СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2-96-192

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MODIFIED CODE FRITIOF.
User's Guide

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1996

1 Nature of Physical Problem

The FRITIOF code [1, 2] that is a program of Monte Carlo simulation of the inelastic hadron-hadron, hadron-nucleus and nucleus-nucleus interactions is very popular in high energy experimental physics. It is explained by its access, its easy of usage, its physical ideas simplicity and a defined beauty of the code by itself. At the same time too simple-hearted interpretation of the physical processes does not allow one to use the program at energies below 10 GeV/nucleon and the absence of a simulation of the nuclear destruction and the residual nucleus relaxation makes narrow its application region. Below we consider a possibility of taking away these deficiencies without a significant complication of the code.

It is assumed that the program cannot be used at the relatively low energies because the picture about the creation and decay of the QCD strings is not valid. An attempt to compel the program to operate at energies below 5 GeV/nucleon is a failure as a rule. Though an analysis of the code operation shows that due to an uncoordinated sampling of the string masses and transverse momenta the kinematical restrictions are violated very often and a new sampling of the interaction takes place — the nucleon fermi-momenta are determined once more, the string masses are re-calculated and the transverse momenta transferred to the strings are sampled independently. It is obvious that at low energies the transverse momentum must be restricted. This fact is not taken into account in the code and, as a result, the kinematical restrictions are violated. Of course due to the sampling the nucleon fermi-momenta one can satisfy the conditions but a probability of the needed selections is small. In the modified code an attempt is realized to take the kinematical restrictions into account more strictly. More exactly, if at the multiple sampling one cannot satisfy the kinematical restrictions, the considered nucleon collision is skipped and the corresponding strings characteristics are changed to original ones that were before the collision. This permitted to lower the formal limit of the program usage to 1 – 2 GeV/nucleon.

The FRITIOF model applies the Glauber approach to calculation of the numbers of the interacting nuclear nucleons and the sequences of the inelastic nucleon-nucleon collisions. It means that like most other programs it is assumed that two nucleons interact if the impact parameter of the collision is smaller than a defined value $\sim$ 1 fm. From Glauber approach's viewpoint it is a very rough approximation which does not correspond to what we know about nucleon-nucleon interactions. Though it manifests itself only in the multiple collisions. This deficiency is over-

come in the modified code on a way of a utilization of DIAGEN code [3] what gives the inelastic nucleus-nucleus cross-sections adding to the pointed characteristics. I was asked by many users about this.

Another disadvantage of the FRITIOF code is an omission of the slow particle cascading into the nuclei. Usually under the "cascading" one understands what to be the standard intra-nuclear cascade scenario (see, e.g., [4]). It is used in the models taking the formation time of the secondary particles into account. Both in the first approach and in the second one the effects of the particle interference are ignored. So I prefer an approach of Ref. [5], where the attempt to consider the amplitudes of the "cascade" interactions within the reggeon theory took place. The efforts to go forward in the direction were presented in Ref. [6, 7]. They resulted in an algorithm of simulation of the nuclear destruction at fast stage of the interaction [6]. It is included in the modified FRITIOF code.

The second point that does not satisfy me in the FRITIOF code is the simulation of the fermi-motion of the nucleons. Usually under the words "fermi-motion" one understands a motion of the nucleons (particles) in a potential well. It seems, all is clear! But an attempt to give the picture a constructive algorithm character meets with the problems as a rule. First of all, it is needed to sample the momentum of the nucleons in such a manner that a sum of the kinetic energies of the nucleons and the potential energies must be a constant in all cases. Second, it is needed to determine a change of a nucleon momentum at a reflection on a wall of the potential well and to decide what to do with a momentum transferred to the well. Third, one has to consider a change of the particle characteristics when it is leaving the well and so on. It is a pity, but I could not find in the codes studied by me the satisfactory answers to the questions. Very often primitive bad grounded solutions are used, and they are not reflected in the papers but they determine the differences between program implementations.

The approach of the quantum molecular dynamics [8, 9, 10] is looked more attractive in the situation. Though there is a problem of preparing an original state or "cooling" a starting system.

If we turn to the quantum mechanics, we will have to describe a system of bounded particles by a wave function. It is not correct to treat the square module of the wave function in the momentum representation as a classical distribution of the particles on the momentum. We cannot use the classical picture of the particles interactions, too. It is needed to consider the amplitudes of the reactions. There are many methods proposed for the amplitude calculation. One of them is Feynman's method.

According to it, one has to determine for the calculation the so-called vertex functions which can be obtained in some models (see, e.g., N/D method [11]). The method of mass dispersion relations [11] seems to me very interesting. Inspired by its main idea, a method of a simulation of the fermi-motion of the constituents of bounded systems with taking into account the energy momentum conservation law was proposed in Ref. [12]. It has been included in the modified FRITIOF code.

The model completeness requires to determine an algorithm of the residual nuclei excitation energy calculation and a method of exited nuclei relaxation. In solving the first question, I followed Ref. [13, 14]. For simulation of the excited nuclei relaxation, I use the evaporation model [15, 4]. Attraction of the more developed nuclear multi-fragmentation models [16, 17] may be interesting only for some users.

2 File Structure of the Code

The modified code consists of the following parts: main.f, mfritiof.f, diagen.f, jetset.f and nuclfra.f. All parts are written in FORTRAN IV language.

Main.f is an administrator of the program. Here one can find a setting up of the code options, a description of the common variables, input and output data. I recommend a user wishing to use the code effectively to study this part carefully.

Mfritiof.f is the main part of the program for the simulation of the inelastic nucleus-nucleus interactions. Its structure is described in Ref. [1, 2]. All changes made by me are marked by "! UZHI" at the end of the corresponding lines.

Diagen.f is a part for a calculation of the glauber cross-section and other characteristics of nucleus-nucleus interactions. You can see its description in Ref. [3].

Jetset.f is a part for a simulation of the string fragmentation. You can find its description in Ref. [18].

Nuclfra.f is a part for a simulation of the residual nuclei relaxation in the framework of the evaporation model [4].

3 Installation of the Code

First of all, a user has to point out a random number generator used at his computer. To do this, he has to take off a comment in the corre-

sponding line of FUNCTION RLU(IDIM) which is at the beginning of the file jetset.f and close the existing definition RLU=RNDM(-1).

To obtain an executable module, a user has to translate all parts and to link them together with a link editor. The code has been created and operates on large computer. A FORTRAN compilator, which is in my hand, does not give me an opportunity to install the code on personal computer. The main problems arise with the part jetset.f.

4 The Code Operation

The program operates interactively in a dialog regime. All code requests are sent to a system unit No. 6 (monitor). User's answers are read from system unit No. 5 (keyboard). An example of a dialog with the program is given below. The user's answers are marked by "*".

```
      THE MODIFYING LUND MONTE CARLO - FRITIOF VERSION 1.7
    IS USED FOR SIMULATION OF NUCLEUS-NUCLEUS INTERACTIONS
                    AT HIGH ENERGIES

                 LAST DATE OF CHANGE :  6 JUNE  1986
                  MODIFIED BY V.V. UZHINSKII IN 1995

     ---------- Where would you like to put Output?-----
     -------------- Please enter 'filename' --------------

test    ****************************************
Enter the requested number of the events
100     ****************************************
Enter projectile mass number, charge and momentum
                         per nucleon (in GeV/c)
1 1 4.5 ****************************************
Enter target mass number and charge
12 6    ****************************************

  GLAUBER'S APPROACH IS USED TO CALCULATE THE CROSS-SECTIONS
      OF VARIOUS INELASTIC PROCESSES IN THE COLLISION OF
      ==================================================
         PROJECTILE      TARGET
         ==========      ======
 A           1              12      (MASS NUMBERS)
 Z           1               6      (CHARGES)
 R         1.070           2.450    (RADII (FM))

  AMPLITUDE PARAMETRIZATION
  =========================
           SIG                        -B*B/(2*A)    SIG = 40.00 (MB)
F  (B) = ------- * (1-I*RO) * E                      RO =  -.23
 NN        4*PI*A                              A =  8.00 (GEV/C)**(-2)
```

All results of the calculations will be written on the mentioned file. In the considered example it is a file "test".

5 Input and Output Values

Input values

First of all, the program requests a file name where the calculation results will be written ("test"). Then the program asks the requested number of events. The next ask is about a mass number and a charge of a projectile nucleus and a projectile momentum in the lab. system in GeV/nucleon (1 1 4.5). At next step a user has to give a mass number and a charge of a target nucleus (12 6). It is assumed that the target nucleus is at rest.

Output values

The output file has a structure:

```
      THE MODIFYING LUND MONTE CARLO - FRITIOF VERSION 1.7
    IS USED FOR SIMULATION OF NUCLEUS-NUCLEUS INTERACTIONS
                 MODIFIED BY V.V. UZHINSKII IN 1995
       100          The requested number of the events
 1.0   1.0   4.5    A proj., Z proj. and P proj. per nucleon
12.0   6.0          The target mass and charge
325.00              Glauber cross-section (in mb)
    ID   Mass   Charge     Px      Py      Pz       E
      13 Number of Particles in the Event
    41  0.938   1.000   0.035   0.194   1.289   1.606
    23  0.135   0.000  -0.147   0.154   0.090   0.268
    42  0.940   0.000   0.304  -0.809   1.313   1.832
    23  0.135   0.000  -0.136  -0.078  -0.049   0.213
    41  0.938   1.000  -0.849   0.448   0.457   1.418
```

```
   -17   0.140  -1.000  -0.041   0.154   0.569   0.608
    42   0.940   0.000   0.836   0.091   0.421   1.329
    42   0.940   0.000  -0.038  -0.114   0.383   1.022
    41   0.938   1.000   0.087  -0.071   0.005   0.945
102004   3.728   2.000   0.129  -0.045  -0.211   3.737
101001   0.939   1.000  -0.054   0.011   0.052   0.942
101001   0.939   1.000  -0.061   0.037   0.039   0.942
100001   0.940   0.000  -0.065   0.027  -0.020   0.942
```

First three lines tell about the program version. Next three lines inform about the event number, the mass number and the charge of the projectile nucleus and the interaction energy. The seventh line contains glauber cross-section of inelastic nucleus-nucleus interaction. The eighth line determines a structure of a record of characteristics of a particle. After that the records for each event follow.

An event record starts with a number of particles in the event. Then there are records of particle characteristics. For each particle an identificator (ID), a mass in GeV, a charge, three momentum components in GeV/c (it is assumed that the collision axis coincides with Z-axis) and energy in GeV are given.

A list of particle identificators is presented in Ref. [18, 19]. The identificators larger than 100000 belong to the particles produced at the residual nuclei relaxcation. For the particles the identificator is determined as

$$ID = 100000 + 1000 * Z_F + A_F,$$

where A_F is a fragment mass number and Z_F is a fragment charge.

6 Change of the Model Parameters

Parameters determining a destruction of nucleus and excitation energy of the nuclear residuals are in SUBROUTINE ANGANT which is in the part mfritiof.f. They are in the lines

```
C-----------------------------------------------------
C-------THE NUCLEAR DESTRUCTION PARAMETERS
C-----------------------------------------------------
      DATA CND,RCND2/0.35, 1.0/                    ! UZHI
      DATA E0EXC,RNEIB/ 8.0, 2.0/                  ! UZHI
```


The meanings of the parameters CND and RCND2 are given in Ref. [6, 7]. The value of RCND2 was found in Ref. [7] at analysis of nucleus-nucleus interactions at 3 — 3.4 GeV/nucleon. For GSI-energies CND=0.2 is quite well. The nuclear multifragmentation is described reasonably well at CND=0.28.

The E0EXC parameter determines excitation energy of nuclear residual. Good results can be obtained at E0EXC=6.4 MeV when the nuclear multifragmentation model [16] is used.

Parameters determining the "fermi-motion" of the nucleons are given in SUBROUTINE HELGE (the part mfritiof.f) in the lines

```
C-----------------------------------------------------
C- PARAMETERS OF FERMI MOMENTUM DISTRIBUTION AND MOMENTUM -
C-          DISTRIBUTION OF EJECTED NUCLEONS           -
C-----------------------------------------------------
      DATA PTFRM /0.07/, PTCOR/0.385/ ! SQRT(0.296/2.) UZHI
      DATA DCOR /0.3/                                  ! UZHI
C
      DXAFRM=0.07/FLOAT(NAP)
      DXBFRM=0.07/FLOAT(NAT)
```

Thier values are estimated very roughly.

7 Destribution of the Code

The copy of the code can be obtained through the E.mail. Call: UZHIN@LCTA9.JINR.DUBNA.SU.

The code takes $\sim$ 320 Kbt in an unpack form. It is easy for me to send the code in a packed form. For this purpose I use PKZIP at PC and then UUENCODE. The files with extension "uue" are sent to a user. The user has to store the files as it is mentioned in the subject line and to use UUDECODE. If the user has other possibility (UNIX utilities), please, specify your needs in your request.

The users are welcome with notes and wishes!

Good luck!

The author makes his apology to the authors of the FRITIOF program if his changes and additions destroy the epic style of the program! He is grateful to V.Sh. Navotny (PTI, Tashkent, Uzbekistan) for his interest to the work and the stimulating discussions.

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Received by Publishing Department
on June 4, 1996.