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THE ATOMIC NUCLEUS AS A TARGET

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1. INTRODUCTION

The purpose of this article is to characterize the atomic nucleus used as a target in hadron-nucleus collision experiments.

Various characteristics of the collision process, provided by experiments are of the statistical nature; as a rule,they are a result of quantitative analysis of very big number of events registered in any of detectors. As is usually practiced, samples of collision events of definite hadrons with definite target-nuclei, at definite energy, are investigated. In any collision event the target-nucleus is destroyed, but, in any of collisions in such sample identical projectile-hadron and identical target-nucleus are always involved. It enables us, in attempts to quantitatively describe the characteristics of the collision process, to treate the sample of events as a result of the collision of spatially homogeneous beam of parallelly moving monoenergetic hadrons with the "slab" of nuclear matter. The way this problem is proposed to be formulated is similar to that in absorption experiments, when the interaction of a particle beam with a slab of a material is studied.

It has been shown that: a) in hadron nucleus collisions the target-nucleus might be, in fact, treated successfully as a "slab" of nuclear matter /1/; b) applying consequently for the analysis of the hadron-nucleus collision characteristics the procedure used in particle absorption experiments, it is possible to account for hadron-nucleus data in terms of our knowledge of hadron-nucleon interactions /2/.

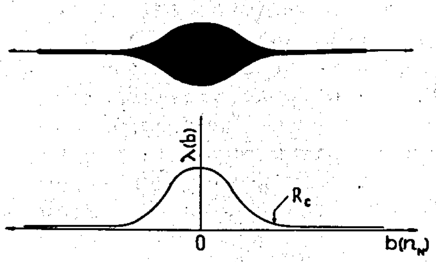
It is necessary, therefore, to characterize adequately and precisely the incident hadron beam by its absorption properties in nuclear matter, and the target-nucleus as the nuclear matter "slab". The hadron beam might be characterized by the hadron mean free path $<\lambda_0>$ in nuclear matter /1/; the method of this quantity measurement has been proposed as well /1/.

The nuclear matter "slab" might be characterized generally by the maximum thickness of nuclear matter layer - λ_{max}, its average thickness - $<\lambda>$, and the potential thickness corresponding to a given collision impact parameter b - $\lambda(b)$ expressed in numbers of nucleons per some area /1/, like the atmosphere thickness is expressed, in cosmic ray physics for example, in units of grams per cm^2.

The subject matter in this paper has been restricted to the characteristics of the ${}^{12}_{6}C$, ${}^{14}_{7}N$, ${}^{16}_{8}O$, ${}^{19}_{9}F$, ${}^{20}_{10}Ne$, ${}^{27}_{13}Al$, ${}^{28}_{14}Si$, ${}^{32}_{16}S$, ${}^{40}_{18}Ar$, ${}^{52}_{24}Cr$, ${}^{54}_{26}Fe$, ${}^{59}_{27}Co$, ${}^{64}_{29}Cu$, ${}^{65}_{30}Zn$, ${}^{73}_{32}Ge$, ${}^{80}_{35}Br$, ${}^{108}_{47}Ag$, ${}^{127}_{53}I$, ${}^{131}_{54}Xe$, ${}^{181}_{73}Ta$, ${}^{184}_{74}W$, ${}^{197}_{79}Au$, ${}^{207}_{82}Pb$, ${}^{238}_{92}U$ atomic nuclei.

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

The nucleon density decreases towards the periphery of any nucleus /3-5/, then any target-nucleus can be considered to be some lens-shaped "slab" of nuclear matter. Such slab can be characterized adequately by the b-dependence of its thickness $\lambda(b)$ measured in units of nucleons per some area S, expressed in fermis^2 (see the figure).



The atomic nucleus as the nuclear matter "slab". The cross section, if the thickness is expressed in nucleons/f ^{2} - upper; typical dependence of the nuclear matter layer thickness $\lambda(b)$, expressed in nucleons/f ^{2}, on the impact parameter b - lower.

The relation between the quantity $\lambda(b)$ and the radial-dependent nucleon density $\rho(r)$ nucleons/f^3 in any nucleus is given by the formula

$$\lambda(b) = 2\int_0^{\sqrt{R^2-y^2}} \rho(r)\,dy = 2\int_0^{\sqrt{R^2-y^2}} \rho(\sqrt{b^2+y^2})\,dy, \qquad (1)$$

where $r=\sqrt{b^2+y^2}$ is the distance between the nucleus center and any point inside the nucleus, defined by the quantities b and y. The quantity $\lambda(b)$ in formula (1) is expressed in units of nucleons/f ^{2}, if the quantities R, y, and b are expressed in fermis, and the quantity $\rho(\sqrt{b^2+y^2})$ in nucleons/f ^{3}. The quantity $\lambda(b)$ might be expressed in protons/f^2 because the ratio between the neutron number N_n and the proton number N_p inside the target-nucleus can be taken to be constant inside the atomic nucleus /6,7/; we use later N_n/N_p to be radial-independent, being (A-Z)/Z, where A is the mass number and Z is the atomic number.

The values of the "slab" thicknesses $\lambda(b)$ for various impact parameters b have been calculated using the so-called Fermi distribution /5/

$$\rho(r) = \frac{\rho_F}{1+e^{(r-c)/a}}, \qquad (2)$$

where $a = s/4\ln 3 \approx 0.23 s$; in all cases $c \gg a$, where c is the value of the distance r at which the nucleon density drops to half its maximum value at r=0. The usual normalization

$$4\pi \int_0^\infty \rho(r)\, r^2 dr = 1 \qquad (3)$$

gives

$$\rho_F = \frac{3}{4\pi c^3}\left(1+\frac{\pi^2 a^2}{c^2}\right)^{-1}, \qquad (4)$$

and for the radius R_e of the equivalent uniform nucleon distribution we have

$$R_e^2 = c^2\left(1+\frac{10\pi^2 a^2}{c^2}+\frac{7\pi^4 a^4}{3c^4}\right)\left(1+\frac{\pi^2 a^2}{c^2}\right)^{-1}. \qquad (5)$$

The radius ℓ of the sphere occupied by a nucleon at the centre of the nucleus, where the density is saturated, is defined by the relation

$$\frac{4}{3}\pi \ell^3 \rho_F = \frac{1}{A}, \qquad (6)$$

which gives

$$\ell = \left(\frac{4}{3}\pi A \rho_F\right)^{-1/3}, \qquad (7)$$

where ρ_F is given in units of f^{-3}. In the case when $A>6$, for heavier nuclei, nuclear matter appears to be virtually saturated and the maximum nuclear density ρ_{max} is effectively constant, being /5/ at $A\rho_{max} \approx 0.168 f^{-3}$. We have, then, $\ell = 1.123 f$. In terms of this length /5/:

$$c = \ell A^{1/3} - \frac{\pi^2 a^2}{3\ell} A^{-1/3} + O(A^{-5/3}), \qquad (8)$$

$$R_e = \ell A^{1/3} + \frac{5\pi^2 a^2}{6\ell} A^{-1/3} - \frac{7\pi^4 A^4}{24\ell^3} A^{-1} + O(A^{-5/3}). \qquad (9)$$

Equations (2)-(9) determine the nucleon density distribution $\rho(r)$ used in expression (1).

It is seen, from the figure, that a long tail exists in the b-dependence of the nuclear matter layer thickness $\lambda(b)$ given by the distribution (1), starting from the $\lambda(b)$ value being 0.5 protons/πD_0^2, where D_0=1.81f. In the tail region the nuclear matter layer thickness, in any nucleus under investigation, is negligibly small, in comparison with the nuclear matter layer thickness in the rest part of the distribution, approaching asymptotically the zero value at unlimitedly large values of the impact parameter b. It has been necessary to cut off this distribution at some distance b, putting some maximum value for the ratio $\rho(r)/\rho(0)$. This value might be estimated by fitting the value of the experimental absorption cross section for collisions of a hadron with any one nucleus to corresponding cross-section given by the formula in which $\lambda(b)$ is used, for example by formula given in one of our paper /8/. Such fitting gives the value $\rho(r)/\rho(0) \approx 10^{-8}$. To this value some value of the nuclear radius R corresponds.

Obviously, in the tail region of the $\lambda(b)$ distribution the quasielementary interactions of hadrons with nucleons take part only. Characteristic properties of the hadron-nucleus collisions might manifest themselves when the hadron-nucleus collisions take place at the impact parameters b corresponding to the region of nuclear matter layer thicknesses larger than those corresponding to the tail region. We call this region "the core-region of the nucleus", later on, and denote the radius of it by R_c (figure).

The values of the quantities $\langle\lambda\rangle$, λ_{max}, and $\lambda(b)$ should be evaluated for the target-nucleus core-region therefore. The average nuclear matter layer thickness $\langle\lambda\rangle$ and the maximum thickness of the target nucleus might be expressed then by formulas:

$$\lambda_{max} = \lambda(b=0) = 2\int_0^R \rho(r)\, dr, \qquad (10)$$

$$\langle\lambda\rangle = \int_0^{R_c} \lambda(b)\, w(b)\, db, \qquad (11)$$

where $w(b)$ is the propability density of the impact parameter b to occur in colliding of the homogeneous beam of parallelly moving hadrons with a target-nucleus; λ_{max} and $\langle\lambda\rangle$ are expressed in nucleons per f^2, when $\rho(r)$ is expressed in nucleons/f^3, r in f, $\lambda(b)$ in nucleons/f^2, b in f.

3. THE MULTIPLICITY n_p OF EMITTED PROTONS AS A MEASURE OF THE NUCLEAR MATTER LAYER THICKNESS

It has been concluded, in result of the experimental data analysis /9-11/, that any high energy hadron traversing nuclear matter causes monotonously the nucleon emission along its course. Usually the emitted protons are observed only in experiments. These protons are of energies roughly from 20 to 400 MeV; the number n_p of emitted protons accompanying a hadron passage through and target-nucleus, without particle creation, is expressed by /12-14/:

$$n_p = \pi D_0^2 \cdot \lambda \cdot \frac{Z}{A}, \qquad (12)$$

where λ, in nucleons/f^2, is the hadron path in nuclear matter, Z is the atomic number and A the mass number; D_0, in f, is determined by the relation

$$D_0^3 \cdot \rho = \frac{1}{A} \qquad (13)$$

and might be interpreted as the average distance between nucleons inside nucleus, where the nucleon density ρ, in f^{-3}, is saturated. D_0 might be interpreted as the nuclear force average range as well.

To any nucleus thickness λ, in formula (12), there corresponds definite proton number n_p, contained in the $\pi D_0^2\lambda$ volume. In particular, there are such values of the quantity λ to which the numbers $n_p = 1,2,3,\ldots$ of emitted protons correspond; using formulas (12) and (13), and the values of λ, in nucleons/f^2, b - dependent, contained in table 1, these values of $\lambda(n_p)$ might be estimated. These values should be treated as some "average", corresponding to some "average" impact parameter b; the term "average" is used because the numbers n_p of emitted protons can occur at impact parameters $b^{+\Delta_1}_{-\Delta_2}$ lying inside b-value interval $(b+\Delta_1, b-\Delta_2)$. Please, do not confuse them with the average target-nucleus thickness $\langle\lambda\rangle$.

It follows, from relation (12), that the nuclear matter layer thickness is expressed in number n_p of emitted protons, if the quantity λ is expressed in protons/S, where $S = \pi D_0^2$. It might be written, therefore, the equality:

$$\lambda\left[\frac{\text{protons}}{S}\right] = n_p\left[\frac{\text{protons}}{S}\right]. \qquad (14)$$

Relation (14) is valid when the hadron passes through the target-nucleus along its initial course without any perturbation causing an appearance of the recoil nucleons being able to cause the monotonous nucleon emission in ones turn in passing through nuclear matter[13,14].

It has been concluded, from experimental data [13,15], that the portion of the hadron-nucleus collision events in which a disturbance takes place is small, no more than a few per cent[14]. We have proved that the relation (14) might be applied for the sample of events with particle production as well [14,15], with an accuracy being well enough for the description of now existing experimental data [14,15].

It is usefull, therefore, to estimate the distribution $W_0(n_p)$ of the proton multiplicity in the ideal case, when the hadron pass through a target-nucleus without any perturbance, causing the monotonous nucleon emission only. This distribution is defined by the target-nucleus geometry only, i.e., by its size and radial nucleon density distribution $\rho(r)$ in it:

$$W_0(n_p) = \frac{2}{R_c^2} \int_{b-\Delta_1}^{b+\Delta_2} b\,db = \frac{\Delta_2^2 - \Delta_1^2}{R_c^2} + \frac{2(\Delta_1 + \Delta_2)}{R_c^2} b. \qquad (15)$$

The values of the intervals Δ_1 and Δ_2 have been estimated using following procedure. The "average" impact parameter $b(n_p)$, corresponding strictly to n_p protons, lie within the value intervals corresponding to $(n_p - 1/2, n_p + 1/2)$ proton multiplicity interval. To some value $b(n_p - 1/2)$ corresponds Δ_1 and to some $b(n_p + 1/2)$ corresponds Δ_2, at any b "average" value.

The distribution $W_0(n_p)$ for various target-nuclei is given in table 2; in calculations the values for b contained in table 1 were used.

4. TABLES

In this section tables containing the characteristics of various nuclei applied as targets are presented. Following symbols are used: c and s are the so-called nucleus parameters [5], in fermis; n_p - the number of protons in the nucleus within the cylindrical volume of $\pi D_0^2 \lambda f^3$; λ - the nuclear matter layer thickness, in nucleons/f^2; $D_0 = 1.81 f$ - mean interaction range; b - impact parameter, in f ; $\bar{\rho} = \bar{\rho}(b)$ - average nuclear matter density along the incident hadron course, at a given b, in nucleons/f^3; $\rho(r)$ - nuclear matter density in dependence on the distance r from the nucleus center, in nucleons per f^3; R_c - the radius corresponding to the impact parameter value $b(n_p = 1/2)$, i.e., to the "nucleus core"; R_t - the radius corresponding to $n_p = 0.25$ in the tail region; R - the radius of the nucleus corresponding to the relative nucleon density $\rho(R)/\rho(0) = 0.725 \cdot 10^{-8}$; W_t - the ratio between $\pi(R - R_c)^2$ and πR_c^2; n_0 - the number of protons inside $\pi D_0^2 \lambda$ volume at $\lambda(b = 0)$, or the maximal "slab" thickness in protons per πD_0^2 area; $L_0 \equiv \lambda(b = 0)$, in protons/$f^2$.

Table 1

Summary of Nuclear target parameters

$^{12}_{6}C$:

$c = 2.16$ $s = 2.49$ $\langle\lambda\rangle = 1.41$
$R_c = 3.43$ $R_t = 4.00$ $R = 12.79$
$W_t = 0.93$ $n_0 = 2.96$ $L_0 = 0.58$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.097	3.434	-	0.09766
1.0	0.194	2.718	0.20506	0.27804
1.5	0.291	2.162	0.33133	0.50998
2.0	0.389	1.643	0.45445	0.72921
2.5	0.486	1.076	0.55671	0.89066

$^{14}_{7}N$:

$c = 2.32$ $s = 2.49$ $\langle\lambda\rangle = 1.51$
$R_c = 3.62$ $R_t = 4.18$ $R = 12.95$
$W_t = 0.92$ $n_0 = 3.27$ $L_0 = 0.64$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.097	3.618	-	0.09292
1.0	0.194	2.919	0.19311	0.26088
1.5	0.291	2.386	0.31087	0.47711
2.0	0.389	1.901	0.42767	0.68666
2.5	0.486	1.405	0.52741	0.84714
3.0	0.583	0.792	0.60476	0.95214
3.5	0.680	-	-	-
4.0	0.777	-	-	-

$^{16}_{8}O$:

$c = 2.46$ $s = 2.49$ $\langle\lambda\rangle = 1.60$
$R_c = 3.78$ $R_t = 4.34$ $R = 13.08$
$W_t = 0.92$ $n_0 = 3.54$ $L_0 = 0.69$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.097	3.781	-	0.08919
1.0	0.194	3.096	0.18386	0.24766
1.5	0.291	2.579	0.29511	0.45189
2.0	0.389	2.117	0.40697	0.65377
2.5	0.486	1.660	0.50466	0.81352
3.0	0.583	1.151	0.58220	0.92115
3.5	0.680	0.315	0.64145	0.99048
4.0	0.777	-	-	-

$^{19}_{9}F$:

$c = 2.64$ $s = 2.49$ $\langle\lambda\rangle = 1.67$
$R_c = 3.95$ $R_t = 4.50$ $R = 13.26$
$W_t = 0.91$ $n_0 = 3.71$ $L_0 = 0.76$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.103	3.951	-	0.09144
1.0	0.205	3.267	0.18769	0.25216
1.5	0.308	2.753	0.29966	0.45618
2.0	0.410	2.297	0.41111	0.65468
2.5	0.513	1.850	0.50777	0.80981
3.0	0.615	1.368	0.58433	0.91333
3.5	0.718	0.723	0.64263	0.97649
4.0	0.820	-	-	-

$^{20}_{10}$Ne:

$c = 2.70$ $s = 2.49$ $\langle\lambda\rangle = 1.77$
$R_c = 4.06$ $R_t = 4.61$ $R = 13.33$
$W_t = 0.91$ $n_o = 4.03$ $L_o = 0.78$

0.5	0.097	4.064	-	0.08358
1.0	0.194	3.398	0.17023	0.22830
1.5	0.291	2.904	0.27201	0.41506
2.0	0.389	2.472	0.37639	0.60507
2.5	0.486	2.059	0.47066	0.76306
3.0	0.583	1.632	0.54837	0.87577
3.5	0.680	1.139	0.60932	0.94833
4.0	0.777	0.267	0.65682	0.99495
4.5	0.874	-	-	-
5.0	0.972	-	-	-

$^{27}_{13}$Al:

$c = 3.06$ $s = 2.49$ $\langle\lambda\rangle = 1.98$
$R_c = 4.43$ $R_t = 4.97$ $R = 13.68$
$W_t = 0.89$ $n_o = 4.55$ $L_o = 0.92$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.101	4.434	-	0.08111
1.0	0.202	3.782	0.16345	0.21824
1.5	0.303	3.304	0.25966	0.39397
2.0	0.404	2.891	0.35908	0.57464
2.5	0.504	2.505	0.45054	0.72880
3.0	0.605	2.120	0.52778	0.84277
3.5	0.706	1.710	0.58987	0.91895
4.0	0.807	1.223	0.63895	0.96649
4.5	0.908	0.375	0.67826	0.99577
5.0	1.009	-	-	-

$^{28}_{14}$Si:

$c = 3.10$ $s = 2.49$ $\langle\lambda\rangle = 2.07$
$R_c = 4.52$ $R_t = 5.05$ $R = 13.72$
$W_t = 0.89$ $n_o = 4.82$ $L_o = 0.94$

0.5	0.097	4.516	-	0.07633
1.0	0.194	3.875	0.15301	0.20404
1.5	0.291	3.408	0.24297	0.36898
2.0	0.389	3.008	0.33742	0.54274
2.5	0.486	2.638	0.42634	0.69637
3.0	0.583	2.274	0.50331	0.81465
3.5	0.680	1.896	0.56651	0.89701
4.0	0.777	1.472	0.61723	0.95051
4.5	0.874	0.908	0.65800	0.98365
5.0	0.972	-	-	-

$^{32}_{16}$S :

$c = 3.27$ $s = 2.49$ $\langle\lambda\rangle = 2.20$
$R_c = 4.70$ $R_t = 5.23$ $R = 13.89$
$W_t = 0.88$ $n_o = 5.14$ $L_o = 1.00$

0.5	0.097	4.704	-	0.07377
1.0	0.194	4.072	0.14704	0.19568
1.5	0.291	3.615	0.23293	0.35312
2.0	0.389	3.225	0.32380	0.52087
2.5	0.486	2.867	0.41055	0.67228
3.0	0.583	2.520	0.48690	0.79191
3.5	0.680	2.167	0.55063	0.87764
4.0	0.777	1.785	0.60247	0.93495
4.5	0.874	1.331	0.64452	0.97135
5.0	0.972	0.629	0.67919	0.99371

$^{40}_{18}$Ar:

$c = 3.57$ $s = 2.49$ $\langle\lambda\rangle = 2.24$
$R_c = 4.95$ $R_t = 5.48$ $R = 14.19$
$W_t = 0.88$ $n_o = 5.14$ $L_o = 1.11$

0.5	0.108	4.948	-	0.08036
1.0	0.216	4.307	0.16038	0.21318
1.5	0.324	3.841	0.25324	0.38163
2.0	0.432	3.442	0.34943	0.55519
2.5	0.540	3.074	0.43887	0.70536
3.0	0.648	2.716	0.51566	0.81896
3.5	0.756	2.349	0.57854	0.89709
4.0	0.864	1.947	0.62913	0.94735
4.5	0.972	1.462	0.67004	0.97796
5.0	1.080	0.692	0.70392	0.99560

$^{52}_{24}$Cr:

$c = 3.94$ $s = 2.49$ $\langle\lambda\rangle = 2.57$
$R_c = 5.38$ $R_t = 5.90$ $R = 14.56$
$W_t = 0.86$ $n_o = 5.92$ $L_o = 1.24$

0.5	0.105	5.381	-	0.07288
1.0	0.211	4.760	0.14375	0.19037
1.5	0.316	4.315	0.22621	0.34037
2.0	0.421	3.940	0.31358	0.50041
2.5	0.526	3.598	0.39785	0.64677
3.0	0.632	3.273	0.47324	0.76509
3.5	0.737	2.950	0.53737	0.85236
4.0	0.842	2.616	0.59055	0.91268
4.5	0.947	2.253	0.63437	0.92241
5.0	1.053	1.828	0.67083	0.97743
5.5	1.158	1.255	0.70179	0.99226

$^{56}_{26}$Fe:

$c = 4.05$ $s = 2.49$ $\langle\lambda\rangle = 2.67$
$R_c = 5.51$ $R_t = 6.03$ $R = 14.67$
$W_t = 0.86$ $n_o = 6.15$ L_o 1.29

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.105	5.507	-	0.07106
1.0	0.209	4.892	0.13972	0.18484
1.5	0.314	4.452	0.21962	0.33027
2.0	0.419	4.082	0.30471	0.48664
2.5	0.523	3.746	0.38749	0.63152
3.0	0.628	3.428	0.46227	0.75053
3.5	0.732	3.114	0.52652	0.83982
4.0	0.837	2.793	0.58022	0.90262
4.5	0.942	2.450	0.62473	0.94475
5.0	1.046	2.059	0.66187	0.97186
5.5	1.151	1.568	0.69340	0.98841
6.0	1.256	0.770	0.72082	0.99773

$^{59}_{27}$Co:

$c = 4.13$ $s = 2.49$ $\langle\lambda\rangle = 2.70$
$R_c = 5.58$ $R_t = 6.10$ $R = 14.75$
$W_t = 0.86$ $n_o = 6.20$ $L_o = 1.32$

0.5	0.106	5.583	-	0.07154
1.0	0.212	4.967	0.14062	0.18597
1.5	0.318	4.527	0.22092	0.33196
2.0	0.425	4.157	0.30633	0.48858
2.5	0.531	3.822	0.38929	0.63332
3.0	0.637	3.503	0.46415	0.75193
3.5	0.743	3.190	0.52842	0.84075
4.0	0.849	2.869	0.58211	0.90314
4.5	0.955	2.526	0.62662	0.94493
5.0	1.062	2.138	0.66377	0.97179
5.5	1.168	1.654	0.69532	0.98818
6.0	1.274	0.899	0.72277	0.99735

$^{64}_{29}$Cu:

$c = 4.26$ $s = 2.49$ $\langle\lambda\rangle = 2.78$
$R_c = 5.71$ $R_t = 6.23$ $R = 14.88$
$W_t = 0.85$ $n_o = 6.35$ $L_o = 1.36$

0.5	0.107	5.713	-	0.07112
1.0	0.214	5.100	0.13953	0.18440
1.5	0.322	4.662	0.21902	0.32880
2.0	0.429	4.294	0.30365	0.48394
2.5	0.536	3.961	0.38607	0.62786
3.0	0.643	3.646	0.46071	0.74641
3.5	0.750	3.337	0.52502	0.83573
4.0	0.858	3.022	0.57893	0.89888
4.5	0.965	2.688	0.62374	0.94150
5.0	1.072	2.314	0.66121	0.96912
5.5	1.179	1.861	0.69305	0.98617
6.0	1.287	1.217	0.72071	0.99589

$^{65}_{30}$Zn:

$c = 4.28$ $s = 2.49$ $\langle\lambda\rangle = 2.83$
$R_c = 5.75$ $R_t = 6.27$ $R = 14.90$
$W_t = 0.85$ $n_o = 6.51$ $L_o = 1.37$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.105	5.754	-	0.06917
1.0	0.211	5.145	0.13542	0.17886
1.5	0.316	4.711	0.21244	0.31899
2.0	0.421	4.348	0.29487	0.47078
2.5	0.526	4.020	0.37580	0.61339
3.0	0.632	3.711	0.44976	0.73264
3.5	0.737	3.409	0.51405	0.82392
4.0	0.842	3.102	0.56834	0.88946
4.5	0.947	2.781	0.61368	0.93438
5.0	1.053	2.426	0.65170	0.96402
5.5	1.158	2.008	0.68401	0.98273
6.0	1.263	1.452	0.71203	0.99378

$^{73}_{32}$Ge:

$c = 4.47$ $s = 2.49$ $\langle\lambda\rangle = 2.86$
$R_c = 5.92$ $R_t = 6.43$ $R = 15.09$
$W_t = 0.85$ $n_o = 6.48$ $L_o = 1.44$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.111	5.917	-	0.07204
1.0	0.222	5.303	0.14121	0.18646
1.5	0.332	4.865	0.22139	0.33176
2.0	0.443	4.498	0.30656	0.48717
2.5	0.554	4.166	0.38930	0.63071
3.0	0.665	3.851	0.46408	0.74849
3.5	0.776	3.543	0.52844	0.83697
4.0	0.887	3.229	0.58238	0.89939
4.5	0.997	2.898	0.62724	0.94147
5.0	1.108	2.530	0.66478	0.96872
5.5	1.219	2.091	0.69671	0.98554
6.0	1.330	1.496	0.72445	0.99513

$^{80}_{35}$Br:

$c = 4.62$ $s = 2.49$ $\langle\lambda\rangle = 2.98$
$R_c = 6.08$ $R_t = 6.59$ $R = 15.24$
$W_t = 0.84$ $n_o = 6.72$ $L_o = 1.49$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.111	6.080	-	0.07072
1.0	0.222	5.471	0.13825	0.18239
1.5	0.333	5.037	0.21653	0.32423
2.0	0.444	4.673	0.29997	0.47678
2.5	0.555	4.346	0.38153	0.61899
3.0	0.666	4.037	0.45580	0.73707
3.5	0.777	3.735	0.52019	0.82693
4.0	0.888	3.431	0.57451	0.89117
4.5	0.999	3.112	0.61989	0.93506
5.0	1.110	2.763	0.65798	0.96394
5.5	1.221	2.359	0.69038	0.98215
6.0	1.332	1.844	0.71850	0.99289
6.5	1.444	1.036	0.74340	0.99850

$^{108}_{47}$Ag:

$c = 5.15$ $s = 2.49$ $\langle\lambda\rangle = 3.37$
$R_c = 6.65$ $R_t = 7.15$ $R = 15.77$
$W_t = 0.82$ $n_o = 7.52$ $L_o = 1.68$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.112	6.647	-	0.06656
1.0	0.223	6.050	0.12903	0.16973
1.5	0.335	5.628	0.20137	0.30081
2.0	0.447	5.278	0.27927	0.44405
2.5	0.558	4.964	0.35685	0.58144
3.0	0.670	4.671	0.42913	0.69971
3.5	0.781	4.388	0.49327	0.79335
4.0	0.893	4.108	0.54849	0.86307
4.5	1.005	3.821	0.59536	0.91273
5.0	1.116	3.519	0.63508	0.94691
5.5	1.228	3.189	0.66902	0.96970
6.0	1.340	2.810	0.69842	0.98430
6.5	1.451	2.345	0.72431	0.99308
7.0	1.563	1.709	0.74748	0.99781
7.5	1.674	0.313	0.76843	0.99992

$^{127}_{53}$I :

$c = 5.46$ $s = 2.49$ $\langle\lambda\rangle = 3.49$
$R_c = 6.94$ $R_t = 7.45$ $R = 16.08$
$W_t = 0.81$ $n_o = 7.67$ $L_o = 1.79$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.116	6.943	-	0.06777
1.0	0.233	6.346	0.13131	0.17261
1.5	0.349	5.923	0.20476	0.30534
2.0	0.466	5.572	0.28364	0.44965
2.5	0.582	5.258	0.36191	0.58721
3.0	0.698	4.964	0.43458	0.70490
3.5	0.815	4.681	0.49890	0.79754
4.0	0.931	4.400	0.55415	0.86618
4.5	1.048	4.113	0.60099	0.91486
5.0	1.164	3.811	0.64068	0.94824
5.5	1.281	3.481	0.67459	0.97042
6.0	1.397	3.105	0.70397	0.98457
6.5	1.513	2.651	0.72984	0.99306
7.0	1.630	2.050	0.75295	0.99763
7.5	1.746	1.054	0.77380	0.99964

$^{131}_{54}$Xe:

$c = 5.52$ $s = 2.49$ $\langle\lambda\rangle = 3.51$
$R_c = 7.00$ $R_t = 7.51$ $R = 16.14$
$W_t = 0.81$ $n_o = 7.66$ $L_o = 1.81$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.118	6.998	-	0.06838
1.0	0.236	6.400	0.13254	0.17422
1.5	0.354	5.997	0.20667	0.30807
2.0	0.471	5.625	0.28616	0.45322
2.5	0.589	5.309	0.36487	0.59112
3.0	0.707	5.015	0.43779	0.70864
3.5	0.825	4.730	0.50218	0.80078
4.0	0.943	4.447	0.55739	0.86878
4.5	1.061	4.159	0.60415	0.91683
5.0	1.179	3.854	0.64373	0.94967
5.5	1.296	3.522	0.67754	0.97140
6.0	1.414	3.142	0.70684	0.98520
6.5	1.532	2.681	0.73264	0.99341
7.0	1.650	2.071	0.75568	0.99778
7.5	1.768	1.055	0.77646	0.99968

$^{181}_{73}$Ta:

$c = 6.19$ $s = 2.49$ $\langle\lambda\rangle = 3.95$
$R_c = 7.69$ $R_t = 8.19$ $R = 16.81$
$W_t = 0.79$ $n_o = 8.46$ $L_o = 2.04$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.120	7.692	-	0.06551
1.0	0.241	7.103	0.12616	0.16544
1.5	0.361	6.689	0.19615	0.29171
2.0	0.482	6.346	0.27168	0.43005
2.5	0.602	6.040	0.34743	0.56400
3.0	0.723	5.756	0.41871	0.68101
3.5	0.843	5.484	0.48270	0.77532
4.0	0.964	5.217	0.53840	0.84693
4.5	1.084	4.947	0.58612	0.89903
5.0	1.205	4.669	0.62686	0.93572
5.5	1.325	4.373	0.66182	0.96085
6.0	1.445	4.048	0.69212	0.97755
6.5	1.566	3.678	0.71875	0.98819
7.0	1.686	3.238	0.74246	0.99455
7.5	1.807	2.681	0.76380	0.99796
8.0	1.927	1.896	0.78309	0.99950

$^{184}_{74}W$:

$c=6.22$ $s=2.49$ $\langle\lambda\rangle=3.96$
$R_c=7.73$ $R_t=8.23$ $R=16.84$
$W_t=0.79$ $n_o=8.49$ $L_o=2.05$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.121	7.728	-	0.06552
1.0	0.242	7.139	0.12615	0.16541
1.5	0.362	6.725	0.19611	0.29162
2.0	0.483	6.382	0.27162	0.42987
2.5	0.604	6.077	0.34734	0.56376
3.0	0.725	5.793	0.41861	0.68073
3.5	0.846	5.521	0.48260	0.77503
4.0	0.966	5.254	0.53831	0.84667
4.5	1.087	4.985	0.58605	0.89879
5.0	1.208	4.707	0.62681	0.93551
5.5	1.329	4.411	0.66178	0.96068
6.0	1.450	4.087	0.69211	0.97742
6.5	1.570	3.719	0.71875	0.98809
7.0	1.691	3.281	0.74247	0.99447
7.5	1.812	2.730	0.76381	0.99792
8.0	1.933	1.959	0.78311	0.99948
8.5	2.054	-	-	-

$^{197}_{79}Au$:

$c=6.37$ $s=2.49$ $\langle\lambda\rangle=4.07$
$R_c=7.89$ $R_t=8.39$ $R=16.99$
$W_t=0.78$ $n_o=8.68$ $L_o=2.10$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.121	7.885	-	0.06479
1.0	0.242	7.299	0.12458	0.16327
1.5	0.363	6.886	0.19354	0.28766
2.0	0.485	6.546	0.26808	0.42428
2.5	0.606	6.243	0.34305	0.55716
3.0	0.727	5.961	0.41388	0.67395
3.5	0.848	5.692	0.47772	0.76873
4.0	0.969	5.428	0.53350	0.84120
4.5	1.090	5.163	0.58144	0.89428
5.0	1.211	4.890	0.62245	0.93194
5.5	1.333	4.602	0.65769	0.95795
6.0	1.454	4.288	0.68825	0.97541
6.5	1.575	3.934	0.71510	0.98668
7.0	1.696	3.520	0.73899	0.99355
7.5	1.817	3.009	0.76047	0.99738
8.0	1.938	2.331	0.77989	0.99922
8.5	2.059	1.220	0.79749	0.99990

$^{207}_{82}Pb$:

$c=6.48$ $s=2.49$ $\langle\lambda\rangle=4.11$
$R_c=7.99$ $R_t=8.49$ $R=17.10$
$W_t=0.78$ $n_o=8.73$ $L_o=2.14$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.123	7.994	-	0.06511
1.0	0.245	7.407	0.12518	0.16403
1.5	0.368	6.994	0.19444	0.28888
2.0	0.491	6.653	0.26926	0.42583
2.5	0.613	6.350	0.34444	0.55884
3.0	0.736	6.069	0.41541	0.67554
3.5	0.858	5.799	0.47931	0.77008
4.0	0.981	5.535	0.53511	0.84227
4.5	1.104	5.269	0.58304	0.89509
5.0	1.226	4.996	0.62404	0.93251
5.5	1.349	4.708	0.65926	0.95833
6.0	1.472	4.393	0.68980	0.97564
6.5	1.594	4.040	0.71663	0.98680
7.0	1.717	3.627	0.74050	0.99360
7.5	1.840	3.120	0.76195	0.99738
8.0	1.962	2.453	0.78134	0.99920
8.5	2.085	1.405	0.79888	0.99988

$^{238}_{92}U$:

$c=6.81$ $s=2.49$ $\langle\lambda\rangle=4.27$
$R_c=8.32$ $R_t=8.82$ $R=17.43$
$W_t=0.77$ $n_o=8.96$ $L_o=2.25$

n_p	λ	b	$\bar{\rho}$	$\rho(r=b)$
0.5	0.126	8.317	-	0.06518
1.0	0.251	7.731	0.12517	0.16391
1.5	0.377	7.319	0.19429	0.28836
2.0	0.503	6.979	0.26894	0.42479
2.5	0.628	6.667	0.34400	0.55733
3.0	0.754	6.397	0.41490	0.67374
3.5	0.880	6.129	0.47882	0.76820
4.0	1.005	5.866	0.53469	0.84046
4.5	1.131	5.603	0.58275	0.89344
5.0	1.257	5.332	0.62389	0.93109
5.5	1.382	5.048	0.65925	0.95714
6.0	1.508	4.740	0.68992	0.97466
6.5	1.634	4.395	0.71686	0.98604
7.0	1.759	3.998	0.74080	0.99303
7.5	1.885	3.519	0.76229	0.99700
8.0	2.011	2.912	0.78170	0.99897
8.5	2.136	2.058	0.79924	0.99978

Table 2

$W_0(n_p)$ distribution for various atomic nuclei A

A \ n_p	1	2	3	4	5	6	7	8	9
C	0.6057	0.2857	0.0986	-	-	-	-	-	-
N	0.5678	0.2827	0.1495	-	-	-	-	-	-
O	0.5341	0.2730	0.1857	0.0072	-	-	-	-	-
F	0.5142	0.2652	0.1876	0.0330	-	-	-	-	-
Ne	0.4898	0.2528	0.1786	0.0788	-	-	-	-	-
Al	0.4476	0.2354	0.1670	0.1427	0.0073	-	-	-	-
Si	0.4342	0.2247	0.1644	0.1371	0.0396	-	-	-	-
S	0.4068	0.2229	0.1591	0.1299	0.0813	-	-	-	-
Ar	0.3958	0.2155	0.1644	0.1370	0.0873	-	-	-	-
Cr	0.3552	0.1970	0.1491	0.1222	0.1216	0.0549	-	-	-
Fe	0.3530	0.1830	0.1445	0.1241	0.1155	0.0799	-	-	-
Co	0.3438	0.1875	0.1439	0.1208	0.1155	0.0885	-	-	-
Cu	0.3363	0.1844	0.1383	0.1214	0.1138	0.1057	-	-	-
Zn	0.3285	0.1844	0.1387	0.1155	0.1124	0.1194	0.0012	-	-
Ge	0.3261	0.1802	0.1362	0.1176	0.1141	0.1258	0.0000	-	-
Br	0.3129	0.1776	0.1312	0.1151	0.1127	0.1214	0.0293	-	-
Ag	0.2836	0.1584	0.1229	0.1042	0.1016	0.1052	0.1219	0.0023	-
I	0.2724	0.1532	0.1197	0.1023	0.1010	0.1045	0.1236	0.0233	-
Xe	0.2702	0.1565	0.1147	0.1054	0.1003	0.1063	0.1237	0.0229	-
Ta	0.2474	0.1373	0.1088	0.0949	0.0880	0.0952	0.1073	0.1211	-
W	0.2423	0.1375	0.1090	0.0951	0.0883	0.0956	0.1081	0.1241	-
Au	0.2377	0.1352	0.1038	0.0944	0.0880	0.0908	0.1051	0.1209	0.0240
Pb	0.2344	0.1336	0.1064	0.0933	0.0872	0.0901	0.1029	0.1215	0.0306
U	0.2259	0.1294	0.1036	0.0880	0.0861	0.0273	0.1007	0.1177	0.0613

5. REMARKS

The nucleon distribution has a core of constant density surrounded by a surface region. The evidence, for the protons, is the clearest in the b>>0 core region and establishes with considerable accuracy the maximum density and the radial distance at which the density has fallen to half its maximum value. It is less clear in the interior, where the possibility of a different, in comparison with the ρ_F, slight variation of the density towards the centre of nucleus cannot be excluded.

In this article we have estimated the average thicknesses $\langle\lambda\rangle$ for the core region of various nuclei; it might be denoted as $\langle\lambda_c\rangle$ instead of $\langle\lambda\rangle$. Inside this region the nuclear effects in hadron-nucleus collisions should be manifested. But, in some of experiments the average thickness corresponding to the total nuclear volume, at $b \leq R$, might be desired; we denote it by $\langle\lambda_t\rangle$, it can be evaluated simply using formula (11) in which R instead R_c should be used.

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