Calorimetric measurements and investigation of the reaction velocities distribution of medium-energy protons bombarding targets.

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A calorimeter for determination of the energy deposition has been developed and applied to the measurements with 0.2 m - diameter by 0.6 m - thick aluminium target bombarded by 0.8, 1.0 and 1.2 GeV protons. The experimental data has been compared with results obtained via Monte Carlo simulation of three dimensional hadron-electromagnetic cascades. The experimental data of the reaction velocities distribution on the aluminium target irradiated by the protons with energy 1 GeV are given.

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Knowledge of heat release in targets during proton exposure is important for high-intensity spallation neutron sources [1,21 and spallation breeding of nuclear fuel [31. Calorimeter measurements of the heat deposition inside of lead and bismuth targets have recently been described [41. In this paper, a brief description is presented of the facility and the target needed for understanding the problem Detailed description of the facility construction, measurement blocks, principles and methods of calorimetric data taking can be found in ref. [4].

Our facility is designed for researching the energy deposition in solid cylindrical targets. It consists of a mobile bench, a test chamber with a target, a measurement block and a digitizer (fig. 1). The test chamber, contain a target and made of duraluminium, is designed to provide an evacuated volume. The bench provide about 10^{-3} mm Hg pressure inside the test chamber preventing convective heat exchange. Proton beam hits the target through the front end of the test chamber with is covered with a 0.8 mm thick aluminium membrane. The prefabricated target (fig. 2,3) consists of some quantity blocks, 2.5 cm thick, used to provide the target mass only and of 10 cylindrical measurements blocks, 20 cm in diameter. The measurement block (MBs) are used both to provide the target mass and to carry out measurements. An MB consists of a set of five thermally insulated discs of 4 mm thickness assembled together (fig. 4). The central disc of the assembly is provided with universal measurement probe allowing for the disc temperature be taken in 12 points. The signals from 120 target points go to 120 precision low noise (OP27) amplifiers. Then they are input into a 128-channal digitizer. The digitized data is communicated to an ISKRA-226 computer.

In accordance with two techniques of energy deposition determination, two types of MBs were fabricated: "whole" and "cut" ones [41. In a "cut" MB three central discs are divided into fore thermally insulated rings with outer diameters of 2, 5, 10 ahd 20 cm (fig.5). With these MBs the energy deposition ΔQ is measured directly as the integrated (through an exposure) temperature variation At of a chosen thermally insulated ring. In a "whole" assembly, the instantaneous temperature can be derived in two orthogonal directions at distances of 5, 13, 27, 50 and 94 mm from the disc center. The digitizing of the data is done approximately 0.1 s after the irradiation pulse. The method of deriving the spatial component of the energy deposition density from instantaneous temperature values in such MBs is based on the. solution of the linear heat transfer equation for the inverse problem [5,61.

The universal measurement probe (fig.5) consists of a maylar membrane of 50 Mkm thickness. It is provided with 12 lead probes of 0.4 mm thickness, 2.5 mm in diameter. A measuring end of differential thermocouple is inserted into each probe and sealed. For operation, thermocouples with a sensitivity of approximately 7 x 10^{-5} V/K, using 300 Mkm diameter wire, were fabricated. All the 12 thermocouples of each MB are soldered to contacts inside the test chamber. Termal contact. of the probe with the target disc is provided by thin layer of a spetial heat-conducting paste.

Table 1 present obtained distribution of energy deposition along aluminium target for inner cylinders with a diameter of 0.1 and 0.2 m. All results are relating to one incident proton, and energy deposition means heat produced in the target disc area from the center to the diameter mentioned. In fig. 6 longitudinal energy deposition in target obtained experimentally and calculated with the MARS10 code [7,81 are compared.

Then we have the results of reaction velocitt is measurement on the targets irradiated by the protons. Experimental samples are mounted on the special frame, that is plased on the shielding target cover. To avoid possible contribution to error from other reactions using higher isotopes of the same element, in our experiments we used the samples, having 100% nuclide composition and samples with high enrichment: 12 - C (98.99%), 19 - F (100%), 27 - Al (100%), 59 - Co (100%), 63 - Cu (99.6%), 65 - Cu (98. 7%), 64 - Zn (99. 4%), 93- Nb (100%), 115 - In (99. 99%), 197 - Au (100%).

Calculation of the absolute values of the nuclear reaction velocities quantities were made in our experiments. Nuclear-physical parameters important for these calculations were taken from [91. Functional, characterizing neutron distribution we may submit as the reaction velocity absolute quantities (n,Xn), (n,α), (n, p), (n, n'), (n, y) or their ratio. Uncertainty in quantities of the measured values of the nuclear reactions velocities was calculated, taking in consideration the parameter root-mean-square error. It was shown that the contribution of the nuclear data error to the measuered quantity error constitutes (10-23)%, stable error (2-4)%, error of falling proton beam monitoring flux dencity (6. 5-10)%.

The experimental results of the absolute values of the inverstigated nuclear reactions velocities are given in Table 2.

References

[11. G.S. Bauer, Proc. Meeting on Targets for Neutron Beam Spallation Sources, Jul-Conf. 34, Kernforschungsanlage, Julich Gmb H, Julich, FRG, (1980) 155.

[21. W.E. Fischer et al., Nucl. Sci. Eng. 93, 273.

[31. M.Steinberg, Proc. Nuclear Technologies in a Sustainable

Entrgy System, (Springer, Berlin, Heidelberg, New York, 1983).
[41. V.I. Belyakov-Bodin et al. Nuclear Inst. and Met. in Phis. Res. NIMA 6037 (1990).
[51. V.I. Belyakov-Bodin - ITEP-81, (1983). -'
[61. V.I. Belyakov-Bodin - ITEP-174, (1985).
['71. A.N. Kalinovsky, N.V. Mokhov and Yu.P. Nikitin, Transport of High Energy Particles in Matter (Energoatomizdat, Moskow, 1985).
[81 . N. V. Mokhov, Sov. I. Part. Nucl. 18 (5) (1987) 960.
[91. GDISP, vers. 1.2, April, 1990. (ENSOF).

Table 1.

The longitudinal energy deposition in aluminium target for cy-
1 inder ϕ_1 = 10 and ϕ_2 = 20 cm.

	0.8 Gev		1.0 GeV		1.2 GeV	
Z (mm)	q_1	q_2	q_1 $\times 10^5$	q_2 (GeV/cm)	q_1	q_2
55	1006± 25	1038± 25	1002± 18	1042± 34		
100		1041± 32		1114± 13		1055± 25
125		996± 30		1063± 27		
145	903± 26	1019± 29	888± 21	1033± 25	888± 25	1062± 26
170	846± 25	987± 34	883± 14	1007± 23		
215		874± 16		897± 24		914± 18
240		839± 33		858± 14		
260	714± 26	872± 27	708± 37	853± 44	711± 22	923± 25
285	668± 14	818± 25	686± 9	855± 21		
330		746± 26		769± 30		832± 33
355		701± 23		749± 13		
375	519± 22	649± 30	543± 29	727± 46	541± 20	710± 37
400	491± 19	614± 30	515± 18	653± 22		
470		504± 40		545± 14		551± 24
515	363± 12	464± 16	373± 21	501± 23	366± 6	459± 20
545		407± 18		437± 31		
590	285± 15	364± 35	285± 6	371± 20		

Table 2.

Measured absolute values of the nuclear reactions velocities with the use of the experimental samples, containing 27-Al, 115-In, 197-Au.

Parameter \ Z, mm	Reaction velocity in the experimental samples * 10^{30}						
	50	100	150	200	250	350	450
^{27}Al $R_{n,\alpha}$	7.0 ± 0.6	9.0 ± 0.'7	10.0± 0.8	10.8± 0.9	10.7± 0.9	10.9± 0.9	10.4± 0.9
^{115}In $R_{n,\gamma}$	301 ± 24	315 + 25	332+ 27	321+ 26	301± 24	310± 25	340± 27
^{115}In $R_{n,n'}$	82.0± 8.4	97.3± 10.0	107.0± 11.1	108.0± 11.2	103.6± 10.8	95.6± 9.9	80.4± 8.3
^{115}In $R_{n,3n}$	4.6 ± 0.4	6.0 ± 0.5	7.1± 0.6	7.8± 0.7	7.8± 0.7	7.2± 0.6	7.0± 0.8
^{115}In $R_{n,5n}$	14.2± 1.5	21.8± 2.3	28.8± 3.0	32.0± 2.9	34.4± 3.1	37.4± 3.4	34.9± 3.1
^{115}In $R_{n,6n}$	3.4 ± 0.5	5.4 ± 0.6	7.5± 0.7	8.2± 0.8	9.0± 0.8	9.3± 0.8	9.3± 1.7
^{115}In $R_{n,7n}$	2.7 ± 0.2	3.6 ± 0.3	6.3± 0.5	7.8± 0.7	8.5± 0.7	9.7± 0.8	9.0± 0.8
^{197}Au $R_{n,\gamma}$	(6.2 ± 0.5)-	(6.7 ± 0.5)-	(6.2± 0.5)	(6.7± 0.5)	(6.5± 0.5)	(6.6± 0.5)	(6.3± 0.5)

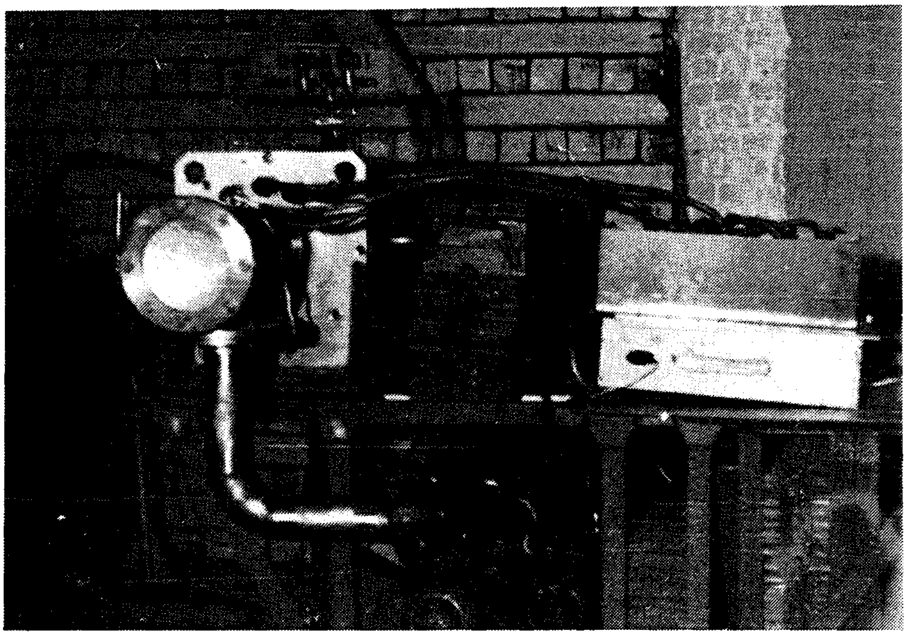

Fig. 1. Common appearance of our facility.

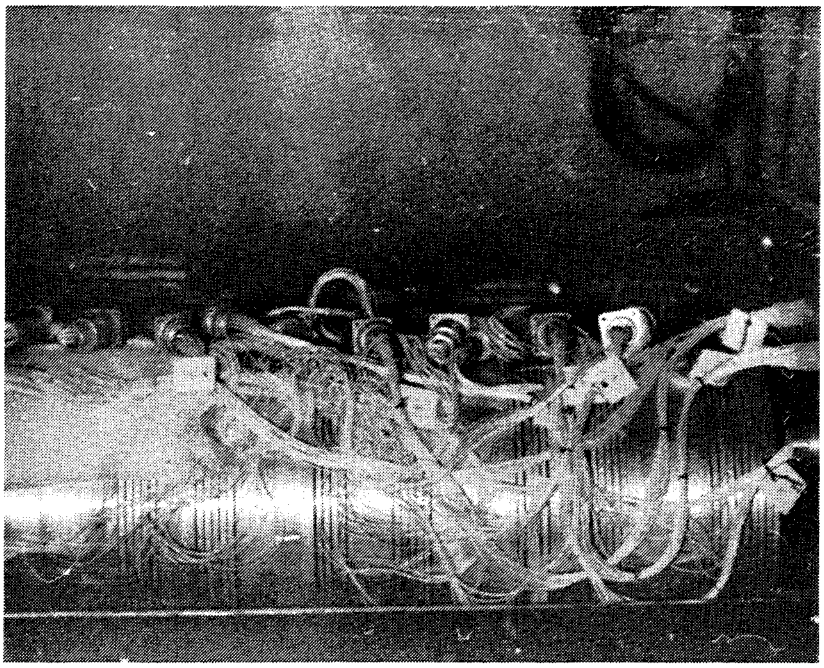

Fig. 2. The prefabricated target.

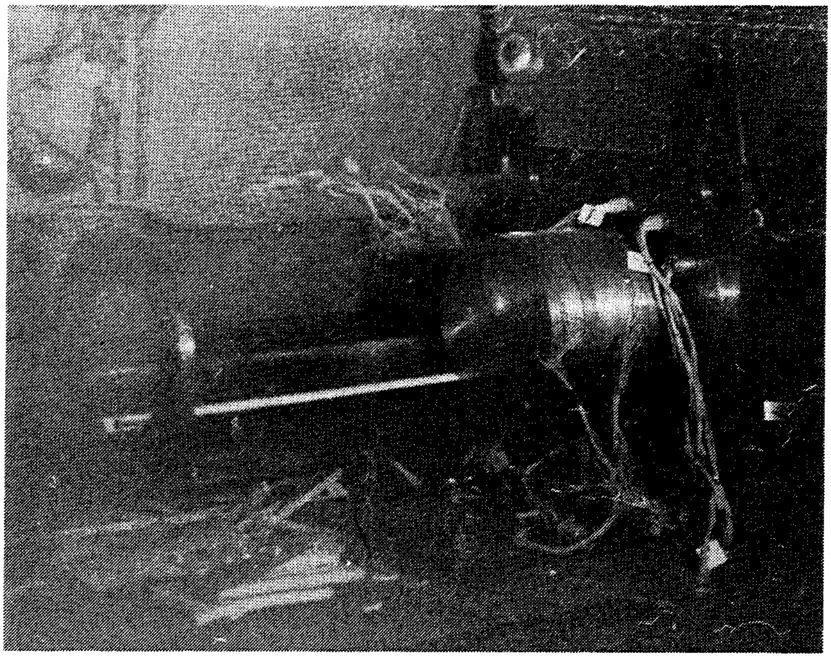

Fig. 3. The test chamber with a target.

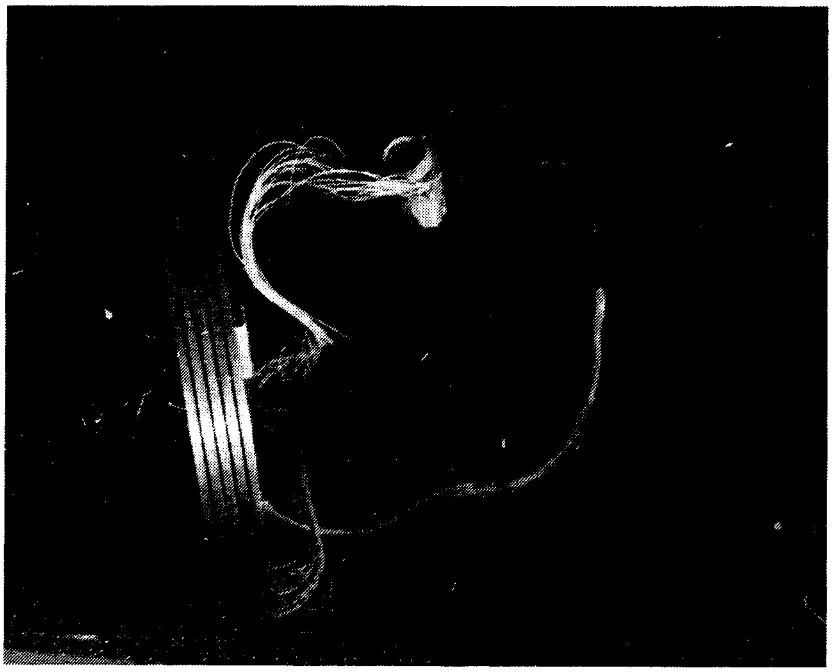

Fig. 4. The measurement block.

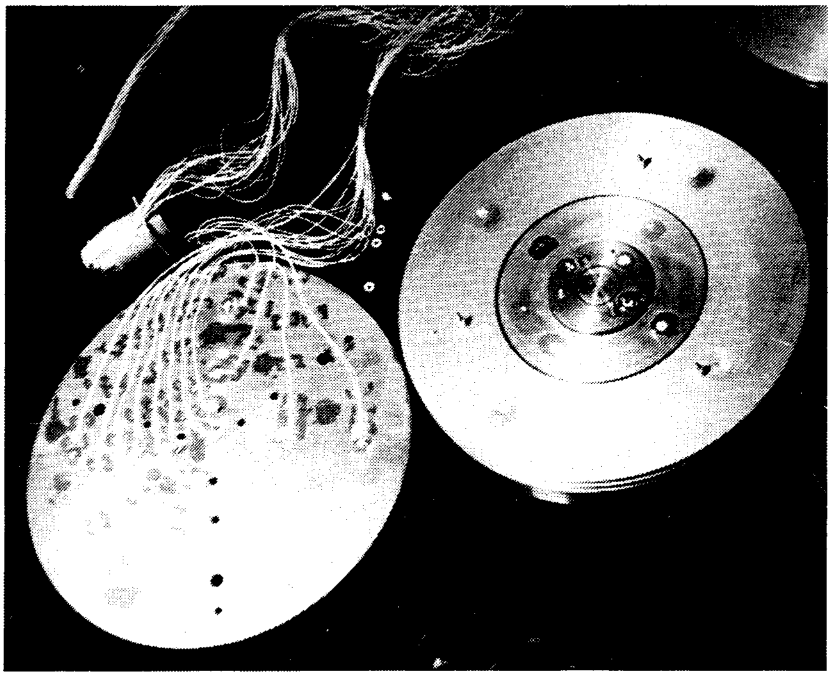

Fig. 5. The universal measurement probe.

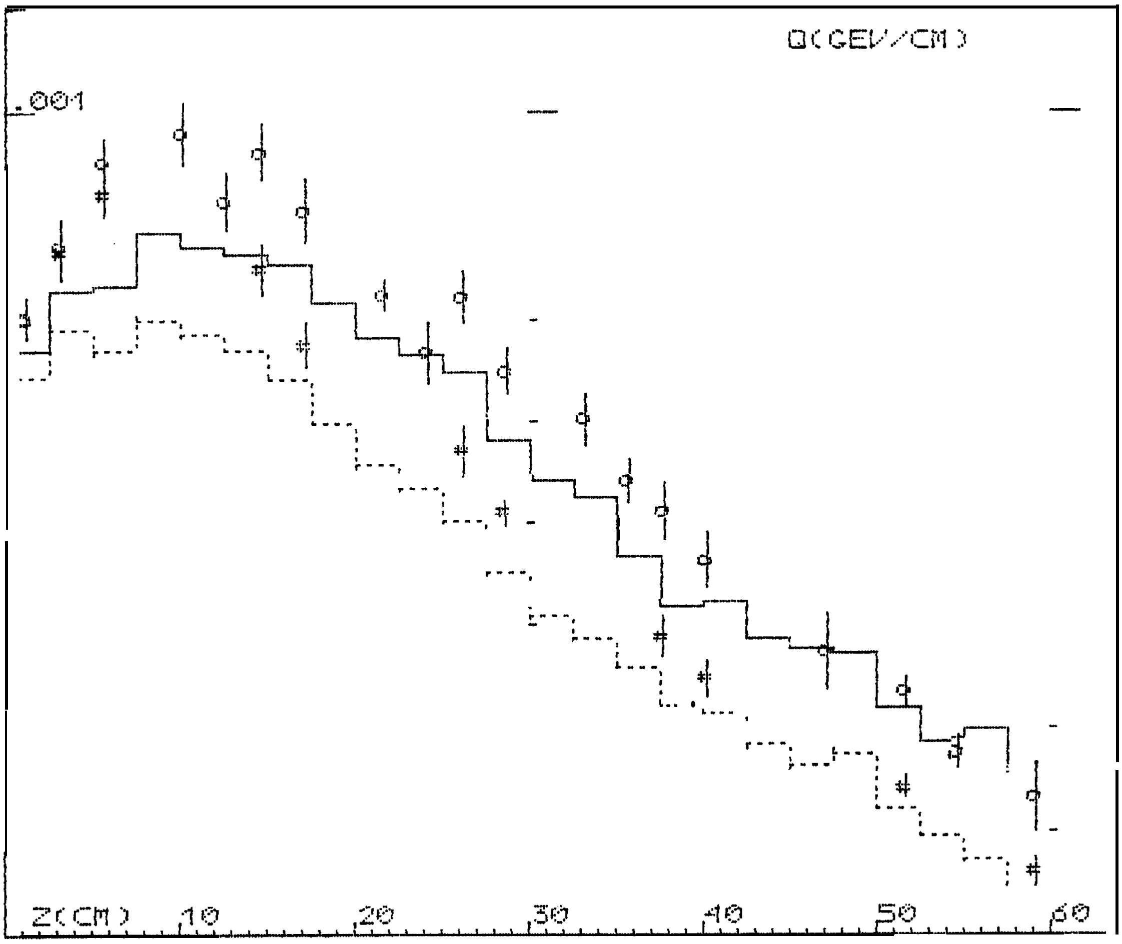

Fig. 6. Comparison of the measured longitudinal energy deposition for 0.8 GeV protons in a alluminium target with theoretical results: # - the experimental results for cylinder $\phi_1 = 10$ cm; o - for cylinder $\phi_2 = 20$ cm; the lines are the results of calculations with the MARS10.