ON ACCURACY OF HUGONIOT MEASUREMENTS IN LASER EXPERIMENTS

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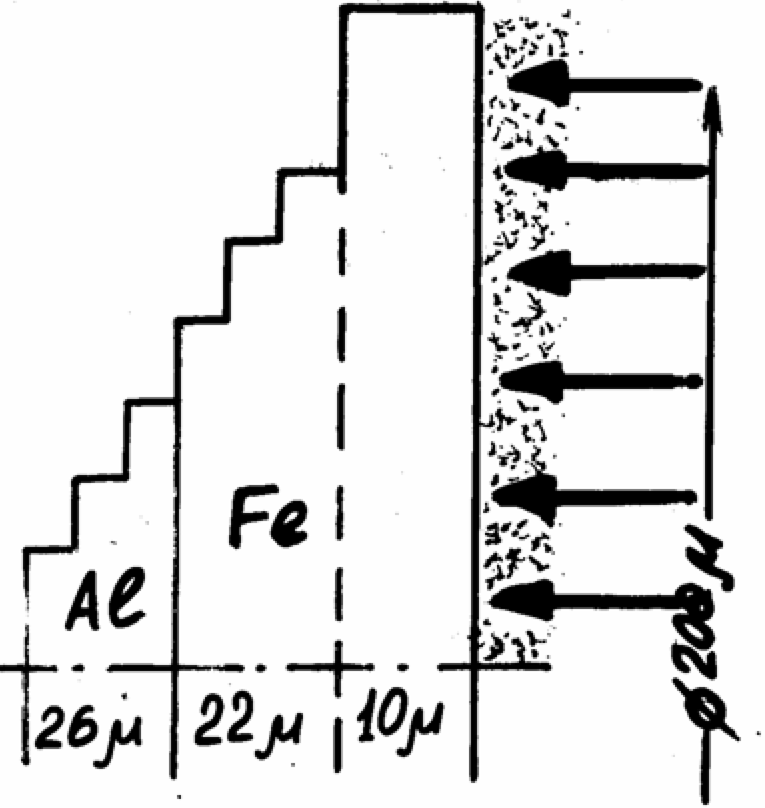
Hugoniot experimental measurements.

1) **With chemical explosives (Compendiums of Livermore, Los Alamos, Sarov): up to 2 Mbars in plane geometry, up to 10 Mbars in spherical geometry, up to 25 Mbars in 2-staged spherical devices; accuracy 1–2% in *P*, *u*.**
2) **5–10 Mbars in 2-staged light gas guns with plane geometry. Accuracy ~0.3% in *D*, *u*.**
3) **Up to 500 Mbars in nuclear underground explosions. Only impedance match method.**
4) **Laser experiments. Pressures 10–20 Mbars. Plane geometry, impedance match method, accuracy ~5%.**

But now we need accuracy ≤0.5%.

In the 1970ths many scientists expected lasers to provide accurate measurements of shock compressions. But we were not so enthusiastic:

N.N. Kalitkin, V.B. Rozanov, Conference in Plasma Physics, 1975, Zvenigorod.



$E = 500$ дж

$W = 1{,}6 \times 10^{15}$ Вт/см^2

$t \approx 1$ нсек

	Fe	Al
ρ Мбар	170	90
D км/сек	55	67
U км/сек	40	51

базы по 7–9 μ

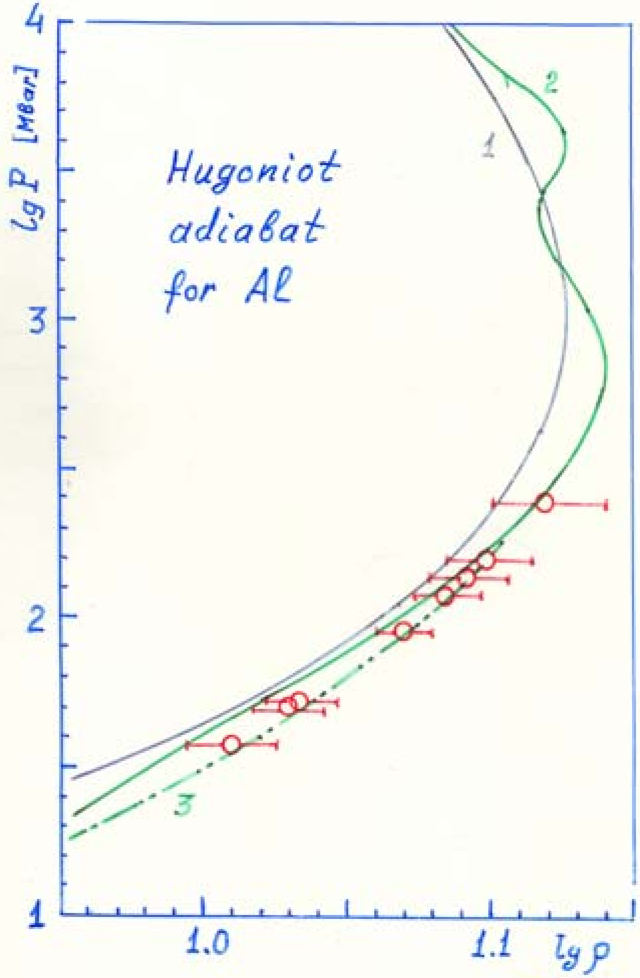
Времена по 135 psек

чтобы получить $D_{Al}(D_{Fe}) \pm 0{,}5\%$ надо точность измерения 200 Å и 0,35 psек

Methods

Complicated original theoretical models based on quantum mechanics and statistical physics. Experimental information at low pressures and temperatures is used for model corrections.

Accuracy



⊢○⊣ experiments of Chelyabinsk - 70.

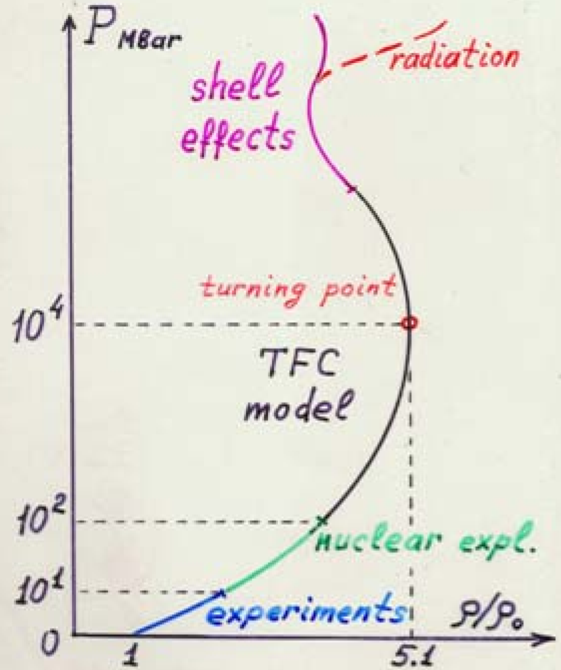
1 - SESAME library * (~10 models with fitting to experiments at low pressures).

2 - TEPHYS library (only 3 theoretical models without fitting to experiments).

3 - TEPHYS with fitting to law pressure experiments.

* SESAME - Los Alamos

Behaviour of Hugoniot



Cu, porosity $m=1$.

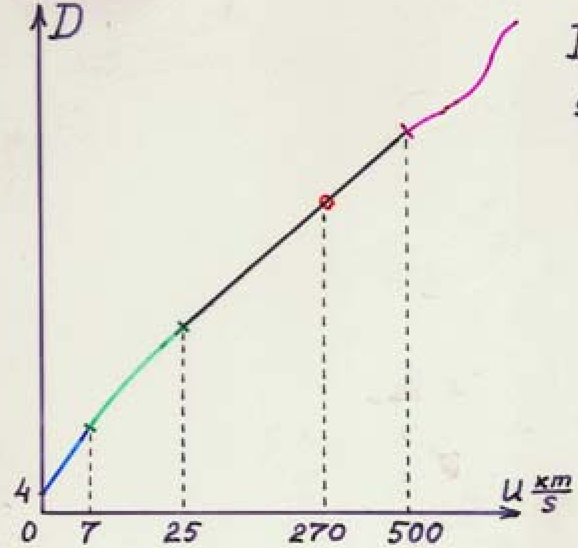
Turning point:

$P_t \approx 7.9$ Gbar,

$u_t \approx 270$ km/s.

For $m>1$

behaviour of all parts of this curve is the same exept experimental part, where the behaviour is much more complicated.



D(u) curve is more suitable for appoximation

Experimental data treatment

L.V. Altshuler in 1970ths treated the whole massive of experimental data using approximation $D(u) \approx c + bu + du^2$. We proposed the better method. It is based on two variants of the theoretical model of not compressed atom:

- **TFC – the Thomas–Fermi model with quantum and exchange corrections,**
- **QS – the quantum–statistical model.**

Both models give good Hugoniots of condenced matters at pressures 25 Mbars – 230 Gbars.

$$D_{QS}(u) \approx C + Bu + Au2 \pm 0.1\%; \quad 0 < A << 1.$$

Coefficients *C*, *B*, *A* were calculated for 83 substances.

At pressures above all phase transitions experimental data are approximated by

$$D(u) \approx D_{QS}(u) - \frac{C' - c}{1 + \mu u + \mu^2 u^2}, \quad \mu \equiv \frac{b - B}{C' - c}.$$

At $u \to 0$ this approximation tends to

$$D(u) \approx c + bu + O \cdot u^2.$$

Coefficients *c*,*b* are fitted by the least square method. For those elements where ≥200 exp. points are measured, accuracy of *D*(*u*) reaches 0.15% (Cu and Fe).

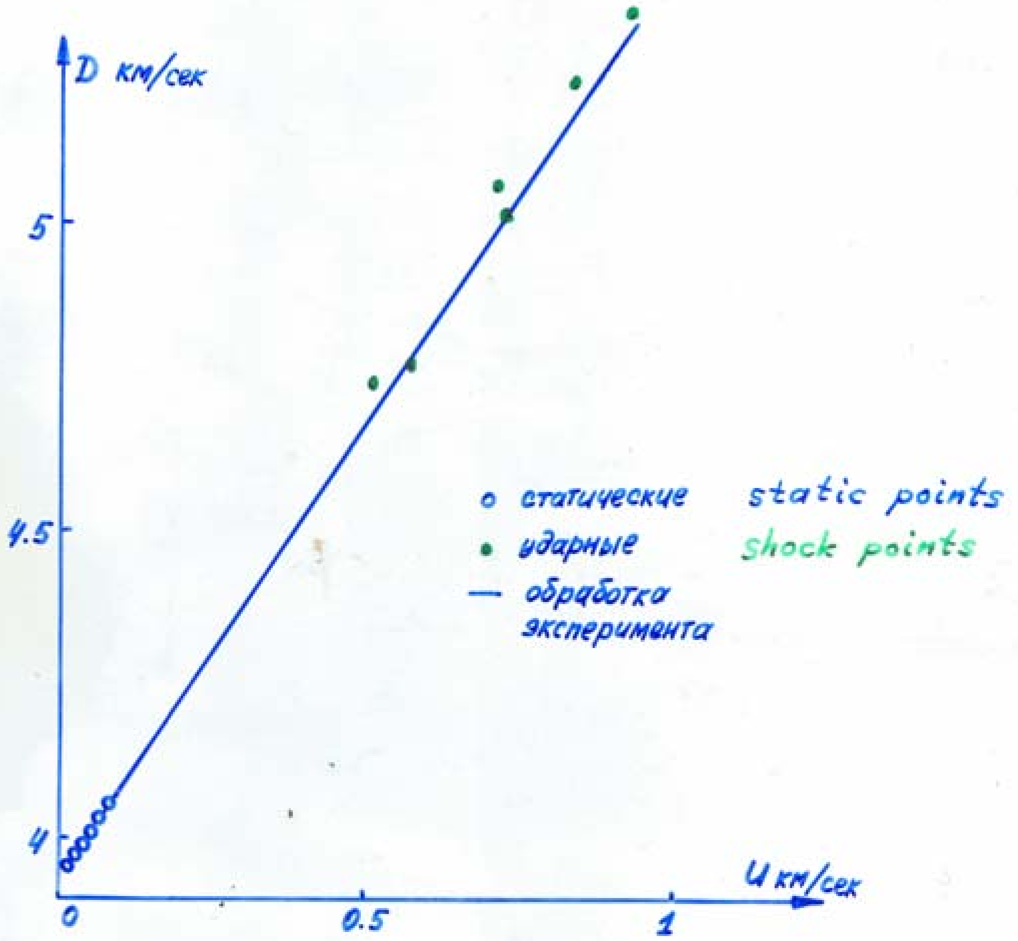
The very illustrative form of graphic representation was proposed: D/D_{QS} versus *u*.

$$D=\sqrt{\frac{P-P_0}{\rho_0}\cdot\frac{\delta}{\delta-1}}$$

$$u=\sqrt{\frac{P-P_0}{\rho_0}\cdot\frac{\delta-1}{\delta}}$$

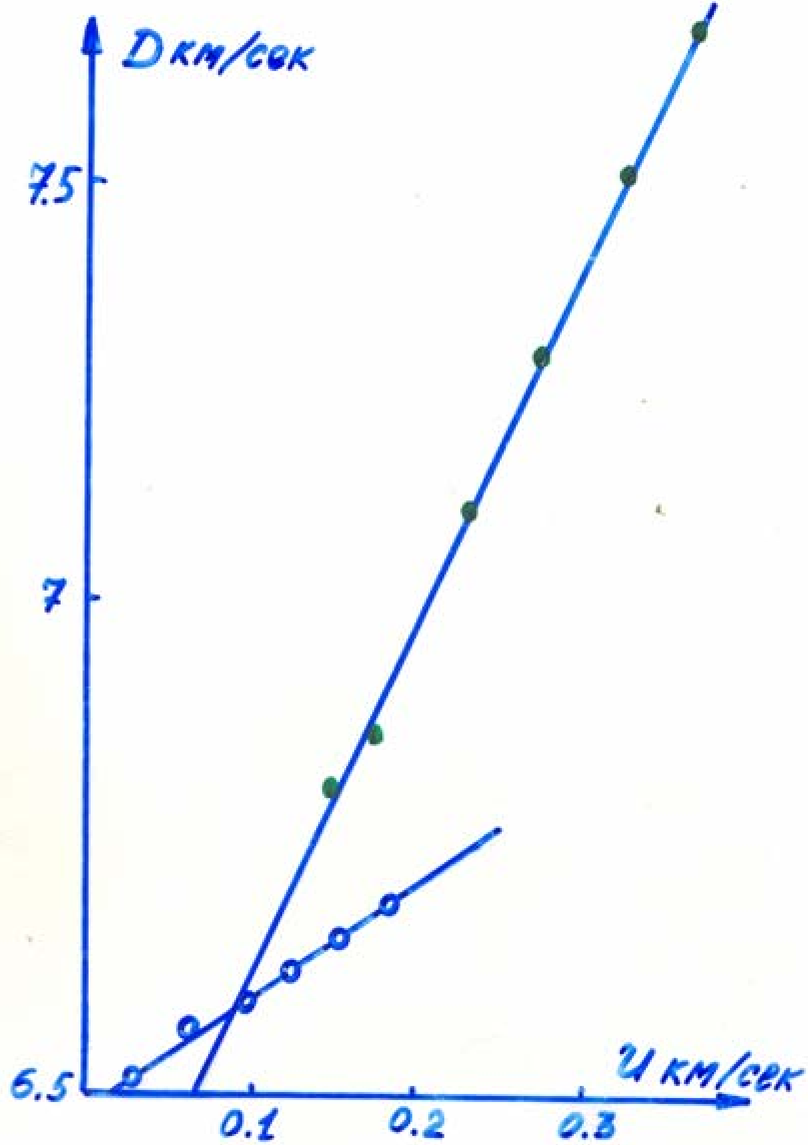
$$\delta=\frac{\rho}{\rho_0}$$

Formulae for treatment of static experiments

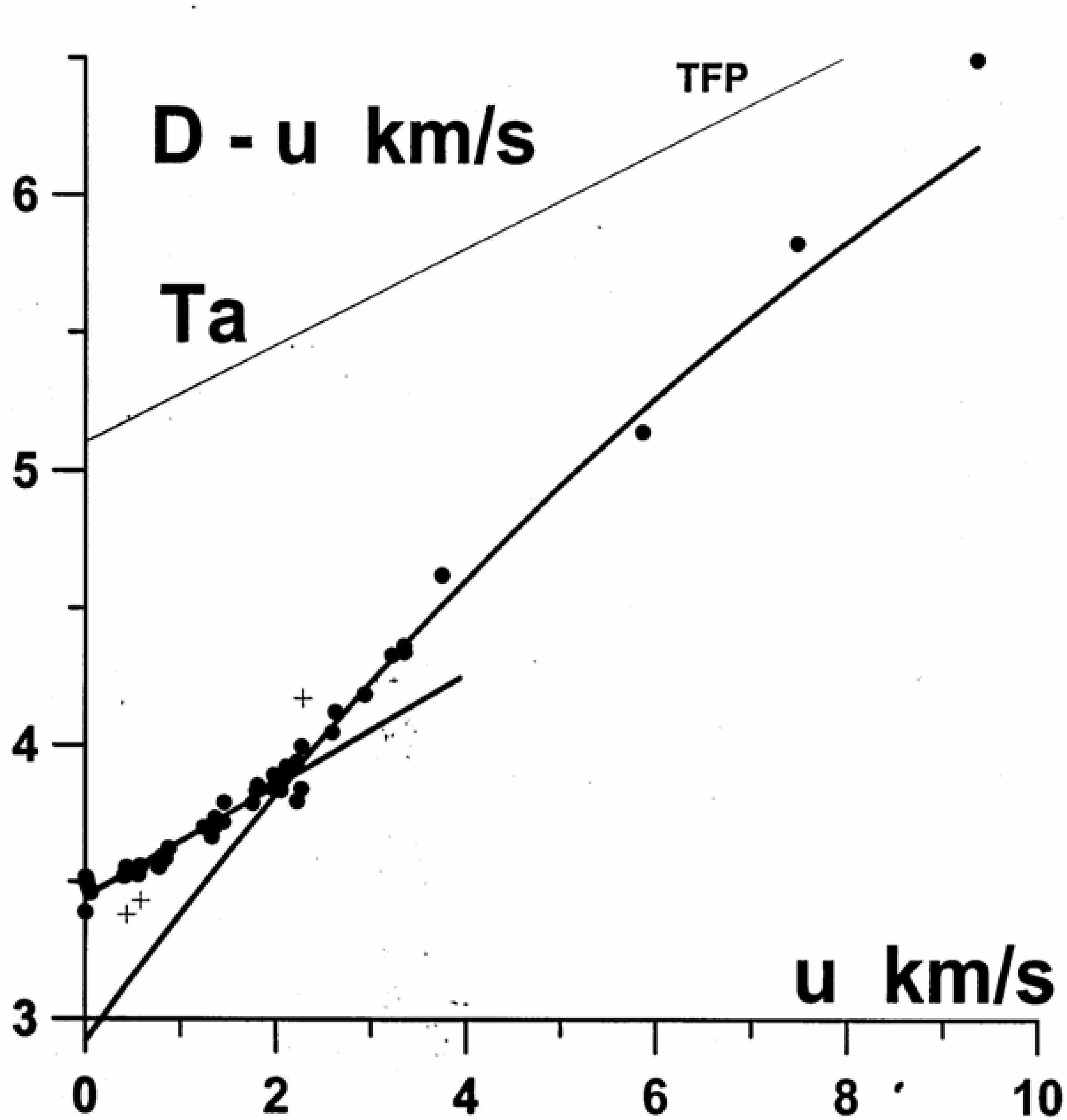


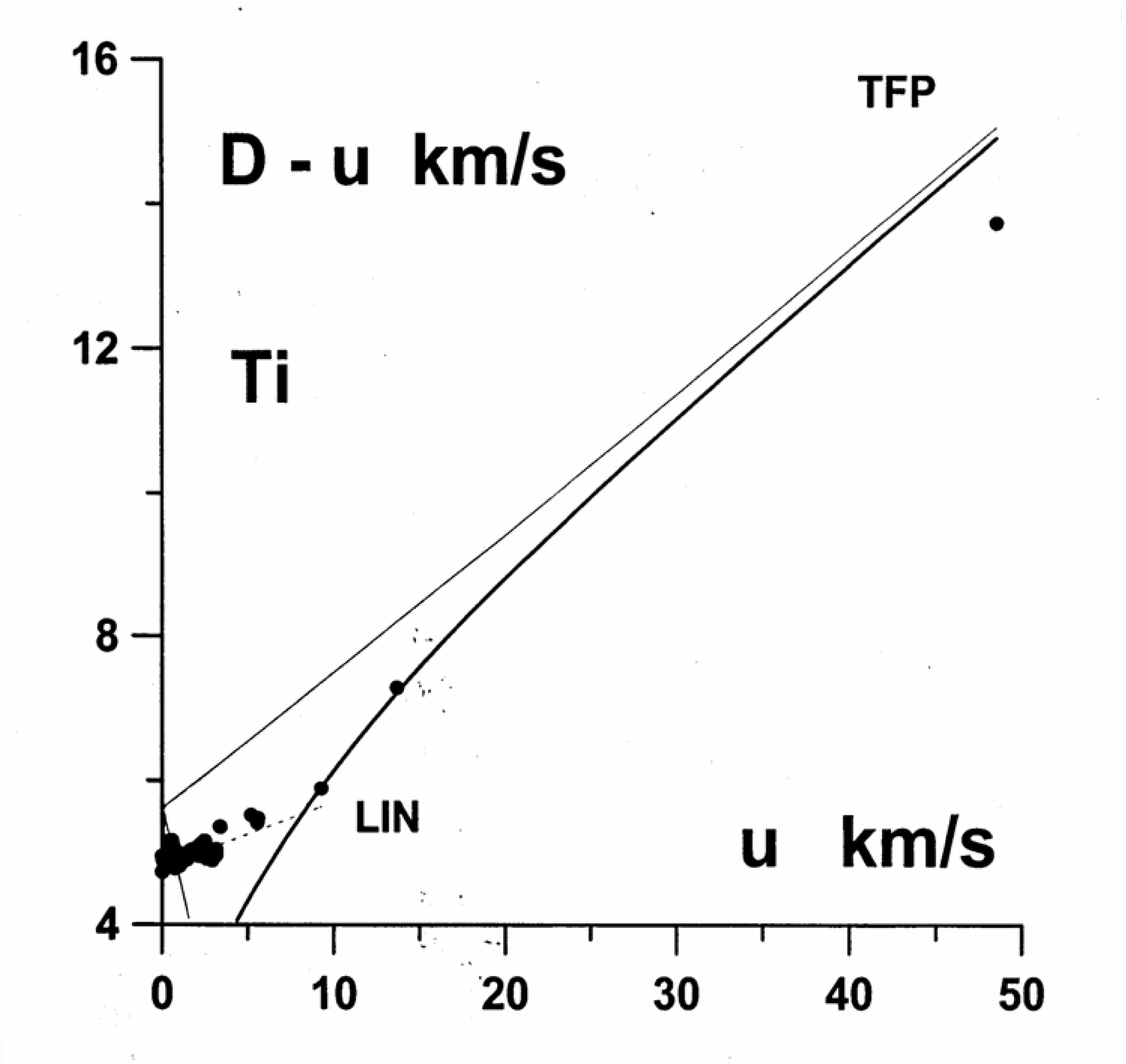
Статическое и ударное сжатие меди.

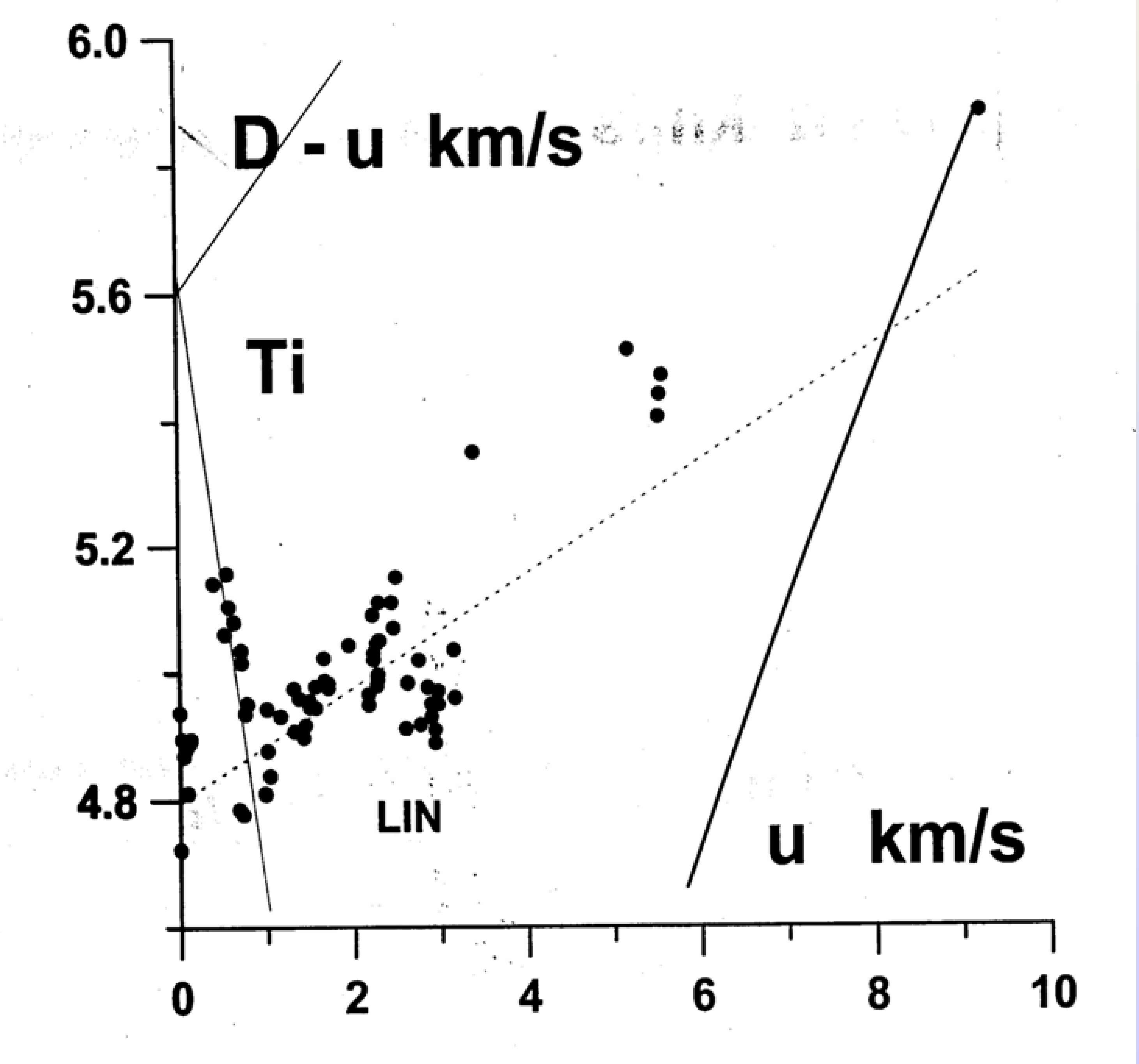
Static and shock compression of Cu



Обработка кривых холодного сжатия кремния Бриджмена, кружки и точки – – работы разных лет.


TFP
D - u km/s
Ta
u km/s
6
5
4
3
0
2
4
6
8
10

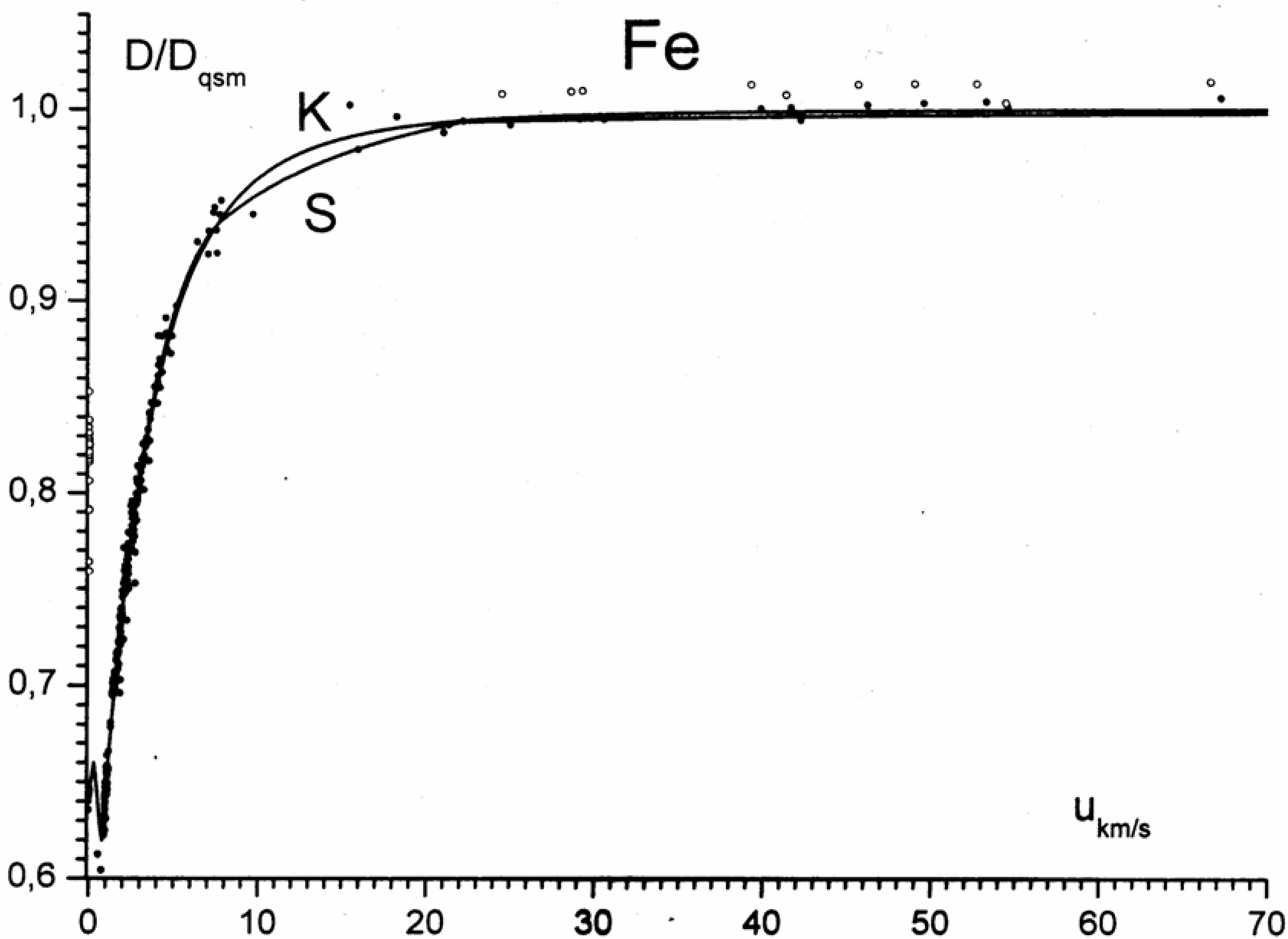

D - u km/s
Ti
TFP
LIN
u km/s
16
12
8
4
0
10
20
30
40
50


6.0
D - u km/s
5.6
Ti
5.2
4.8
LIN
u km/s
0
2
4
6
8
10

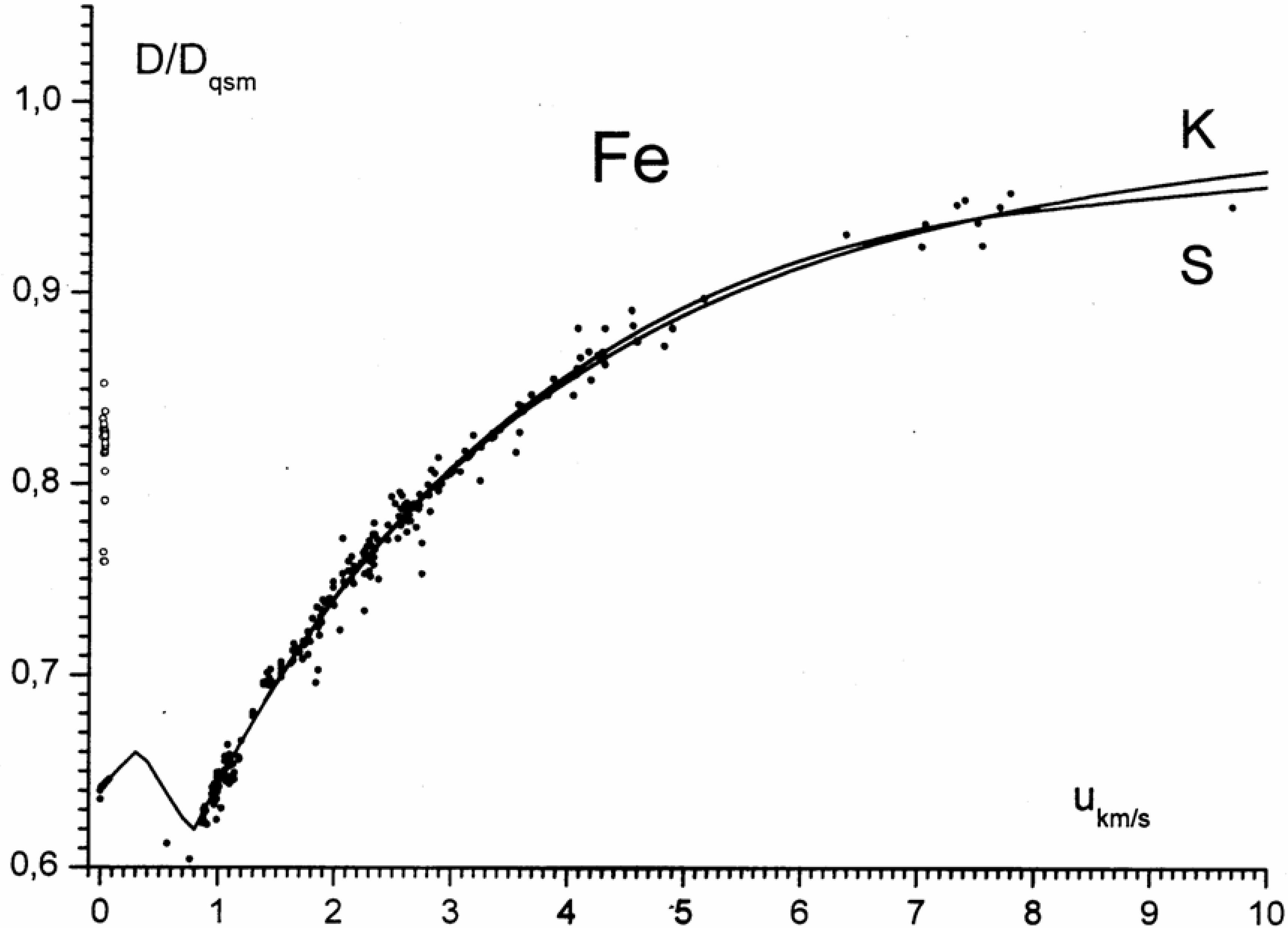
2

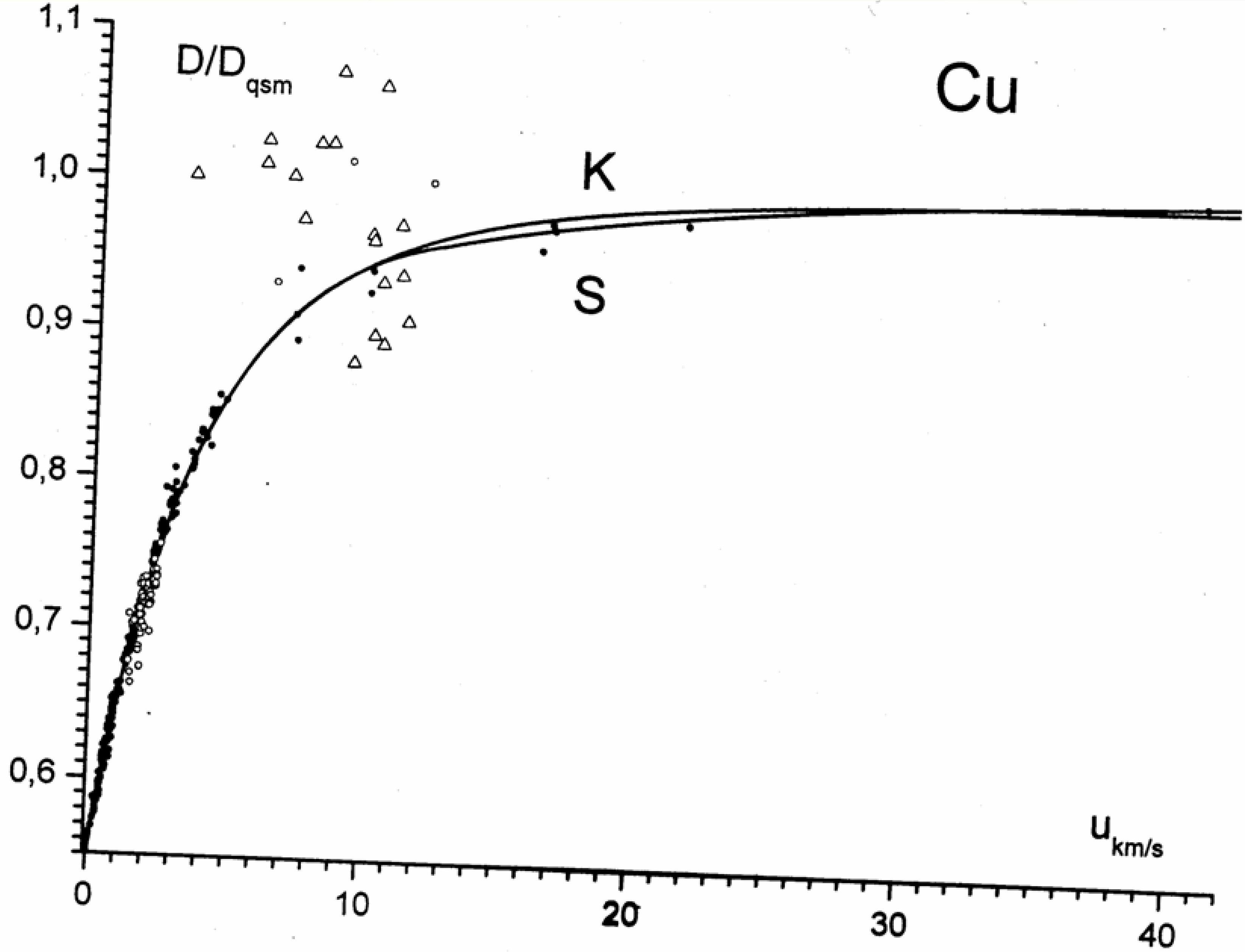
Таблица 2. Эталонные *D*(*u*) – зависимости из [3].

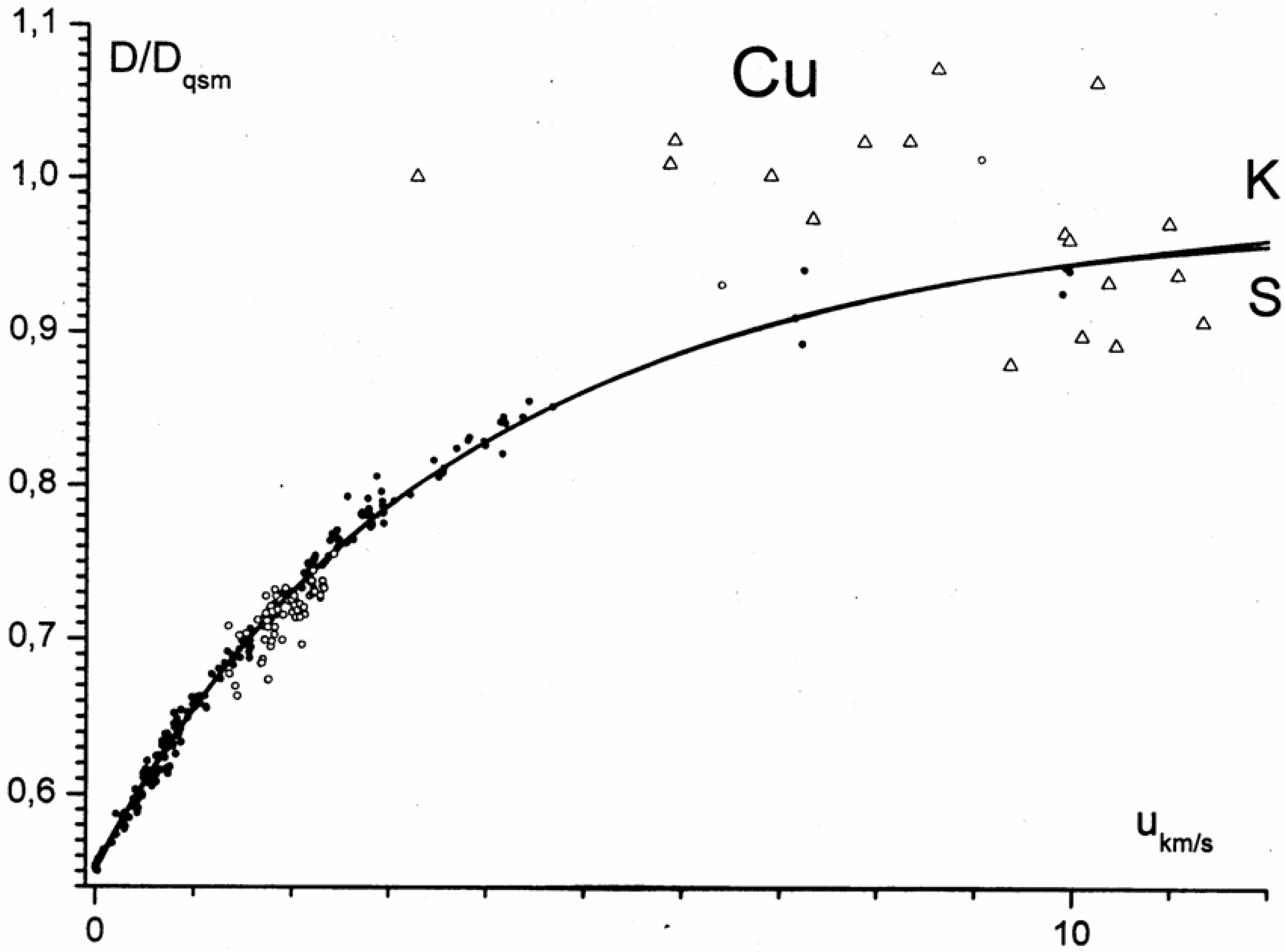
Вещ–во	ρ_0 г/см^3	*C* км/с	*B*	$A\cdot10^4$ с/км	*c* км/с	*b*	δ%	*u* км/с
Cu	8.93	7.0924	1.19013	0.999	3.923±0.002	1.511±0.003	0.16	0÷533
Fe	7.87	7.2220	1.18959	1.099	3.671±0.013	1.753±0.007	0.14	0.782÷500
					5.042		~1	0.333÷0.782
					4.629±0	1.241	~1	0÷0.333
Al	2.71	5.7889	1.19380	1.568	5.236±0.009	1.470±0.014	0.13	0÷384



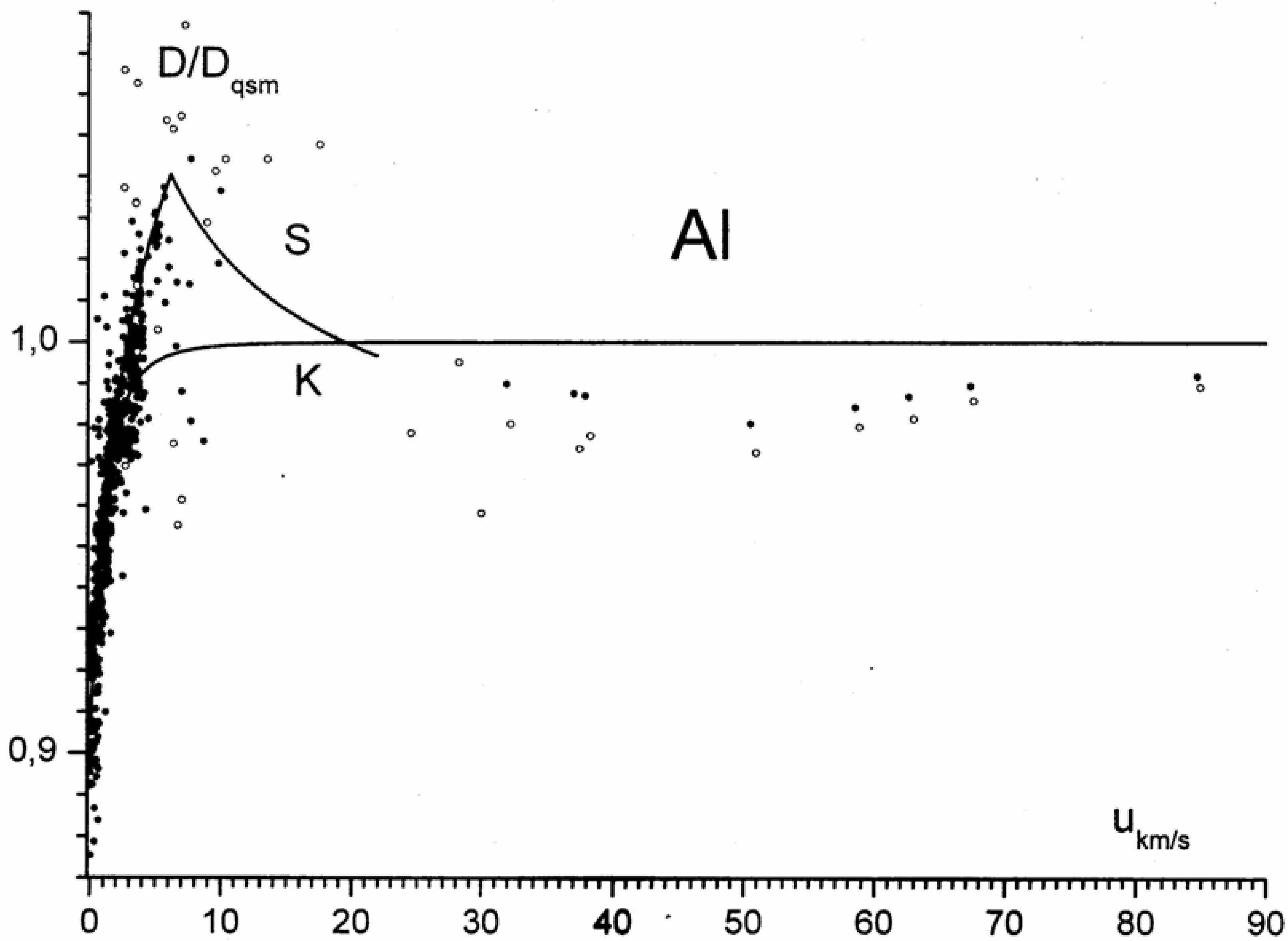
Fe
D/D_qsm
K
S
1,0
0,9
0,8
0,7
0,6
u_km/s
0
10
20
30
40
50
60
70


D/D_qsm
1,0
0,9
0,8
0,7
0,6
Fe
K
S
u_km/s
0
1
2
3
4
5
6
7
8
9
10

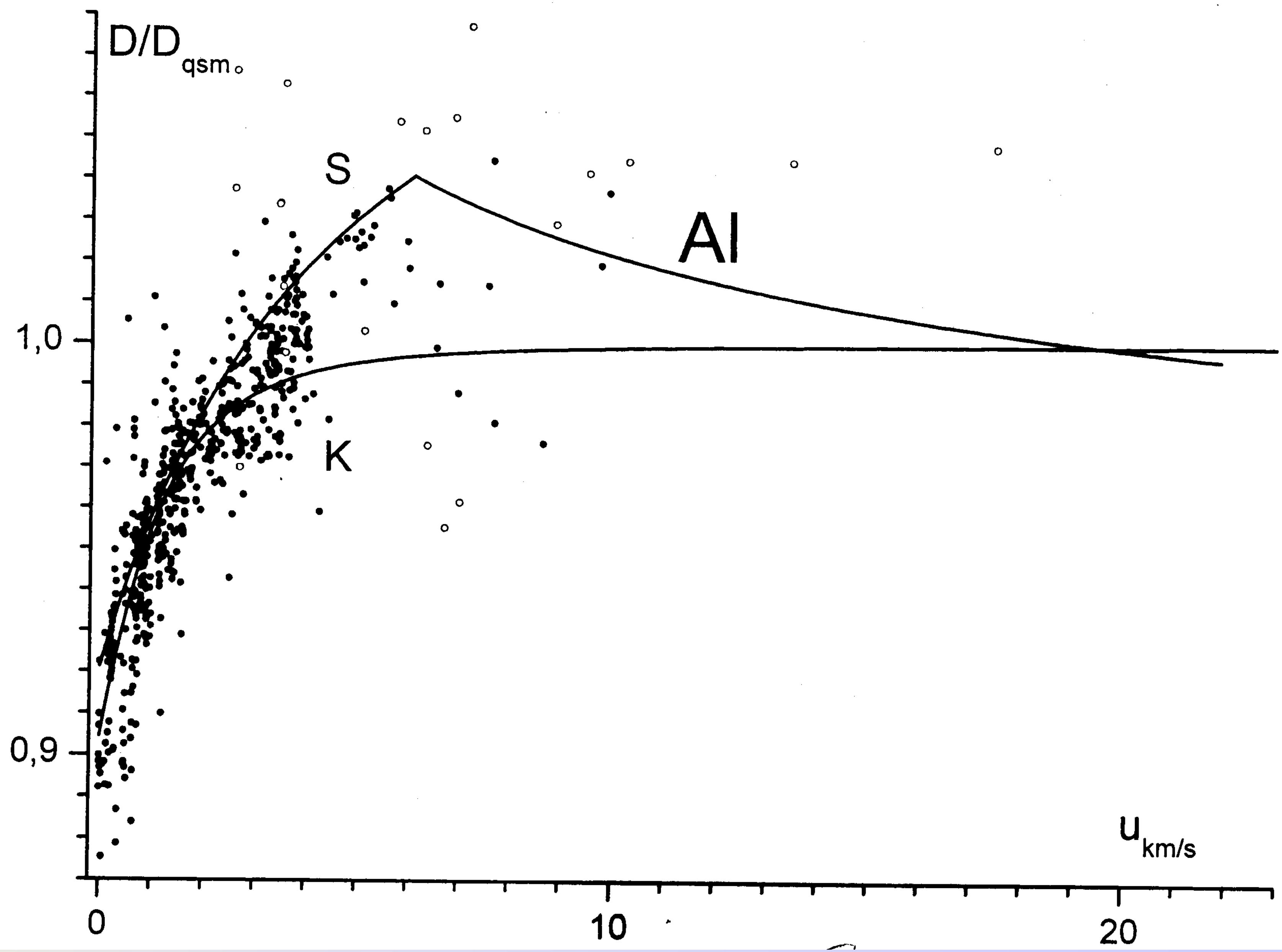

1,1
D/D_qsm
Cu
1,0
K
0,9
S
0,8
0,7
0,6
u_km/s
0
10
20
30
40



1,1
1,0
0,9
0,8
0,7
0,6
D/D_qsm
Cu
K
S
u_km/s
0
10



D/D_qsm
S
Al
1,0
K
0,9
u_km/s
0
10
20
30
40
50
60
70
80
90


D/D_qsm
S
Al
K
1,0
0,9
u_km/s
0
10
20

So the treatement described above provides high accuracy 0.2–0.5% in *D*(*u*).

Now laser experiments can’t exeed such accuracy.

But there is one important example, where less accuracy may solve the problem. It is Hugoniot for Al near parameters *u*≈6 km/s, *D*≈13 km/s, *P*≈2 Mbars. Here is the serious disrepancy between our group and Sarov interpretation.

Especially important may be experiments with the impacte method, but not the impedance match method.

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