/
		30	/N,NxG/
		31-34	lst-4th level
		46	/N,2N/
		50	/N,NP/
		x71-78	
13000	Al	x 1	
		x 2	
		30	/N,NxG/
		31-37	lst-7th level
		46	/N,2N/
		x71-78	
		701-708	inelastic f1-f8
14000	Si	x 1	
		x 2	
		9	non-elastic
		30	/N,NxG/
		31-32	lst-2nd level
		x71-78	
		701-708	inelastic f1-f8
16000	S	x 1	
		x 2	
		20	/N,G/
		30	/N,NxG/
		31-34	lst-4th level
		x71-78	
20000	Ca	x 1	
		x 2	
		30	/N,NxG/
		31-34	lst-4th level
		x71-78	
24000	Co	x 1	
		x 2	
		30	/N,NxG/
		31-32	lst-2nd level
		x71-78	

Element identifier	Element	Cross section identifier	Cross section
19000	K	x 1	
		x 2	
		9	non-elastic
		20	/N,G/
		21	/N,P/
		22	/N,A/
		23	/N,D/
		30	/N,NxG/
		31-35	1st-5th level
		46	/N,2N/
		50	/N,NP/
		53	/N,NxA/
		x71-78	

APPENDIX B

THE COLLISION TAPE: HISTAPE

B.1. The collision parameter list

The parameters listed below can be stored on the collision tape by punching 1 in the appropriate field of Record I of O5R input.

1. NCOLL — An integer identifying the type of collision /in general sense, i.e. a boundary crossing is also a collision/ to which the parameters following apply.

NCOLL =
- 1 source neutron data
- 2 real collision
- 3 neutron killed by Russian roulette
- 4 escape from the system
- 5 splitting, the data for the original neutron are given with its weight after splitting
- 6 same as 5, except that the data for the new neutron are given
- 7 crossing a medium boundary
- 8 neutron survives a Russian roulette
- 9 not presently used

2. NAME — An integer which identifies the colliding neutron

3. SPDSQ — The speed squared after collision.

4. U
5. V
6. W

— Velocities in the X, Y, Z directions, after collision.

7. X
8. Y
9. Z

— The coordinates of the collision site.

10. WATE — The neutron weight after collision.

11. SPOLD — The speed squared befor collision.

12. UOLD
13. VOLD
14. WOLD

— Velocities in the X, Y, Z directions, before collision.

15. XOLD
16. YOLD
17. ZOLD

Coordinates of the site of the previously recorded event.

18. OLDWT — The neutron weight before collision.

19. THETM — The mean free flight time to the collision.

20. PSIE — The nonabsorption probability at the collision site.

21. ETAUSD — The mean free paths used to arrive at the collision point, measured from the last collision point /which may be a boundary crossing/.

22. NGROUP — An integer identifying the energy supergroup within which SPOLD lies. NGROUP is 1 for the highest supergroup.

23. LELEM — An integer identifying the nuclide collided with. LELEM is 1 for the first scatterer listed in the medium.

24. NREG — An integer identifying the region in which the collision occurs.

25. NMED — An integer identifying the medium of collision site.

26. NAMEX — An integer identifying the neutron from which the current neutron was produced by splitting. NAMEX = 0 for source neutrons.

27. WATEF — The fission weight produced at this collision point /WATEF = OLDWT $x\nu\Sigma_f/\Sigma_t$/.

28 BLZNT — A packed word /see Section 3.5/ giving the block and zone location of X, Y and Z.

29. BLZON — A packed word giving the block and zone location of XOLD, YOLD and ZOLD.

30. LAMBDA — The mean free path in the medium before the collision /LAMBDA = THETM x SO/

31. SO — The speed of the neutron before collision /SO = SQRT(SPOLD)/

32. S1 — The speed after collision /S1 = SQRT(SPDSQ)/

33. ETATH — The time taken to arrive at the collision point from the previous collision point /ETATH = THETM x ETAUSD/

34. FONE — The average value of the cosine of the scattering angle in the center of mass system.

35-36 — Not used, till now.

E.2. THE INFORMATION STORED IN HISTAPE

The maximum length of a record is equal to 256 words. The room for the collision data is equal only to 253 words as two words are used for special purpose mentioned below and the last word is always empty. The number of parameters to be stored is given by NBIND /05R input, Record I/. These two values /253 and NBIND/ determine the number of collisions stored in a single record. /A new record is begun if in the current record there is no room for all the parameters of the next collision./ The first two words /NBANK1, NBANK2/ of each record have particular importance, as the first designes the serial number of the current record, while the second determines the kind of the record according with the following list:

NBANK2 = 0: the record contains the collision parameters,

1: designes the end of a batch. In this case the other words of this terminal record are zeros.

3: the end of run, the other words here are also zeros.

Only the parameters determined by NBIND are written on the tape, in the same order as in the list /mentioned earlier/. All the information are stored unformatted.

APPENDIX C

SPECIAL RANDOM NUMBER SELECTING TECHNIQUES

I. SELECTING FROM MAXWELLIAN DISTRIBUTION

The Maxwellian distribution has the form

$$f(R)dR = \frac{2}{\sqrt{\pi}} \sqrt{R}\, e^{-R}\, dR \qquad 0 \leq R < \infty \qquad /1/$$

where $R = E/T$, T = the nuclear temperature /see subroutine SOURCE 2/

As it is well known the χ^2_3 distribution / χ^2 distribution whith 3 degrees of freedom/ has the same form, so far selecting from a Maxwellian distribution one has to choose 3 independent random numbers from a Gaussian distribution $N(0,1)$ and sum them as follows:

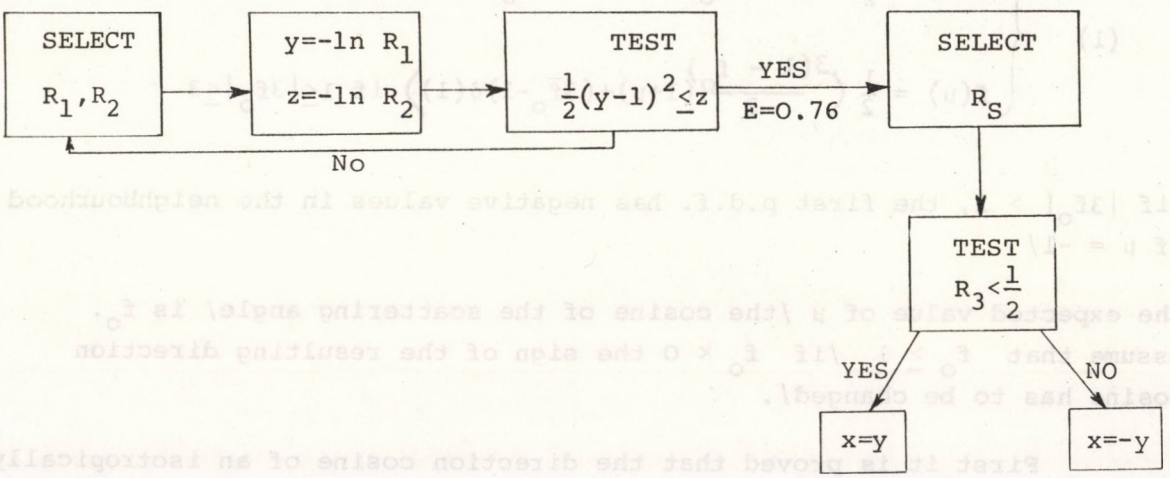
$$P(\chi^2_3 < y) = \frac{1}{\sqrt{2\pi}} \int_0^y \sqrt{t}\, e^{-\frac{t}{2}}\, dt \qquad y > 0$$

thus p . d . f /replacing t by 2R/

$$f_{\chi^2_3}(R)\, dR = \frac{2}{\sqrt{\pi}} \sqrt{R}\, e^{-R}\, dR$$

the same as eq. /1/

The generation of Gaussian distributed random numbers is given in the flow chart [9]



Instead of detailed proof it is enough to mention that probability of selecting a given x value is equal to the product of the probability of choosing and that of the exceptence of this value.

Or

$$Ef(x)dx = P(x_o<x<x_o+dx)*P(\tfrac{1}{2}|x_o-1|^2 \leq z) = e^{-x_o}.e^{-\frac{(x_o-1)^2}{2}} = e^{-\frac{1}{2}}e^{-\frac{x_o^2}{2}}$$

The efficiency of the selecting technique is:

$$E = \sqrt{\frac{\pi}{2e}} \approx 0,76$$

Thus selecting 3 independent normally distributed random numbers ξ_1, ξ_2, ξ_3 and giving

$$R = \frac{\xi_1^2 + \xi_2^2 + \xi_3^2}{2}$$

R is just the proper random variable.

II. DETERMINATION OF LINEAR ANISOTROPIC ANGULAR DISTRIBUTION WITH A TECHNIQUE OF COVEYOU

The probability density function of a linear anisotropic angular distribution may be written in the form:

$$(1) \quad \begin{cases} f(\mu) = \frac{1}{2}\ (1 + 3f_o\mu) & \text{if } |3f_o| \leq 1 \quad -1 \leq \mu \leq 1 \\ f(\mu) = \frac{1}{2}\left(\frac{3(1-f_o)}{2}(1+\mu)+(3f_o-1)\delta(1)\right) & \text{if } 1 \leq |3f_o| \leq 3 \end{cases}$$

/if $|3f_o| > 1$, the first p.d.f. has negative values in the neighbourhood of $\mu = -1$/

The expected value of μ /the cosine of the scattering angle/ is f_o. Assume that $f_o \geq 1$ /if $f_o < 0$ the sign of the resulting direction cosine has to be changed/.

First it is proved that the direction cosine of an isotropically choosen direction vector to an arbitrary direction has a uniform distribution.

Consider the unit sphere, and let the Z axis be this arbitrary direction. The probability that the cosine of the angle between the Z axis and the unit vector choosen isotropically, lies between Z_o and $Z_o + dZ$ $/Z_o < 1/$, proportional to the surface of the spherical shell, determined by the $Z = Z_o$ and $Z = Z_o + dZ$ planes.
As this surface is equal to $2\pi dZ$, so the distribution is uniform.

The flow chart of the COVEYOU selection technique is given in Figure 1.

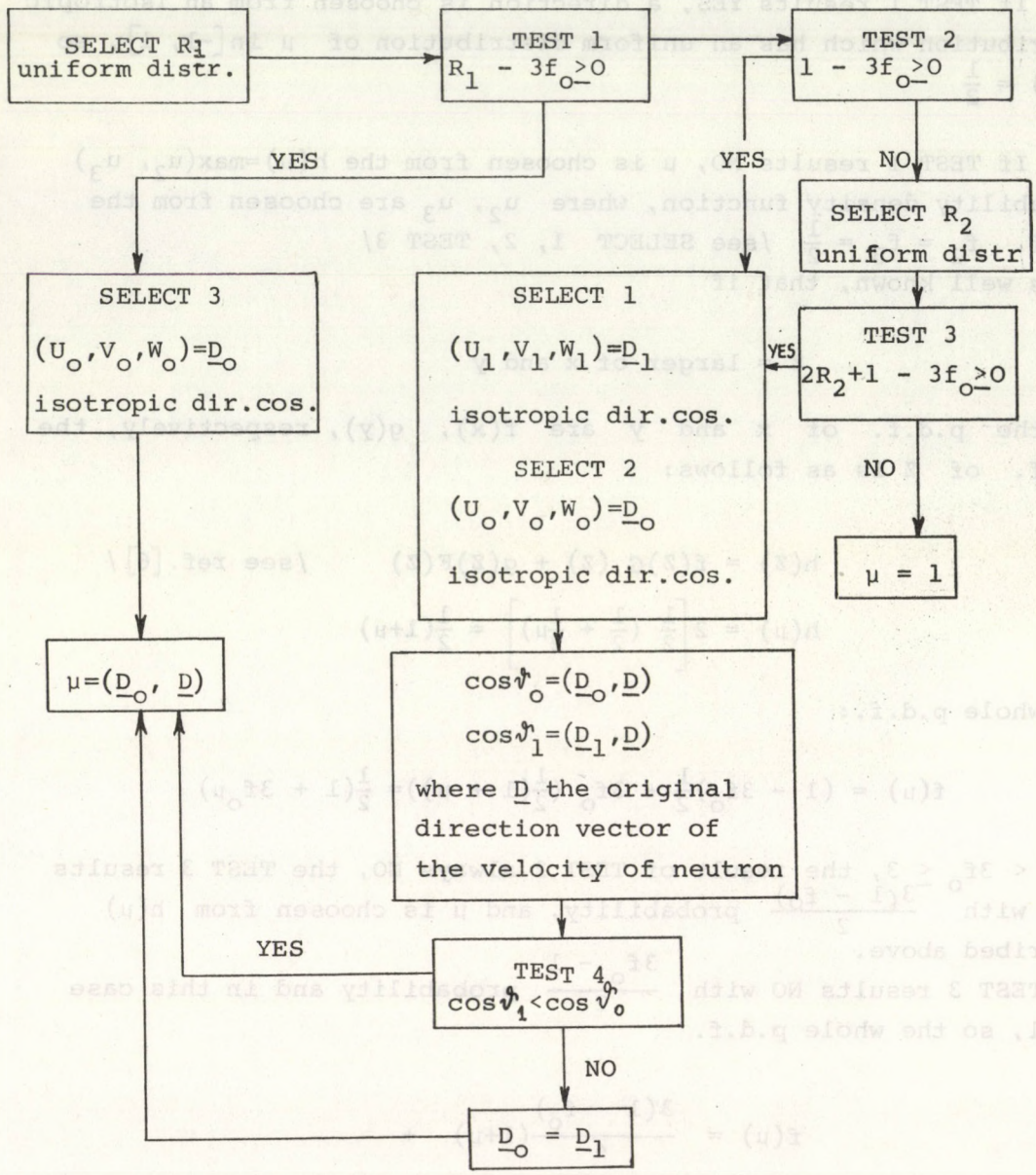


Figure 1

Following the procedure represented by the flow chart the cosine of the scattering angle, distributed as (1) can be determined.

Proof

1. Assume that $3f_o \leq 1$

In this case TEST 2 results always YES. The result of TEST 1 is YES with $(1 - 3f_o)$ probability and NO with $3f_o$ probability.

If TEST 1 results YES, a direction is choosen from an isotropic distribution which has an uniform distribution of μ in $[-1, 1]$, so $f_1(\mu) = \frac{1}{2}$

If TEST 1 results NO, μ is choosen from the $h(\mu)=\max(u_2, u_3)$ probability density function, where u_2, u_3 are choosen from the p.d.f. $f_2 = f_3 = \frac{1}{2}$ /see SELECT 1, 2, TEST 3/
It is well known, that if

$$Z = \text{larger of } x \text{ and } y$$

and the p.d.f. of x and y are f(x), g(y), respectively, the p.d.f. of Z is as follows:

$$h(Z) = f(Z)G(Z) + g(Z)F(Z) \qquad \text{/see ref.[6]/}$$

so

$$h(\mu) = 2\left[\frac{1}{2}\left(\frac{1}{2} + \frac{1}{2}\mu\right)\right] = \frac{1}{2}(1+\mu)$$

The whole p.d.f.:

$$f(\mu) = (1 - 3f_o)\frac{1}{2} + 3f_o\left(\frac{1}{2}(1 + \mu)\right) = \frac{1}{2}(1 + 3f_o\mu)$$

2. If $1 < 3f_o \leq 3$, the result of TEST 2 always NO, the TEST 3 results YES with $\frac{3(1 - f_o)}{2}$ probability, and μ is choosen from $h(\mu)$ described above.
The TEST 3 results NO with $\frac{3f_o - 1}{2}$ probability and in this case $\mu = 1$, so the whole p.d.f.

$$f(\mu) = \frac{3(1 - f_o)}{4}(1+\mu) + \frac{-1 + 3f_o}{2}\,\delta(1)$$

q.e.d.

APPENDIX D

SAMPLE PROBLEMS

The program system was tested for two problems. One of these was proposed in the original report [1], while the second is a model of a reactor, the criticality of which was calculated by other codes.

1st test

Carlson and Bell [7] proved that a sphere having a radius of 4.8727 mean free paths is critical, when $c = (\sigma_s + \sigma_f)/\sigma_T = 1.1$. The first test is the simulation of this critical system.

Let $\sigma_t = 1$ b, $\sigma_s = 1$ b and $\nu\sigma_f = 0.1$ b. With a nuclear density of 10^{24} nuclei/cm^3 the radius of the sphere must then be 4.8728 cm.

To achieve isotropic scattering in the laboratory system, a scatterer having a mass of two and appropriate anisotropic scattering in the center of mass system was chosen.

A single medium with a single scatterer /called: Pandemonium/ was used. The initial source used for the first batch was a point isotropic source having a Watt fission spectrum and it was located 3.3 cm from the center of the sphere. The succeeding batches use the neutrons produced by the neutrons of the previous batch. At the start of each batch RX5R automatically adjusts the neutron weight so that all batches have the same total starting weight, and thus are statistically equivalent.

10 batches each of which contained 50 neutrons were handled.
The input is given in Figs. 2 - 7.
Our result: $k_{average} = 0.9382$
standard deviation:0.0377
Running time = 14.5 minutes /RX5R/

2nd test

The criticality of a homogenised real reactor model was also studied by the O5R code system. However, it has to be mentioned, the Monte Carlo codes are not appropriate for critical thermal reactor calculations because very long time is needed.

The geometry of the reactor is given in Fig.8.

The dimensions of the critical reactor were earlier calculated by the code GRACE [8].

The neutrons of the first batch started from a point source with energies selected from Watt fission spectrum. One batch contained 20 neutrons /or neutrons produced by fission having the weights of 20/ and 5 batches were considered.

Number of subgroups:

for cross sections: 128

for Legendre coeff.: 32

Order of Legendre polinomials: 5

Our result: $k_{average} = 1.04$

standard deviation: 0.082

Running time = 5 h 32 min /RX5R/ without Russian roulette

TITLE DKPC 1st test

I.C.T. FORTRAN CODING SHEET

SHEET 1 /

PROGRAMMER

DATE / /

C STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
CODE	1	1 4	CODE 1
999		1 8 2 2.0 PANDEMONIUM TOTAL	RECORD A
		1.E8 1.0	B
		1.00 1.0	B
			BLANK
999		2 8 2 2.0 PANDEMONIUM ELASTIC	A
		1.E8 1.0	B
		1.00 1.0	B
			BLANK
999		5 8 2 2.0 PANDEMONIUM NU*FISSION	A
		1.E8 0.1	B
		1.00 0.1	B
			BLANK
999		71 8 2 2.0 PANDEMONIUM F1	A
		1.68 -3.33333E-01	B
		1.00 -3.33333E-01	B
			BLANK

FORM 1/542 (8.64)

Fig. 2

TITLE DKPC 1st test

I.C.T. FORTRAN CODING SHEET

SHEET 2. /

PROGRAMMER

DATE / /

C STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
999		72 8 2 2.0 PANDEMONIUM F2	RECORD A
		1.E8 1.50000E-01	B
		1.00 1.50000E-01	B
			BLANK
999		73 8 2 2.0 PANDEMONIUM F3	A
		1.E8 -7.14286E-02	B
		1.00 -7.14286E-02	B
			BLANK
999		74 8 2 2.0 PANDEMONIUM F4	A
		1.E8 3.74222E-02	B
		1.00 3.74222E-02	B
			BLANK
999		75 8 2 2.0 PANDEMONIUM F5	A
		1.E8 -1.70455E-02	B
		1.00 -1.70455E-02	B
			BLANK
999		76 8 2 2.0 PANDEMONIUM F6	A

FORM 1/542 (8.64)

Fig. 3

TITLE DKPC 1st test

I.C.T. FORTRAN CODING SHEET

SHEET 3 /

PROGRAMMER

DATE / /

C STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
		1.E8 8.413466E-03	RECORD B
		1.00 8.413466E-03	B
			BLANK
999		77 8 2 2.0 PANDEMONIUM F7	A
		1.E8 -4.166667E-03	B
		1.00 -4.166667E-03	B
			BLANK
999		78 8 2 2.0 PANDEMONIUM F8	A
		1.E8 2.068014E-03	B
		1.00 2.068014E-03	B
			BLANK
			BLANK
ENDX	1	1 4	END

FORM 1/542 (8.64)

Fig. 4

TITLE DK5R 1st test

I.C.T. FORTRAN CODING SHEET

SHEET 1 /

PROGRAMMER

DATE / /

C STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
CODE	6	1 7	CODE 6
CROSS		SECTIONS FOR THE FIRST TEST	RECORD A
1		1.8E7 2.5E-2	B
1		512	C
999		1 2 5 0 0 1.0	D
0			E
CODE	8	1 8	CODE 8
PHI	TAPE	FOR THE FIRST TEST	RECORD A
1		8 8	B
	1	.8E7 2.5E-2 1	C
999		71 72 73 74 75 76 77 78	D
ENDX	1	1 4	END

FORM 1/542 (8.64)

Fig. 5

TITLE RX5R 1st test

I.C.T. FORTRAN CODING SHEET

SHEET 1 /

PROGRAMMER

DATE / /

C STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
1 2 3 4 5	6	7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80
1ST TEST			05R A
50		250 10 1 1.0 1	B
1		3 3	C
-1			D
		2.0	E
		1.0 1.0 0.1	F
		0.0 0.0 0.0 0.0 1.0	G
		3.3 0.0 0.0 0. 0	H
1		1 1000000001000000000000000000000000000 1101000000	I
0		0 1 0	K
1		2	N
		1.0	O
4		0	P
2		MALE	GEOM A
XZONE		-1.E+30, 1.E+30	B
YZONE		-1.E+30, 1.E+30	C
ZZONE		-1.E+30, 1.E+30	D

FORM 1/542 (8.64)

Fig. 6

TITLE RX5R 1st test

I.C.T. FORTRAN CODING SHEET

SHEET 2 /

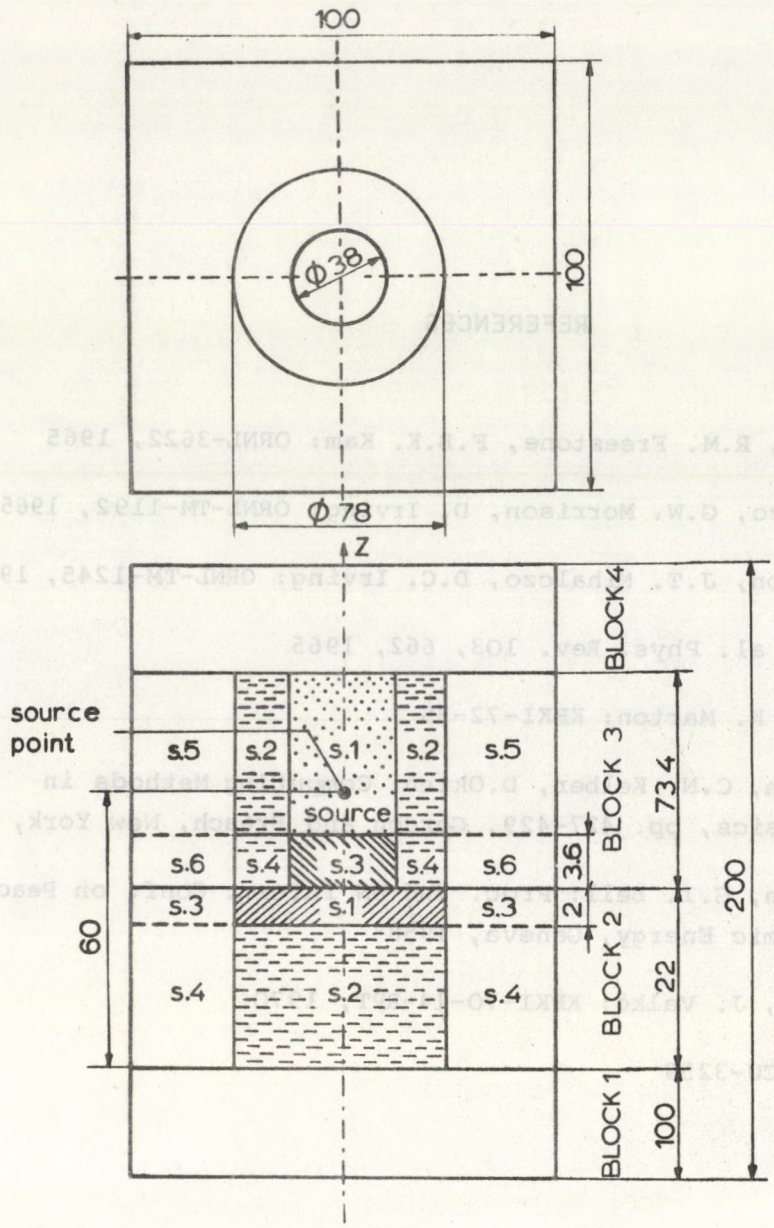
PROGRAMMER

DATE / /

C	STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
	ZONE		1 1 1	GEOM E
	X BLOCK		-1.E+30, 1.E+30	F
	Y BLOCK		-1.E+30, 1.E+30	G
	Z BLOCK		-1.E+30, 1.E+30	H
	BLOCK		1 1 1	J
	MEDIA		1, 0	K
	SURFACES		1	L
	SECTOR		-1	M
	SECTOR		1	M
	1		QUADRIC SURFACE	Q
			1.0XSQ 1.0YSQ 1.0ZSQ -23.7432 L	R
	2			SPCTRM A
	C.C			SOURCE A

FORM 1542 (8.64)

Fig. 7



all dimensions in cm
s.= sector
media : 0 vacuum
1 fuel
2 water
3 fuel pin end pieces + water
4 core support plate

Fig. 8

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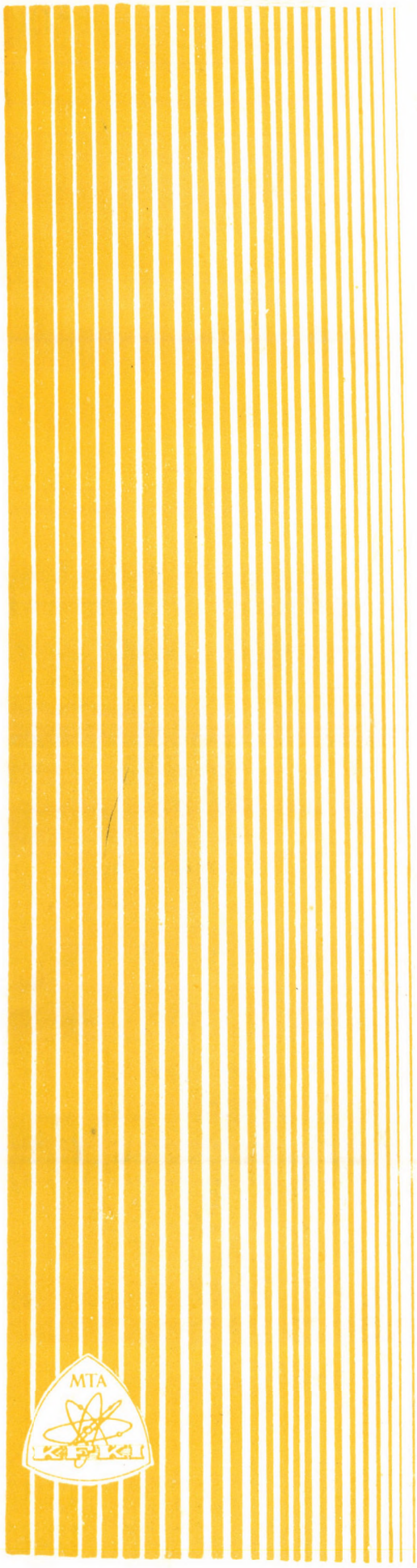

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