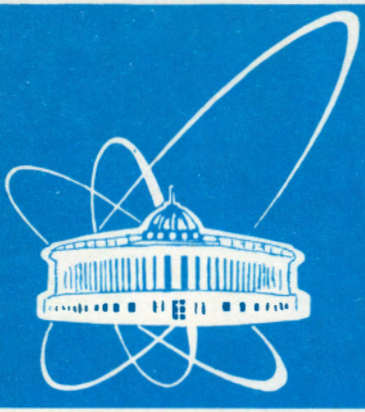

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TEMPERATURE AND DENSITY DEPENDENCE OF μ-CATALYSIS CYCLING RATE IN DENSE **D/T** AND **H/D/T** GAS MIXTURES

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1 Motivation

The present work is a part of a wide experimental program of the MCF study carried out by our collaboration at the JINR phasotron. In Refs. [1], [2] we have reported on measurements with liquid D-T and H-D-T mixtures (T=22 K). Here we present the results of measurements with D-T and H-D-T mixtures at high temperatures (up to 800 K). At these temperatures one should expect the increase in the $d+t$ cycling rate according to the resonant mesomolecular model [3], [4], [5], [6]. As follows from theory, the cycling rate rises with temperature and reaches the maximum at few thousand Kelvin, where the energies of thermalyzed $t\mu$-atoms are of the order of tenth eV. The advantage of the direct measurements with a "hot" target in comparison with the investigation of epithermal effects in a "cold" target is that it is not necessary to consider additional kinetics parameters [7].

The first experiment at high temperatures was preformed at JINR [8] with a D-T mixture of relatively low density and low tritium concentration. The next were the LAMPF measurements [9] with a dense D-T mixture at T=15 - 800 K. Note that the experiments [8] and [9] were carried out by the "standard" method, where time spectra of all detected neutrons are measured and analyzed. The principal feature of our work is the use of novel methods for measurements and data analysis [10], [1].

The aim of the experiment was to measure the main characteristics of the muon catalyzed fusion (cycling rate and effective muon losses) in a dense mixture of hydrogen isotopes **at high temperatures** and thus
1) to perform new, independent measurements with a double D-T mixture using the novel methods;
2) to obtain for the first time the data for the H-D-T mixture where the most interesting situation is expected due to resonances occurring on HD-molecules [6], [11], [12].

2 Experiment

The essence of the experimental method is described in [1], [10]. The experimental method is similar to that used in the experiment [1]. The installation was mounted on the muon beam of the JINR phasotron. The central part of the installation is the high pressure target [13] of volume 16.5 cm^3. The target is able to bear the pressure loading up to 1200 bar at temperatures up to 800 K. The target was filled with tritium containing mixtures by cryogenic compression. The complex of devices [14] was used for the handling of the gaseous mixtures.

The set of detectors around the target is practically the same as in the experiment [1]. The multi-wire proportional counter MWPC (inner diameter 100 mm) analogous to that described in [15] was used to select muon stops in the target and to detect decay electrons. Large volume neutron detectors [16] were used to detect fusion

Table 1: Exposures with a high pressure target January - February 1998

Date	Run	Cp,%	Cd,%	Ct,%	Temp., K	Press.,bar	Den., LHD
29.01	T52-T53	0(1)	67(1)	33(2)	304(10)	1197(20)	0.787(24)
30.01	T54-T56	0(1)	65(1)	35(2)	300(10)	522(20)	0.443(18)
31.01	T58-T63	0(1)	65(1)	35(2)	500(10)	811(20)	0.425(13)
1.02	T64-T65	0(1)	66(1)	34(2)	800(10)	1137(40)	0.400(16)
2.02	T66	48(1)	34(2)	18(2)	300(10)	526(20)	0.446(18)
3.02	T67	53(1)	30(2)	17(2)	664(10)	1011(20)	0.412(12)
4.02	T68-T69	34(2)	53(1)	13(2)	300(10)	520(20)	0.446(18)
4.02	T70	34(2)	53(1)	13(2)	664(10)	1020(20)	0.413(12)

neutrons. As compared with [1], [2] additional scintillation counters were mounted between the MWPC and the neutron detectors. The trigger is described in [17].

The measurements were carried out both with a double D/T and a triple H/D/T mixture. The experimental conditions for all exposures are shown in Table 1. The run time for each exposure was limited to 9 hours because of spoiling the mixture with tritium decay inside the target. The exposure with the target filled with pure D_2 was carried out to measure the electron timing spectrum in the "pure" conditions (without $d+t$ neutrons, see Fig. 1). Besides the exposure with the target filled with helium was carried out to determine the neutron background and to obtain the "apparatus" muon life time. Chromatography measurements showed that the molecular content for each exposure corresponded to the equilibrium state of the isotope mixture.

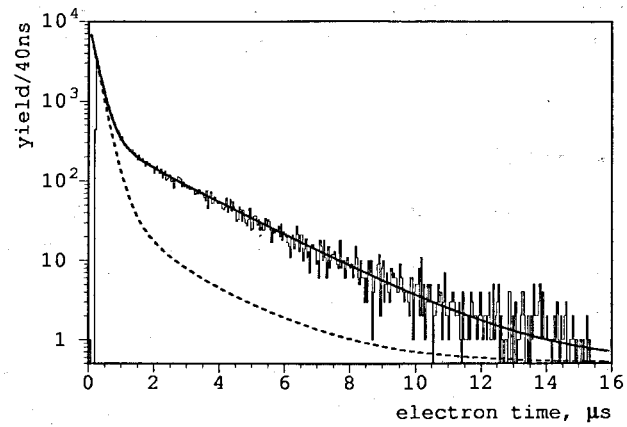

Figure 1: Electron time spectra for the filled target(histogram) and for the empty target (dashed line)

3 Results

3.1 D/T mixture

We processed the data by three different methods [1], [10]. In the first method both the neutron charge time spectrum and the electron time spectrum are analyzed. The second method is based on measurements of the distribution of neutron multiplicity in the definite time interval [18]. The third method [19] is concerned about the analysis of the time distribution between the last registered neutron and the decay electron. Below these methods are designated I, II and III respectively.

The tentative experimental results for the main parameters of d+t muon catalysis in D/T mixture are shown in Table 2.

Here λ_c is the normalized cycling rate, ω is the total sticking probability, φ is the relative target density. One takes into account both the statistical uncertainties and those connected with the calculation of the neutron detection efficiency [20].

Temperature dependence of the cycling rate in the D/T mixture is presented in Fig. 2 in comparison with theory. The theoretical dependence $\lambda_c(T)$ is shown by the solid line. It was calculated by the formula

$$\frac{1}{\lambda_c(T)} = \frac{q_{1s}C_d}{\lambda_{dt}C_t} + 0.75\frac{\lambda^0_{dt\mu}(T) - \lambda^1_{dt\mu}(T)}{\lambda^0_{dt\mu}(T)(\lambda_t C_t + \lambda^1_{dt\mu}(T)C_t)} + \frac{1}{\lambda^0_{dt\mu}(T)C_d} \qquad (1)$$

where

$$\lambda^0_{dt\mu}(T) = C_d\lambda^0_{dt\mu-d}(T) + C_t\lambda^0_{dt\mu-t}(T), \quad \lambda^1_{dt\mu}(T) = C_d\lambda^1_{dt\mu-d}(T) + C_t\lambda^1_{dt\mu-t}(T)$$

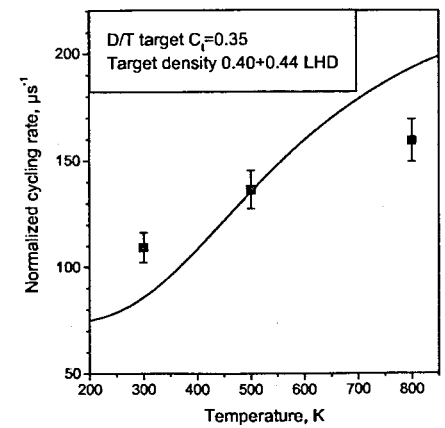

Figure 2: Dependence of the cycling rate on temperature in the double D/T mixture

Table 2: Tentative experimental results for gaseous D/T mixture

Run	Method I		Method II		Method III	
	λ_c, μs^{-1}	ω, %	λ_c, μs^{-1}	ω, %	λ_c, μs^{-1}	ω, %
T52-T53	124(8)	0.82(6)	123(8)	0.83(7)	127(12)	0.77(8)
T54-T56	109(7)	0.90(7)	105(7)	0.94(8)	105(10)	0.89(12)
T58-T63	136(9)	0.90(7)	132(9)	0.93(8)	138(13)	0.80(10)
T64-T65	159(10)	0.90(7)	157(10)	0.94(8)	156(15)	0.82(11)

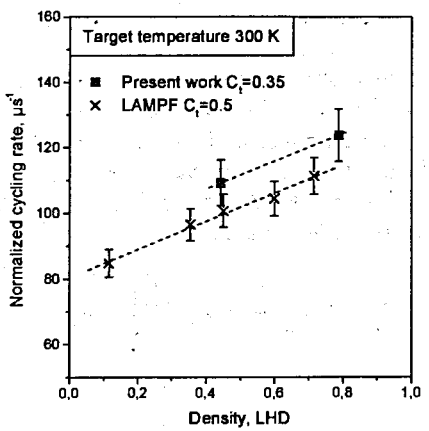

Figure 3: Dependence of the cycling rate on density in the double D/T mixture at T=300 K

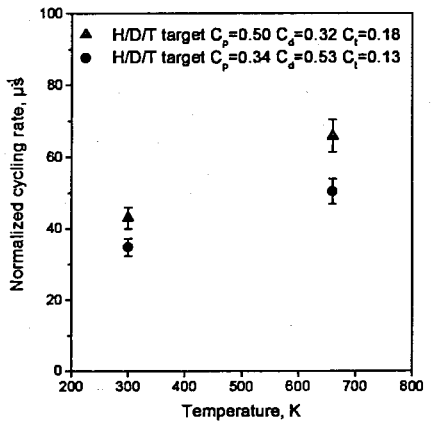

Figure 4: Dependence of the cycling rate on temperature in the triple H/D/T mixture

The calculated data [6] were taken for $\lambda_{dt\mu-d}$ and $\lambda_{dt\mu-t}$ as functions of temperature. Some disagreement of our data with theory can be explained by the absence of a clear theoretical description of the density effect in dtμ molecule formation. Formula (1) neglects possible effects resulting from epithermal $t\mu$ atoms [7], which, according to our estimations, could be 10-15%.

The density dependence of the dtμ cycling rate in the double D/T mixture was measured at the temperature 300 K. It is shown in Fig. 3 in comparison with the LAMPF result [9].

3.2 H/D/T mixture

The experimental data for the triple H/D/T mixture were analyzed by method I because other methods are less precise at low fusion yields and high sticking probability. The results for main parameters of the $d+t$ muon catalysis are given in Table 3. Temperature dependence of $d+t$ cycling rate in the H/D/T mixture is shown in Fig. 4.

Table 3: Tentative results for gaseous H/D/T mixtures

Run	T66	T67	T68-69	T70
λ_c, μs^{-1}	43(3)	66(5)	35(3)	50(4)
ω, %	7.8(6)	5.3(4)	7.2(6)	5.2(4)

4 Conclusion

We have fulfilled the initial part of the program for the MCF study with dense D-T and H-D-T mixtures at high temperatures. It follows from the first results that we are able to obtain reliable data by three independent methods including the novel ones developed in Dubna. The data on the H-D-T mixture have been obtained for the first time. One can draw the following conclusions from these first results.

1. It follows from the comparison of the data presented in Tables 2,3 with our results for the liquid mixtures [1], [2] that addition of protium to a D-T mixture leads to a significant decrease in the cycling rate (*or* Y_n), namely,
- by a factor of 14 in the liquid mixture
- by more than factor of two in the gaseous mixture at 300-600 K.

2. Our results for the temperature dependence of the cycling rate are in qualitative agreement both with the experimental data of LAMPF [9] and with the theoretical predictions [5], [6]. Fuller comparison and extraction of the $dt\mu$-molecule formation rate will be possible after new measurements with various deuterium and tritium concentrations.

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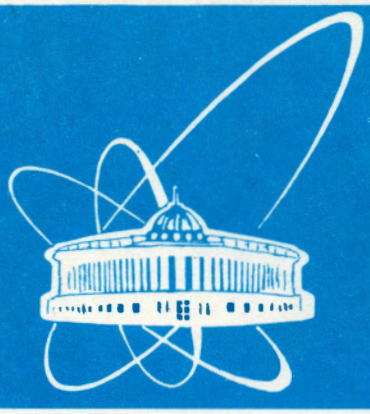

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FIRST MEASUREMENTS OF $dt\mu$ CYCLE CHARACTERISTICS IN LIQUID **H/D/T** MIXTURE

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