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T.Pawlak*, W.Peryt*, E.Strugalska-Gola*,
K.Miller, Z.Strugalski

CHARACTERISTICS OF ATOMIC NUCLEI EMPLOYED AS TARGETS IN HIGH ENERGY NUCLEAR COLLISIONS

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* Institute of Physics of the Warsaw Technical University, Poland

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1. INTRODUCTION

The present work is the additional part to the paper "The Atomic Nucleus as a Target" published by Z.Strugalski and T.Pawlak five years ago [1]. The aim here is to characterize the atomic nuclei as targets and as projectiles in high energy nuclear collisions - at kinetic energies of the hadronic projectiles over about 1 GeV and at kinetic energies of the nuclear projectiles of over about 1 GeV per nucleon.

Various data on a collision process provided by experiments are of the statistical nature; as a rule, they are a result of quantitative analysis of the mass phenomena observed in detectors - thousands events are considered in various samples. As usually is practiced, samples when definite hadrons or nuclei collide with definite target nucleus at definite energy are investigated. In any of the collisions the nuclei: the target nucleus in hadron-nucleus and the target- and the projectile-nuclei in nucleus-nucleus collisions are destroyed, but in any of collisions identical projectile and identical target nucleus are always employed. It enables us, in attempts to express quantitatively the characteristics of the collision process, to treat the sample of collision events of a given hadron or nucleus with a given nucleus as a result of the collision of the spatially homogeneous beam of parallelly moving hadrons or nuclei with definite nucleus. In the laboratory system, where the target nucleus is resting, a sample of collision events may be treated as a result of the collision of spatially homogeneous beam of definite monoenergetic hadrons or nuclei with the target nucleus - with a "piece" of nuclear matter distributed in a definite manner through a sphere of definite size; the nuclear matter distribution should be taken as experimentally known [2]. The way this problem was proposed to be formulated [1,3] is similar to that in absorption experiments, when the interaction of a particle beam with a slab of a material is studied.

It is necessary, therefore, to characterize adequately and precisely the incident beam of hadrons or nuclei by its absorption properties in nuclear matter, and the target nucleus as the nuclear matter "slab". The hadron beam may be characterized by its intensity and by the hadron mean free path λ_c for a given sort of collisions in nuclear matter [1,3]; the beam of identical nuclei may be characterized by the intensity of the beam of monoenergetic packets containing A nucleons distributed spatially in a definite manner, where A is the mass number of the projectile nucleus, and by the nucleon mean free path λ_c for a given sort of collisions in nuclear matter. The nuclear matter "slab" may be characterized by the maximum thickness of nuclear matter layers λ_{max}, its average thickness $<\lambda>$, and the potential thicknesses $\lambda(b)$ corresponding to given collision impact parameters.

Because the nucleon density $\rho(r)$ nucleons/fm^3 varies with the distance r from the nucleus center, at larger values of r, conveniently to express the thicknesses λ_{max}, $<\lambda>$, and $\lambda(b)$ in nucleons per some area, like the atmosphere layers thickness is expressed in cosmic ray physics, for example, in units of grams per cm^2.

In this paper we present the characteristics of the same atomic nuclei as in the previous paper[1]: $^{12}C_6$, $^{14}N_7$, $^{16}O_8$, $^{19}F_9$, $^{20}Ne_{10}$, $^{27}Al_{13}$, $^{28}Si_{14}$, $^{32}S_{16}$, $^{40}Ar_{18}$, $^{52}Cr_{24}$, $^{54}Fe_{26}$, $^{59}Co_{27}$, $^{64}Cu_{29}$, $^{65}Zn_{30}$, $^{73}Ge_{32}$, $^{80}Br_{35}$, $^{108}Ag_{47}$, $^{127}J_{53}$, $^{131}Xe_{54}$, $^{181}Ta_{73}$, $^{184}W_{74}$, $^{197}Au_{79}$, $^{207}Pb_{82}$, $^{238}U_{92}$.

2. HADRONS AND NUCLEI AS PROJECTILES

Hadrons can traverse atomic nuclei without causing the particle generation; the passage is accompanied by fast nucleon emission in a strictly definite manner[4]. Quasi-free or quasi-elementary hadron-nucleon collisions with nucleons in target nuclei may occur, at least at the nuclei peripheries[5,6]. It enables us to apply following picture of the hadron-nucleus collision process, in defining the hadron mean free path for a hadron-nucleon interaction inside the target nucleus, or in nuclear matter - in other words: the projectile hadron interacts in a collision with single nucleons met in its passage through nuclear matter, the collision is quasi-elementary two-body hadron-nucleon collision.

The collision mean free path of a hadron is simple related to corresponding elementary hadron-nucleon collision cross-section σ_c, and the average density of nucleons at the distance r from the nucleus center, $<\rho(r)>$, under condition that: a) The mass number of the nucleus is not too small $A \gtrsim 12$; b) The nucleons scatter or absorb the hadron wave independently of each other. At energies above 1 GeV the wave length $\lambdabar$ of hadrons is shorter than about 10^{-14} cm, and the mean nucleon-nucleon separation inside nuclei is about $1.8 \cdot 10^{-13}$ cm, so the condition that $\lambdabar$ be small is well satisfied[7]. For the independence condition to hold strictly it is necessary that both the hadron wavelength $\lambdabar$ and the range of hadron-nucleon interactions be smaller than the average internucleon spacing. In fact the range of nuclear forces is about equal to the internucleon spacing in the central region of the nucleus. But, the average internucleon distance increases near the edge of the nucleus, and it turns out that is the important region for the calculation at least for medium and heavy nuclei; this region is involved in more than 65% of the collisions. We therefore assume that any nonadditive effects due to the failure of this condition will be small.

Under such assumptions, the connection between the hadron-nucleon collision cross-section σ_c and the mean free path λ_c for this collision in nuclear matter can be expressed as:

$$\lambda_c = \frac{1}{\rho \cdot \sigma_c}, \qquad (1)$$

where ρ is the mean number of nucleons per volume unit in nuclear matter, along the hadron path in it; σ_c is in an area unit per nucleon; λ_c is in length unit.

From the relation $\lambda_c \cdot \rho = 1/\sigma_c$, λ_c may be expressed in nucleons per an area unit; we use $<\lambda_c>$ notation for the mean free path in these units. In this work, it will be naturally and conveniently to use as units for $<\lambda_c>$ the nucleons/S, where the area $S = \pi D_0^2 \doteqdot 10.3$ fm^3 and D_0 is the nucleon diameter.

In nucl/S units relation (1) is:

$$<\lambda_c> = \frac{1}{\sigma_c}, \qquad (1')$$

where σ_c is in S/nucleon. Usually, in various cross-section tables σ_c are given in milibarns, 1 mb = 10^{-27} cm^2 = 0.1 fm^2; then, formula (1') should be rewritten as $<\lambda_c> = 102.9 \frac{1}{\sigma_c}$, where $<\lambda_c>$ is in units nucl/S, if σ_c is in mbarns per nucleon, and the scaling constant k = 102.9 is in mbarns/S. In principle, the $<\lambda_c>$ quantity can be measured for collision-reactions of a given type[3].

When a nucleus is employed as a projectile, it can be treated as consisting of parallelly moving monoenergetic nucleons distributed spatially in a definite manner, correspondingly to the nucleon density distribution in the nucleus. Consequently, definite and the same mean free path $<\lambda_c>$ should be ascribed for every of the nucleons moving, when the nuclear projectile collides with a target nucleus. Appropriate transformations of the collision act, from a given system of references to another one, should be obviously applied in considerations about hadrons and nuclei collisions with nuclei.

3. THE ATOMIC NUCLEUS AS A NUCLEAR MATTER "SLAB"

Many aspects about the nuclear matter distribution inside atomic nuclei are now so firmly established that it has been possible to use them in order to investigate other physical quantities. Our knowledge about the nuclear matter distribution based on results of many experiments[2,5,8-11] is substantial. The proton distribution has a spherical core of almost constant density surrounded by a surface region in which the density decreases outwards to zero[2,5,8-11]. There is inadequate direct evidence on the neutron distribution, but the indications are quite strong that the neutron distribution does not differ by much from the proton distribution and does not extend much beyond it[2,5].

Nuclei, in particular those of relatively large mass numbers, $A \gtrsim 12$, can be treated, at least as seen by the hadron projectiles, as spherical objects consisting of protons and neutrons. But, a nucleus is a quantum mechanical system and thus is represented by a wave function. This in theory extends over all space, although in practice it is confined to a definite finite region. It is not, however, confined to as sharply a delimited region as is, for example, the ivory of a billiard ball. But, if the density of nuclear matter is sensibly uniform over certain region and drops to zero in a second region which surrounds the first, and if the thickness of this transition region is small compared with the linear dimensions of the first region, then something of nuclear radius exists[2]. This is expressed quantitatively in the following manner. The nuclear matter density distribution is characterized by the so-called half-way radius c and a surface thickness s; c gives the distance from the centre at which the density has dropped to half its maximum value, s gives the surface thickness which has been defined as the distance over which the density drops from 90% to 10% of its maximum value[2].

The above described features of the nuclear matter density radial distribution $\rho(r)$ are expressed simply by various formulas[2]; we use here the well-known Fermi distribution[2];

$$\rho(r) = A\rho_0/(1 - e^{(r-c)/a}), \qquad (2)$$

where $a = s/4\ln 3 = 0.23s$; in all cases $c \gg a$. The surface width is independent of the mass number A and equals 2.49 fm.

3.1. The Nuclear Matter Layer Thicknesses $\lambda(b)$ at Various Impact Parameters b

Let us consider a high energy hadron traversing an atomic nucleus at an impact parameter b. The thickness $\lambda(b)$ in nucleons/S can be obtained from the distribution (2) by simple integration over the cylindrical volume $V(b, D_0) = \pi D_0^2 \lambda(b) = S \cdot \lambda(b)$ centered on the hadron path inside the nucleus:

$$\lambda(b) = \frac{1}{S} \int_{V(b, D_0)} \rho(r) \cdot dV = \frac{1}{S} n_N(b), \qquad (3)$$

where $n_N(b)$ is the number of nucleons inside the volume $V(b, D_0)$. The maximum thickness λ_{max} nucl/S will be obtained from the relation (3), when integration is over $V(D, D_0) = V(0, D_0)$ and D is the nucleus diameter.

The mean thickness of the nucleus $\langle\lambda\rangle$ nucl/S is:

$$\langle\lambda\rangle = \int_0^{R_c} \lambda(b) \cdot \frac{2b}{R_c^2} db, \qquad (4)$$

where $2b/R_c^2$ is the probability density of finding an impact parameter b by the uniform projectile beam, R_c being the radius limit for the nucleus. In calculations of $\langle\lambda\rangle$, the value for R_c was accepted which corresponds to the nuclear matter layer thickness $\lambda(R_c)$ of $0.5\frac{A}{Z}$ nucleons/S, what means that we define the sharp limit for the target nucleus size, where about one nucleon is at the distance R_c; it may be reasonably accepted, because the proton-neutron ratio at the peripherical layer of the nucleus is approximately as large as[5] $Z/(A-Z)$.

3.2. Distribution $W[\lambda(b)]$ of the Nuclear Matter Layer Thicknesses $\lambda(b)$ in Nuclei

The distribution of the nuclear matter layer thicknesses $\lambda(b)$ nucl/S, or of the numbers n_N of nucleons contained inside the volumes $v(b) = \lambda(b) \cdot S$ centered on the hadron paths $\lambda(b)$ is:

$$W[\lambda(b)] = \int_{b(n_N+1/2)}^{b(n_N-1/2)} \frac{2b}{R_c^2} db = \frac{b^2(n_N - 1/2) - b^2(n_N + 1/2)}{b^2(1/2)}, \qquad (5)$$

where $n_N = 1, 2, 3, \ldots, n_{N\,max}$ are the numbers of nucleons within the volumes $\pi D_0^2 \lambda[b(n_N)]$ to which the impact parameters $b(n_N \pm 1/2)$ correspond. Because $\lambda(b)$ are in nucleons/S, formula (5) gives as well the distribution of the nucleon numbers n_N contained within the volumes $\lambda[b(n_N)] \cdot S$ at the impact parameters $b(n_N)$.

Values of the quantities: c fm, λ_{max} nucl/S, $\langle\lambda\rangle$ nucl/S, $\lambda(b)$ nucl/fm^2 b fm, $\rho(r=b)$ nucl/fm^3 are given in the Table presented below. The distribution $W[\lambda(b)]$ is presented there as well.

4. DISTRIBUTION OF THE NUCLEAR MATTER LAYERS THE HADRONS COLLIDE WITH IN HADRON-NUCLEUS COLLISIONS

In the analysis above, we have identified the effective nuclear matter density which may be seen by high energy hadrons with the true proton density as measured electrically[2,8-11].

Table

The characteristics of the atomic nuclei as nuclear matter slabs. Denotations and units are given in the section 3.2. The mean thicknesses <λ> in nucl/S are from the values of <λ> in prot/S multiplied by A/Z ratio; the values of <λ> in prot/S are from our previous work[1].

n_N	λ(b)	b	ρ	W	W1	
1	2	3	4	5	6	
0.5	0.049	4.009	0.006	------	------	$^{12}C_6$
1	0.097	3.435	0.016	0.424	0.791	
2	0.194	2.719	0.046	0.208	0.075	c = 2.16
3	0.291	2.163	0.084	0.143	0.052	λ_{max} = 5.92
4	0.389	1.643	0.121	0.108	0.039	<λ> = 2.82
5	0.486	1.072	0.148	0.086	0.031	
5.5	0.534	0.707	0.157	------	------	
6	0.583	------	------	0.031	0.011	
0.5	0.049	4.183	0.006	------	------	$^{14}N_7$
1	0.097	3.623	0.015	0.402	0.777	
2	0.194	2.922	0.043	0.199	0.074	c = 2.32
3	0.291	2.387	0.079	0.137	0.051	λ_{max} = 6.53
4	0.389	1.901	0.114	0.105	0.039	
5	0.486	1.405	0.141	0.085	0.032	<λ> = 3.02
6	0.583	0.786	0.158	0.071	0.026	
6.5	0.632	0.156	0.165	------	------	
7	0.680	------	------	0.001	0.001	
0.5	0.049	4.337	0.006	------	------	$^{16}O_8$
1	0.097	3.785	0.015	0.384	0.765	
2	0.194	3.097	0.041	0.191	0.073	c = 2.46
3	0.291	2.580	0.075	0.133	0.051	λ_{max} = 7.09
4	0.389	2.117	0.109	0.102	0.039	
5	0.486	1.660	0.136	0.083	0.032	<λ> = 3.20
6	0.583	1.148	0.154	0.071	0.027	
6.5	0.632	0.823	0.160	------	------	
7	0.680	0.298	0.165	0.036	0.014	
0.5	0.049	4.533	0.006	------	------	$^{19}F_9$
1	0.097	4.003	0.014	0.364	0.749	
2	0.194	3.331	0.039	0.181	0.071	c = 2.64
3	0.291	2.831	0.071	0.127	0.050	λ_{max} = 7.83
4	0.389	2.391	0.103	0.099	0.039	
5	0.486	1.969	0.130	0.081	0.032	<λ> = 3.53
6	0.583	1.527	0.148	0.069	0.027	
7	0.680	0.999	0.160	0.061	0.024	
7.5	0.729	0.613	0.164	------	------	
8	0.777	------	------	0.018	0.007	
0.5	0.049	4.616	0.006	------	------	$^{20}Ne_{10}$
1	0.097	4.070	0.014	0.359	0.745	
2	0.194	3.401	0.038	0.178	0.071	c = 2.70
3	0.291	2.906	0.069	0.125	0.050	λ_{max} = 8.06
4	0.389	2.472	0.101	0.097	0.039	
5	0.486	2.059	0.128	0.080	0.032	<λ> = 3.54
6	0.583	1.630	0.147	0.069	0.027	
7	0.680	1.134	0.159	0.061	0.024	
7.5	0.729	0.812	0.163	------	------	
8	0.777	0.261	0.167	0.031	0.012	
0.5	0.049	5.006	0.005	------	------	$^{27}Al_{13}$
1	0.097	4.471	0.013	0.326	0.717	
2	0.194	3.825	0.035	0.163	0.069	c = 3.06
3	0.291	3.353	0.063	0.115	0.048	λ_{max} = 9.46
4	0.389	2.951	0.092	0.091	0.038	
5	0.486	2.575	0.118	0.076	0.032	<λ> = 4.11
6	0.583	2.206	0.138	0.066	0.028	
7	0.680	1.821	0.152	0.059	0.025	
8	0.777	1.377	0.160	0.054	0.023	
8.5	0.826	1.108	0.163	------	------	
9	0.874	0.764	0.166	0.049	0.021	
0.5	0.049	5.057	0.005	------	------	$^{28}Si_{14}$
1	0.097	4.522	0.013	0.323	0.714	
2	0.194	3.877	0.034	0.161	0.068	c = 3.10
3	0.291	3.409	0.062	0.114	0.048	λ_{max} = 9.63
4	0.389	3.010	0.091	0.090	0.038	
5	0.486	2.638	0.117	0.075	0.032	<λ> = 4.14
6	0.583	2.273	0.137	0.065	0.028	
7	0.680	1.895	0.151	0.059	0.025	
8	0.777	1.467	0.160	0.054	0.023	
9	0.874	0.899	0.165	0.052	0.022	
9.5	0.923	0.392	0.167	------	------	
10	0.972	------	------	0.006	0.003	
0.5	0.049	5.241	0.005	------	------	$^{32}S_{16}$
1	0.097	4.711	0.012	0.308	0.702	
2	0.194	4.077	0.033	0.156	0.067	c = 3.27
3	0.291	3.618	0.059	0.111	0.048	λ_{max} = 10.29
4	0.389	3.226	0.088	0.087	0.038	
5	0.486	2.868	0.113	0.073	0.032	<λ> = 4.40
6	0.583	2.520	0.133	0.064	0.028	
7	0.680	2.166	0.148	0.058	0.025	
8	0.777	1.782	0.157	0.053	0.023	
9	0.874	1.331	0.163	0.051	0.022	
9.5	0.923	1.037	0.165	------	------	
10	0.972	0.616	0.167	0.039	0.017	

$^{40}Ar_{18}$

c = 3.57

λ_{max} =11.42

$\langle\lambda\rangle$ = 4.98

1	2	3	4	5	6
0.5	0.049	5.560	0.005	------------	
1	0.097	5.041	0.012	0.289	0.682
2	0.194	4.415	0.031	0.145	0.065
3	0.291	3.975	0.055	0.104	0.046
4	0.389	3.597	0.082	0.083	0.037
5	0.486	3.257	0.107	0.070	0.031
6	0.583	2.931	0.127	0.061	0.027
7	0.680	2.607	0.142	0.055	0.025
8	0.777	2.271	0.153	0.051	0.023
9	0.874	1.902	0.160	0.049	0.022
10	0.972	1.457	0.165	0.048	0.022
10.5	1.020	1.175	0.166	------------	
11	1.069	0.801	0.167	0.045	0.020

$^{52}Cr_{24}$

c = 3.94

λ_{max} =12.83

$\langle\lambda\rangle$ = 5.57

1	2	3	4	5	6
0.5	0.049	5.968	0.005	------------	
1	0.097	5.448	0.011	0.266	0.657
2	0.194	4.843	0.028	0.136	0.064
3	0.291	4.414	0.051	0.096	0.045
4	0.389	4.051	0.076	0.077	0.036
5	0.486	3.727	0.100	0.066	0.031
6	0.583	3.422	0.120	0.058	0.027
7	0.680	3.124	0.136	0.052	0.024
8	0.777	2.822	0.148	0.049	0.023
9	0.874	2.506	0.156	0.046	0.022
10	0.972	2.158	0.162	0.045	0.021
11	1.069	1.751	0.165	0.045	0.021
12	1.166	1.194	0.167	0.047	0.022
12.5	1.215	0.752	0.168	------------	
13	1.263	------------		0.016	0.007

$^{56}Fe_{26}$

c = 4.05

λ_{max} =13.25

$\langle\lambda\rangle$ = 5.75

1	2	3	4	5	6
0.5	0.049	6.083	0.005	------------	
1	0.097	5.571	0.011	0.261	0.651
2	0.194	4.966	0.028	0.131	0.062
3	0.291	4.543	0.050	0.096	0.045
4	0.389	4.186	0.074	0.076	0.036
5	0.486	3.865	0.098	0.065	0.030
6	0.583	3.564	0.118	0.057	0.027
7	0.680	3.272	0.135	0.052	0.024
8	0.777	2.978	0.147	0.048	0.023
9	0.874	2.673	0.155	0.046	0.022
10	0.972	2.344	0.161	0.044	0.021
11	1.069	1.961	0.164	0.044	0.021
12	1.166	1.481	0.167	0.046	0.022
12.5	1.215	1.157	0.168	------------	
13	1.263	0.661	0.168	0.036	0.017

$^{59}Co_{27}$

c = 4.13

λ_{max} =13.54

$\langle\lambda\rangle$ = 5.90

1	2	3	4	5	6
0.5	0.049	6.164	0.005	------------	
1	0.097	5.661	0.011	0.255	0.646
2	0.194	5.059	0.027	0.130	0.062
3	0.291	4.634	0.049	0.094	0.045
4	0.389	4.281	0.073	0.075	0.036
5	0.486	3.963	0.097	0.064	0.030
6	0.583	3.665	0.117	0.056	0.027
7	0.680	3.376	0.133	0.051	0.024
8	0.777	3.087	0.146	0.047	0.023
9	0.874	2.788	0.154	0.045	0.021
10	0.972	2.467	0.160	0.044	0.021
11	1.069	2.106	0.164	0.044	0.021
12	1.166	1.657	0.166	0.045	0.021
13	1.263	0.994	0.168	0.047	0.022
13.5	1.312	0.289	0.168	------------	
14	1.360	------------		0.002	0.001

$^{64}Cu_{29}$

c = 4.26

λ_{max} =14.01

$\langle\lambda\rangle$ = 6.14

1	2	3	4	5	6
0.5	0.049	6.305	0.004	------------	
1	0.097	5.802	0.010	0.249	0.638
2	0.194	5.203	0.027	0.128	0.062
3	0.291	4.776	0.048	0.091	0.044
4	0.389	4.428	0.072	0.074	0.035
5	0.486	4.115	0.095	0.062	0.030
6	0.583	3.823	0.115	0.055	0.027
7	0.680	3.540	0.132	0.050	0.024
8	0.777	3.259	0.144	0.047	0.022
9	0.874	2.971	0.153	0.044	0.021
10	0.972	2.665	0.159	0.043	0.021
11	1.609	2.323	0.163	0.042	0.020
12	1.166	1.918	0.166	0.044	0.021
13	1.263	1.379	0.168	0.046	0.022
13.5	1.312	0.987	0.168	------------	
14	1.360	0.091	0.168	0.025	0.012

$^{65}Zn_{30}$

c = 4.28

λ_{max} =14.10

$\langle\lambda\rangle$ = 6.13

1	2	3	4	5	6
0.5	0.049	6.333	0.004	------------	
1	0.097	5.829	0.010	0.248	0.637
2	0.194	5.230	0.027	0.128	0.062
3	0.291	4.805	0.048	0.091	0.044
4	0.389	4.456	0.071	0.073	0.035
5	0.486	4.145	0.094	0.062	0.030
6	0.583	3.853	0.115	0.055	0.027
7	0.680	3.751	0.131	0.050	0.024
8	0.777	3.292	0.144	0.046	0.022
9	0.874	3.005	0.153	0.044	0.021
10	0.972	2.702	0.159	0.043	0.021
11	1.069	2.366	0.163	0.042	0.020
12	1.166	1.965	0.166	0.043	0.021
13	1.263	1.447	0.167	0.046	0.022
13.5	1.312	1.074	0.168	------------	
14	1.360	0.430	0.168	0.029	0.014

1	2	3	4	5	6
0.5	0.049	6.538	0.004	------------	
1	0.097	6.028	0.010	0.241	0.626
2	0.194	5.435	0.026	0.124	0.061
3	0.291	5.022	0.046	0.088	0.043
4	0.389	4.677	0.069	0.070	0.035
5	0.486	4.370	0.092	0.060	0.030
6	0.583	4.084	0.112	0.053	0.026
7	0.680	3.809	0.128	0.048	0.024
8	0.777	3.538	0.141	0.045	0.022
9	0.874	3.262	0.151	0.043	0.021
10	0.972	2.975	0.157	0.041	0.020
11	1.069	2.663	0.162	0.041	0.020
12	1.166	2.308	0.165	0.041	0.020
13	1.263	1.877	0.167	0.044	0.022
14	1.360	1.269	0.168	0.047	0.023
14.5	1.409	0.767	0.168	------------	
15	1.457	-----------		0.014	0.007

$^{73}Ge_{32}$

$\lambda_{c} = 4.47$

$\lambda_{max} = 14.79$

$\langle \lambda \rangle = 6.52$

1	2	3	4	5	6
0.5	0.049	6.701	0.004	------------	
1	0.097	6.186	0.010	0.235	0.618
2	0.194	5.601	0.025	0.118	0.059
3	0.291	5.193	0.045	0.086	0.043
4	0.389	4.853	0.067	0.069	0.034
5	0.486	4.550	0.090	0.059	0.029
6	0.583	4.269	0.110	0.052	0.026
7	0.680	3.999	0.126	0.047	0.024
8	0.777	3.735	0.139	0.044	0.022
9	0.874	3.468	0.149	0.042	0.021
10	0.972	3.191	0.156	0.040	0.020
11	1.069	2.895	0.161	0.040	0.020
12	1.166	2.566	0.164	0.041	0.020
13	1.263	2.182	0.166	0.042	0.021
14	1.360	1.676	0.168	0.044	0.022
14.5	1.409	1.341	0.168	------------	
15	1.457	0.866	0.168	0.040	0.020

$^{80}Br_{35}$

$\lambda_{c} = 4.62$

$\lambda_{max} = 15.35$

$\langle \lambda \rangle = 6.81$

1	2	3	4	5	6
0.5	0.049	7.260	0.004	------------	
1	0.097	6.766	0.009	0.213	0.590
2	0.194	6.183	0.023	0.110	0.057
3	0.291	5.787	0.041	0.079	0.041
4	0.389	5.458	0.062	0.063	0.033
5	0.486	5.167	0.083	0.054	0.028
6	0.583	4.898	0.103	0.048	0.025
7	0.680	4.646	0.120	0.044	0.023
8	0.777	4.399	0.133	0.041	0.021
9	0.874	4.154	0.144	0.039	0.020
10	0.972	3.907	0.152	0.037	0.020
11	1.069	3.649	0.157	0.037	0.019
12	1.166	3.373	0.162	0.036	0.019
13	1.263	3.070	0.164	0.037	0.019
14	1.360	2.726	0.166	0.039	0.020
15	1.457	2.313	0.167	0.041	0.021
16	1.555	1.758	0.168	0.044	0.023
16.5	1.603	1.382	0.168	------------	
17	1.652	0.817	0.169	0.036	0.019

$^{108}Ag_{47}$

$\lambda_{c} = 5.15$

$\lambda_{max} = 17.27$

$\langle \lambda \rangle = 7.74$

1	2	3	4	5	6
0.5	0.049	7.592	0.004	------------	
1	0.097	7.084	0.009	0.206	0.576
2	0.194	6.524	0.022	0.103	0.055
3	0.291	6.125	0.040	0.075	0.040
4	0.389	5.803	0.059	0.061	0.033
5	0.486	5.520	0.080	0.052	0.028
6	0.583	5.258	0.099	0.046	0.024
7	0.680	5.010	0.116	0.042	0.022
8	0.777	4.772	0.130	0.039	0.021
9	0.874	4.537	0.141	0.037	0.020
10	0.972	4.300	0.149	0.036	0.019
11	1.069	4.059	0.155	0.035	0.019
12	1.166	3.802	0.160	0.034	0.018
13	1.263	3.528	0.163	0.035	0.019
14	1.360	3.224	0.165	0.036	0.019
15	1.457	2.875	0.167	0.038	0.020
16	1.555	2.454	0.168	0.041	0.022
17	1.652	1.900	0.168	0.043	0.023
17.5	1.700	1.527	0.168	------------	
18	1.749	1.016	0.169	0.040	0.022

$^{127}J_{53}$

$\lambda_{c} = 5.46$

$\lambda_{max} = 18.38$

$\langle \lambda \rangle = 8.36$

1	2	3	4	5	6
0.5	0.049	7.655	0.004	------------	
1	0.097	7.152	0.009	0.203	0.573
2	0.194	6.590	0.022	0.103	0.055
3	0.291	6.194	0.039	0.074	0.040
4	0.389	5.872	0.059	0.060	0.032
5	0.486	5.589	0.079	0.051	0.028
6	0.583	5.328	0.098	0.045	0.024
7	0.680	5.081	0.115	0.042	0.022
8	0.777	4.845	0.129	0.039	0.021
9	0.874	4.611	0.140	0.037	0.020
10	0.972	4.377	0.149	0.035	0.019
11	1.069	4.137	0.155	0.034	0.018
12	1.166	3.884	0.160	0.034	0.018
13	1.263	3.615	0.163	0.035	0.019
14	1.360	3.319	0.165	0.036	0.019
15	1.457	2.981	0.167	0.037	0.020
16	1.555	2.572	0.168	0.039	0.021
17	1.652	2.058	0.168	0.043	0.023
18	1.749	1.273	0.168	0.046	0.025
18.5	1.797	0.483	0.169	------------	
19	1.846	-----------		0.004	0.002

$^{131}Xe_{54}$

$\lambda_{c} = 5.52$

$\lambda_{max} = 18.59$

$\langle \lambda \rangle = 8.52$

1	2	3	4	5	6
0.5	0.049	8.351	0.004	------------	
1	0.097	7.865	0.008	0.184	0.543
2	0.194	7.309	0.020	0.092	0.052
3	0.291	6.923	0.036	0.068	0.038
4	0.389	6.613	0.054	0.056	0.031
5	0.486	6.340	0.073	0.646	0.026
6	0.583	6.089	0.092	0.042	0.023
7	0.680	5.857	0.108	0.039	0.022
8	0.777	5.634	0.122	0.035	0.020
9	0.874	5.415	0.134	0.034	0.019
10	0.972	5.199	0.143	0.032	0.018
11	1.069	4.981	0.151	0.032	0.018
12	1.166	4.758	0.156	0.031	0.017
13	1.263	4.524	0.160	0.031	0.017
14	1.360	4.279	0.163	0.032	0.018
15	1.457	4.011	0.165	0.032	0.018
16	1.555	3.710	0.166	0.034	0.019
17	1.652	3.367	0.167	0.036	0.020
18	1.749	2.962	0.168	0.038	0.021
19	1.846	2.455	0.168	0.040	0.023
20	1.943	1.754	0.169	0.044	0.025
20.5	1.992	1.226	0.169	------------	
21	2.040	------------		0.022	0.012

$^{181}Ta_{73}$

c = 6.19
λ_{max} =20.98
$\langle\lambda\rangle$ = 9.79

0.5	0.049	8.390	0.004	------------	
1	0.097	7.901	0.008	0.184	0.542
2	0.194	7.348	0.020	0.092	0.051
3	0.291	6.963	0.036	0.068	0.038
4	0.389	6.653	0.054	0.055	0.031
5	0.486	6.380	0.073	0.046	0.026
6	0.583	6.128	0.091	0.042	0.023
7	0.680	5.899	0.108	0.038	0.022
8	0.777	5.675	0.122	0.035	0.020
9	0.874	5.457	0.134	0.034	0.019
10	0.972	5.242	0.143	0.032	0.018
11	1.069	5.025	0.150	0.031	0.018
12	1.166	4.803	0.156	0.030	0.017
13	1.263	4.571	0.160	0.031	0.018
14	1.360	4.330	0.163	0.031	0.018
15	1.457	4.061	0.165	0.032	0.018
16	1.555	3.764	0.166	0.033	0.019
17	1.652	3.426	0.167	0.035	0.020
18	1.749	3.028	0.168	0.038	0.021
19	1.846	2.541	0.168	0.040	0.023
20	1.943	1.867	0.168	0.043	0.024
20.5	1.992	1.391	0.169	------------	
21	2.040	0.559	0.169	0.027	0.015

$^{184}W_{74}$

c = 6.22
λ_{max} =21.11
$\langle\lambda\rangle$ = 9.85

1	2	3	4	5	6
0.5	0.049	8.554	0.004	------------	
1	0.097	8.052	0.008	0.180	0.535
2	0.194	7.512	0.020	0.092	0.052
3	0.291	7.129	0.035	0.066	0.038
4	0.389	6.818	0.053	0.052	0.030
5	0.486	6.545	0.072	0.046	0.026
6	0.583	6.301	0.090	0.041	0.023
7	0.680	6.071	0.106	0.037	0.021
8	0.777	5.848	0.121	0.035	0.020
9	0.874	5.635	0.133	0.033	0.019
10	0.972	5.422	0.142	0.032	0.018
11	1.069	5.210	0.149	0.030	0.017
12	1.166	4.991	0.155	0.030	0.017
13	1.263	4.769	0.159	0.030	0.017
14	1.360	4.528	0.162	0.030	0.017
15	1.457	4.272	0.165	0.032	0.018
16	1.555	3.994	0.166	0.033	0.018
17	1.652	3.679	0.167	0.034	0.019
18	1.749	3.310	0.168	0.036	0.021
19	1.846	2.862	0.168	0.038	0.022
20	1.943	2.290	0.168	0.042	0.024
21	2.040	1.459	0.169	0.044	0.025
21.5	2.089	0.681	0.169	------------	
22	2.138	------------		0.006	0.004

$^{197}Au_{79}$

c = 6.37
λ_{max} =21.64
$\langle\lambda\rangle$ =10.15

0.5	0.049	8.673	0.003	------------	
1	0.097	8.176	0.008	0.177	0.531
2	0.194	7.630	0.020	0.092	0.052
3	0.291	7.249	0.035	0.064	0.037
4	0.389	6.939	0.052	0.052	0.030
5	0.486	6.666	0.071	0.046	0.026
6	0.583	6.427	0.089	0.041	0.023
7	0.680	6.197	0.105	0.036	0.021
8	0.777	5.978	0.120	0.034	0.020
9	0.874	5.765	0.132	0.032	0.018
10	0.972	5.555	0.141	0.031	0.018
11	1.069	5.344	0.149	0.030	0.017
12	1.166	5.131	0.154	0.030	0.017
13	1.263	4.909	0.159	0.029	0.017
14	1.360	4.675	0.162	0.030	0.017
15	1.457	4.431	0.164	0.031	0.017
16	1.555	4.155	0.166	0.031	0.018
17	1.652	3.848	0.167	0.033	0.019
18	1.749	3.498	0.168	0.035	0.020
19	1.846	3.082	0.168	0.038	0.022
20	1.943	2.570	0.168	0.040	0.023
21	2.040	1.863	0.169	0.043	0.025
21.5	2.089	1.340	0.169	------------	
22	2.138	0.366	0.169	0.024	0.014

$^{207}Pb_{82}$

c = 6.48
λ_{max} =22.04
$\langle\lambda\rangle$ =10.38

1	2	3	4	5	6
0.5	0.049	9.011	0.003	------------	
1	0.097	9.529	0.008	0.168	0.518
2	0.194	7.965	0.019	0.087	0.050
3	0.291	7.590	0.034	0.063	0.036
4	0.389	7.291	0.050	0.051	0.030
5	0.486	7.029	0.068	0.043	0.025
6	0.583	6.786	0.086	0.038	0.022
7	0.680	6.563	0.102	0.036	0.021
8	0.777	6.348	0.117	0.032	0.019
9	0.874	6.141	0.129	0.031	0.018
10	0.972	5.937	0.139	0.030	0.017
11	1.069	5.734	0.147	0.029	0.017
12	1.166	5.526	0.153	0.028	0.016
13	1.263	5.318	0.157	0.028	0.016
14	1.360	5.095	0.161	0.028	0.016
15	1.457	4.864	0.163	0.029	0.017
16	1.555	4.614	0.165	0.030	0.017
17	1.652	4.336	0.166	0.031	0.018
18	1.749	4.026	0.167	0.033	0.019
19	1.846	3.672	0.168	0.035	0.020
20	1.943	3.251	0.168	0.037	0.021
21	2.040	2.735	0.168	0.040	0.023
22	2.138	2.040	0.169	0.042	0.024
22.5	2.186	1.566	0.169	------------	
23	2.235	0.818	0.169	0.030	0.017

$^{238}U_{92}$

$c = 6.81$

$\lambda_{max} = 23.19$

$\langle\lambda\rangle = 11.05$

This cannot be correct, since it implies that our method of calculations applies to the mean density of point nucleons, whereas in fact each nucleon's influence extends over a region of radial extent at least 0.9 fm.

Within the present framework of nuclear theory there is no reliable way to treat such problem from a fundamental standpoint. We suggest here a simplest treatment, therefore, taking into account the nucleon's influence on the incident hadron at the nucleus peripheral region and vice versa - the hadron's influence extent on the nucleons at the peripheral region of the target nucleus. Namely, we determine the distribution of the nuclear matter layers the hadrons collide with in hadron-nucleus collisions, $W_1[\lambda(b)\cdot S] = W_1(n_N)$:

$$W_1(n_N) = \frac{b^2(n_N - 1/2) - b^2(n_N + 1/2)}{[b(3/2) + 2D_0]^2}, \qquad (6)$$

when, $n_N \geq 2$, and

$$W_1(1) = \frac{[b(3/2) + 2D_0]^2 - b^2(3/2)}{[b(3/2) + 2D_0]^2}.$$

The distribution (6) may be used for the hadron-nucleus collision events analysis later on. It is given in the Table as well.

5. ACKNOWLEDGMENT

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ТЕМАТИЧЕСКИЕ КАТЕГОРИИ ПУБЛИКАЦИЙ ОБЪЕДИНЕННОГО ИНСТИТУТА ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Индекс	Тематика
1.	Экспериментальная физика высоких энергий
2.	Теоретическая физика высоких энергий
3.	Экспериментальная нейтронная физика
4.	Теоретическая физика низких энергий
5.	Математика
6.	Ядерная спектроскопия и радиохимия
7.	Физика тяжелых ионов
8.	Криогеника
9.	Ускорители
10.	Автоматизация обработки экспериментальных данных
11.	Вычислительная математика и техника
12.	Химия
13.	Техника физического эксперимента
14.	Исследования твердых тел и жидкостей ядерными методами
15.	Экспериментальная физика ядерных реакций при низких энергиях
16.	Дозиметрия и физика защиты
17.	Теория конденсированного состояния
18.	Использование результатов и методов фундаментальных физических исследований в смежных областях науки и техники
19.	Биофизика

Павляк Т. и др. E1-86-643
Характеристики атомных ядер, используемых
в качестве мишеней в столкновениях при высоких
энергиях

Приводятся величины, определяющие свойства атомных ядер, применяемых в качестве мишеней в ядерных столкновениях. Рассчитаны средние и максимальные толщины слоев ядерной материи, вовлекаемых в столкновения при разных прицельных параметрах. Расчет проведен для 24 атомных ядер, от углерода до урана; приведены таблицы, содержащие результаты расчетов. Таблицы предназначены для использования при анализе данных об адрон-ядерных и ядро-ядерных столкновениях.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1986

Pawlak T. et al. E1-86-643
Characteristics of Atomic Nuclei Employed
as Targets in High Energy Nuclear Collisions

Characteristics of hadrons employed as projectiles in high energy hadron-nucleus collisions are defined. Parameters describing atomic nuclei as targets are given. The mean and maximum thicknesses of nuclear matter layers at various impact parameters are calculated for 24 nuclei used usually in experiments. Tables of the data are given.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1986