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MONTE CARLO SIMULATION OF HIGH-FLUX 14 MeV NEUTRON SOURCE BASED ON MUON CATALYZED FUSION USING A HIGH-POWER 50 MW DEUTERON BEAM

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As it has been mentioned in /1-4/ there is an interest to build a 14-MeV high-intensity neutron source in order to study the behaviour of materials under an intense irradiation by 14-MeV neutrons. The main purpose of the present work is to present Monte Carlo simulation of an intense neutron source based on muon catalyzed fusion process mCF-INS /1/.

The layout of the setup is presented on Fig.1. A deuteron beam (12mA, E_d) is directed onto a cylindrical carbon target (primary target L_t, R_t), located in vacuum chamber (converter L_c, R_c) with a strong solenoidal magnetic field (H_{max}, H_o) to produce negative pions. The direction of the d-beam is 180°(back pion production). The pions and muons which originate from pion decay are guided along magnetic field lines to a DT-cell (synthesizer). We assume that the sythesizer has the shape of a cylinder and the material of the front d_{fr}, lateral d_{lat} and back d_b walls is titanium. Assuming X_c=100 fusion per muon, mCF-INS produces 14-MeV neutrons with a source strength of up to 10^{17} n/s.

It is interesting to note that the neutron intensity depends directly on the deuteron current.

The range for the basic parameters of the setup specified on Fig1. is as follows:

L_c = 500 - 1300 cm, R_c = 20 - 50 cm, H_o= 7 - 10T, E_d= 1 -2 GeV/N,
L_t = 30 - 100 cm, R_t = 0.4 - 10 cm, d_{fr} = 0.25 cm, d_{lat} = 0.5 cm,
d_b = 0.25 cm, DTdensity = 0.5 (LHD), H_{max}/H_o = 1.3-1.5, q_{back}= 120°- 143°,
L_s = 5 - 50 cm, R_s = 4 cm, SR=single reflection, DR=double reflection,

Pion production in the primary target is simulated by means of Intranuclear and Internuclear cascade codes created in the Institute for Nuclear Research of Russian Academy of Sciences while pion and muon transport process is studied by a Monte Carlo code based on GEANT3.21 created at CERN /6/.

Two important problems coexist: the correct efficiency estimation of the pion production and utilisation processes and the problem of optimal choice of the parameters of the setup in order to obtain the highest intensity of the neutron flux. An opportunity which discussed in /1,3/ deals with the deuteron beam of the energy about 1 GeV/N and with 30 cm carbon cylinder as the primary target.

In a paper /5/ we tried to expand the region of optimisation of the efficiency. of negative pion production by deuterons /5/ respect to the region considered previously /1,3/ both for the deuteron energy and primary target geometry. Dependencies of the pion yield on the target size and deuteron energy have been investigated in detail. However, the calculations /5/ of the pion yield have been done without taking into account a loss of pions in the primary target due to the influence of the magnetic field during the pion and muon transportation to the fusion target (pions can re-enter the primary target by spiral trajectories).

The main purpose of the present work is to calculate the pion and muon utilisation efficiency taking into account the above-mentioned of pion absorption in the primary target as well as all the other losses of pions and muons in the walls of converter and DT-cell.

1. Pion production and absorption in the primary target.

Initial distributions of pions leaving the primary target in space and momentum (x,y,z,P_x,P_y,P_z) were calculated by means of Intranuclear and Internuclear Cascade Codes /5/ created in INR. It is well known fact that the outgoing pions have a wide angular and energy distribution. An example of momentum, angle and longitudinal momentum distributions presented on Fig.2.

Table1 presents the integral characteristics of negative pions and deuterons leaving the primary target. As it was already noted /5/, the length of the target of 30 cm seems to be not sufficient "to consume" all the deuterons for pion production and one can conclude that an essential part of beam particles goes out of the target. For the targets listed in the Table 1, the integral absorption rate due to re-entering into the primary target in the magnetic field (with the values specified above) turns out to be at the level of 13% for T8 case and 35% for T2 case.

2. Pion and muon transport to DT-cell.

Pion and muon transport to DT-cell is simulated by GEANT3.21.

Some trajectory calculations is shown on Fig.1. For the case of homogeneous magnetic field in setup and in assumption of quasi-continuous slowing down approximation there are exist some simple analytical solutions of the motion equations of pions and muons. Comparison of z-coordinate and cyclotron radius dependencies on energy demonstrates a good agreement between analytical solutions and results obtained by means of GEANT3.21.

In order to confine pions which travel backward a simple model of a magnetic mirror has been employed with mirror ratio $H_{max}/H_0 = 1.3 - 1.5$. According to this model each particle is reflected at its starting point in P-Z plane if its momentum direction angle belongs to the range $[90^o, \theta_{back}]$. One can see the influence of magnetic trap on the spectrum of outgoing pions on Fig. 3.

Preliminary results of simulation are presented in Tab.1- Tab.3 and on Fig.2, Fig.3-4.

It seems to be necessary to test our program by means of calculation of the setup variants which have been considered by other groups before /3,7/. Unfortunately it is difficult or even impossible to reproduce each that situation entirely but as one can see from Tab.2 our results have the same order of magnitude as the results of above-mentioned groups. In the Tab.3 we present detailed description of the several most encouraging variants of neutron source setup.

4. Conclusion

Preliminary estimations demonstrate the possibility to reach the level of 10^{14} $n/s/cm^2$ for the neutron flux. This flux can be used to study the behaviour of materials of fusion reactors /1/ or to drive into operation a hybrid nuclear reactor /8/.

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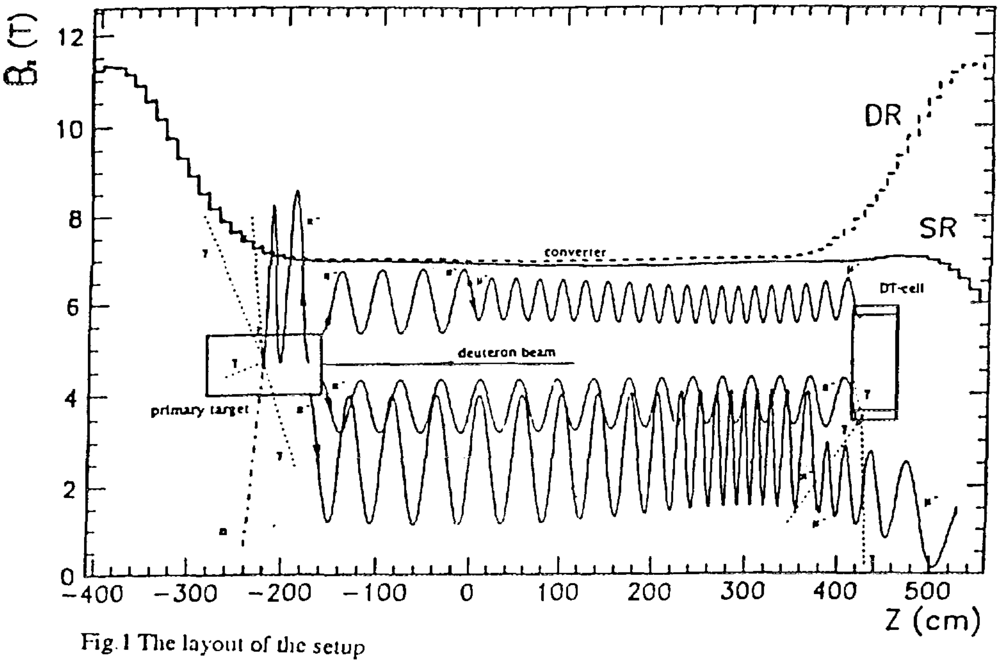

Fig.1 The layout of the setup

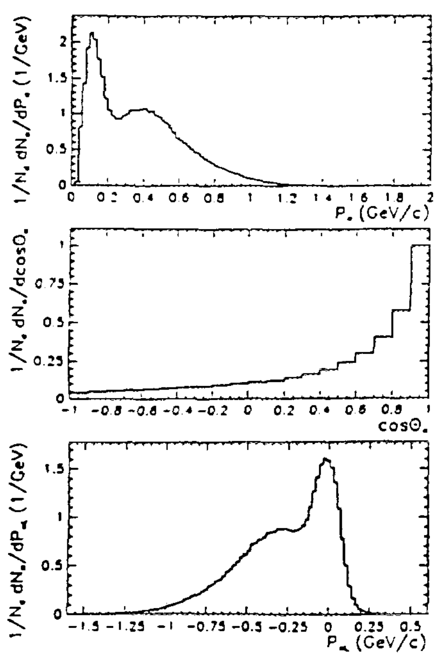

Fig.2The initial momentum and angular distributions obtained by means of INR codes

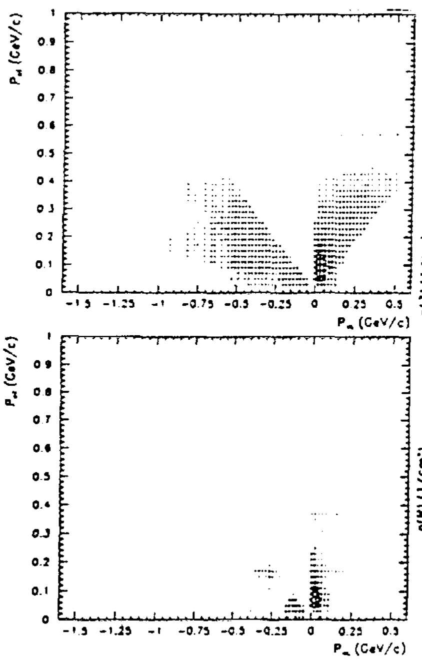

Fig.3,up Two-dimensional momentum distributions of outgoing pions after the trap impact
Fig.3,down two-dimensional initial momentum distributions for the pions stopped in the primary target

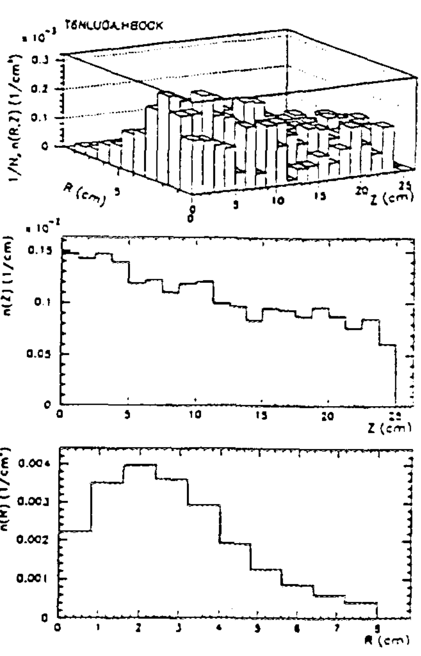

Fig.4 Two-dimensional distributions for muons stopped in the DT-cell

Table 3. Conversion coefficients and fraction of stopped pions and muons for different components of set-up. Dimensions are in cm.

run	name	T8MARKU	T8MARKU2	T6NMARCE	T6NLUDA
primary	target	T8N	T8N	T6N	T6N
beam	direction	180°	180°	180°	180°
converter	R	50	50	50	50
	L	700	700	1000	1300
DT-cell	R	8	8	8	8
	L	40	40	25	25
	$d_{lateral\ wall}$	1.6	1.6	0.5	0.5
	$d_{front\ wall}$	0.8	0.8	0.3	0.3
	$d_{back\ wall}$	2	2	2	2
magnetic field (T)	H_0	9	10	7	9
	H_{max}	15	10	10	15
pion statistics (% per pion)	escape via trap	28.25	54.18	41.42	34.15
	absorption in primary target	10.49	12.77	15.77	18.52
	decays	43.33	30.08	33.44	38.24
	escape via lateral wall of converter	0.0	0.0	1.39	0.1
	stops in walls of DT-cell	12.30	2.76	1.89	1.84
	stops in DT-mixture	2.68	1.21	0.54	0.47
	escape via right wall of convertor	7.92	0.47	8.17	10.06
muon statistics (%per pion)	escape via trap	6.32	14.37	5.07	3.90
	absorption in primary target	0.93	0.98	1.30	1.29
	escape via lateral wall of converter	0.0	0.0	0.02	0.0
	stops in front wall of DT-cell	11.33	6.69	2.43	2.33
	stops in lateral wall of DT-cell	9.39	2.00	4.09	3.22
	escape via right wall of convertor	5.95	0.68	13.47	17.89
	decays	1.39	0.93	1.12	1.39
	stops in back wall of DT-cell	2.78	1.48	3.02	4.61
	stops in DT-mixture	5.24	2.95	2.92	3.62
estimated 10^{14}	neutron flux (n/s/cm^2)	0.2	0.1	0.5	0.6

Table 1. Integral characteristics of particles leaving primary graphite target.

run name	T (GeV/N)	d_{beam} (cm)	d_{target} (cm)	L_{target} (m)	N_{π^-}	$\langle E_{\pi^-}\rangle$ (MeV)	N_d
T0	1	0.8	0.8	0.3	0.117	157.17	0.424
T1	1	10	10	0.3	0.107	166.97	0.354
T2	2	10	10	0.3	0.254	285.50	0.355
T3	2	10	10	1	0.457	273.33	0.071
T4	2	0.6	10	1	0.478	272.90	0.040
T5	2	0.6	0.6	1	0.318	273.91	0.270
T6	2	2	2	1	0.395	274.48	0.172
T7	2	2	2	0.6	0.366	276.21	0.216
T8	1	0.6	0.8	0.3	0.120	157.57	0.417

Table 2. Comparison with results of other groups. Dimensions are in cm, muon stops in % per one pion.

run	name or ref.	[7]	T0Upp	[3]	T8MARKU2	[3]	T8MARKU
beam	energy	1 GeV/N	1 GeV/N	1 GeV/N	1 GeV/N	1 GeV/N	1 GeV/N
	direction	0°	0°	180°	180°	180°	180°
target	material	Be	C	C	C	C	C
	diameter	point	point	0.8	0.8	0.8	0.8
	length	like	like	30	30	30	30
converter	R	20	20	50	50	50	50
	L	4000	4000	500	700	800	700
DT-cell	R	10	10	8	8	8	8
	L	30	30	40	40	40	40
	$d_{lateral\ wall}$	5	5	1.6	1.6	1.6	1.6
	$d_{front\ wall}$	0.8	0.8	0.8	0.8	0.8	0.8
	$d_{back\ wall}$	2	2	-	2	-	2
magnetic field (T)	H_0	10	10	10	10	9	9
	H_{max}	12	12	10	10	15	15
pion	decays (%)	71	80		30.08		43.33
muon stops	in walls of of DT-cell	35	30.6	6.8	8.69	18	20.7
	in DT-mixture	4.3	6.2	2.1	2.95	3.2	5.24