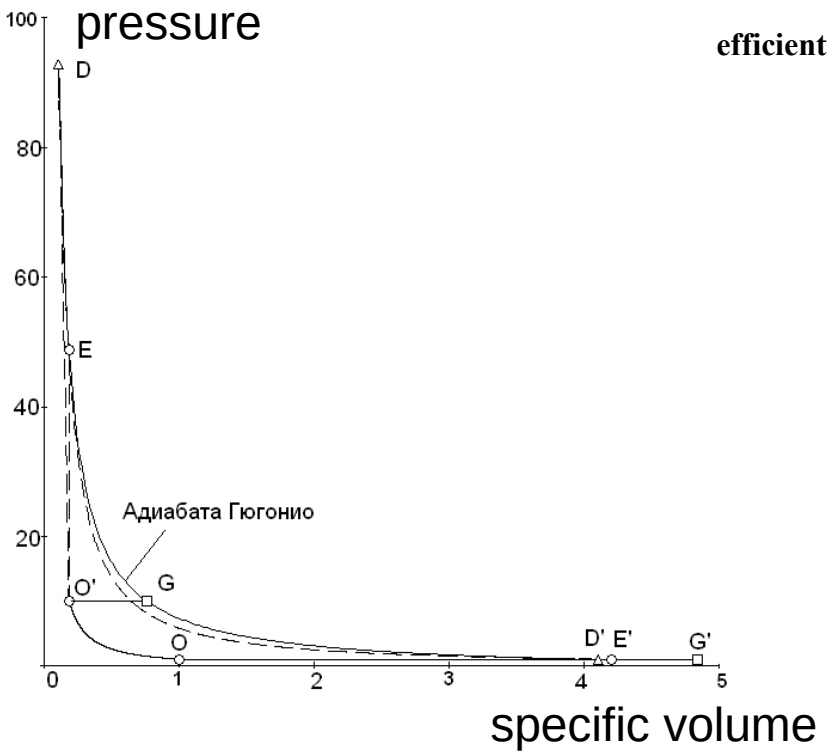
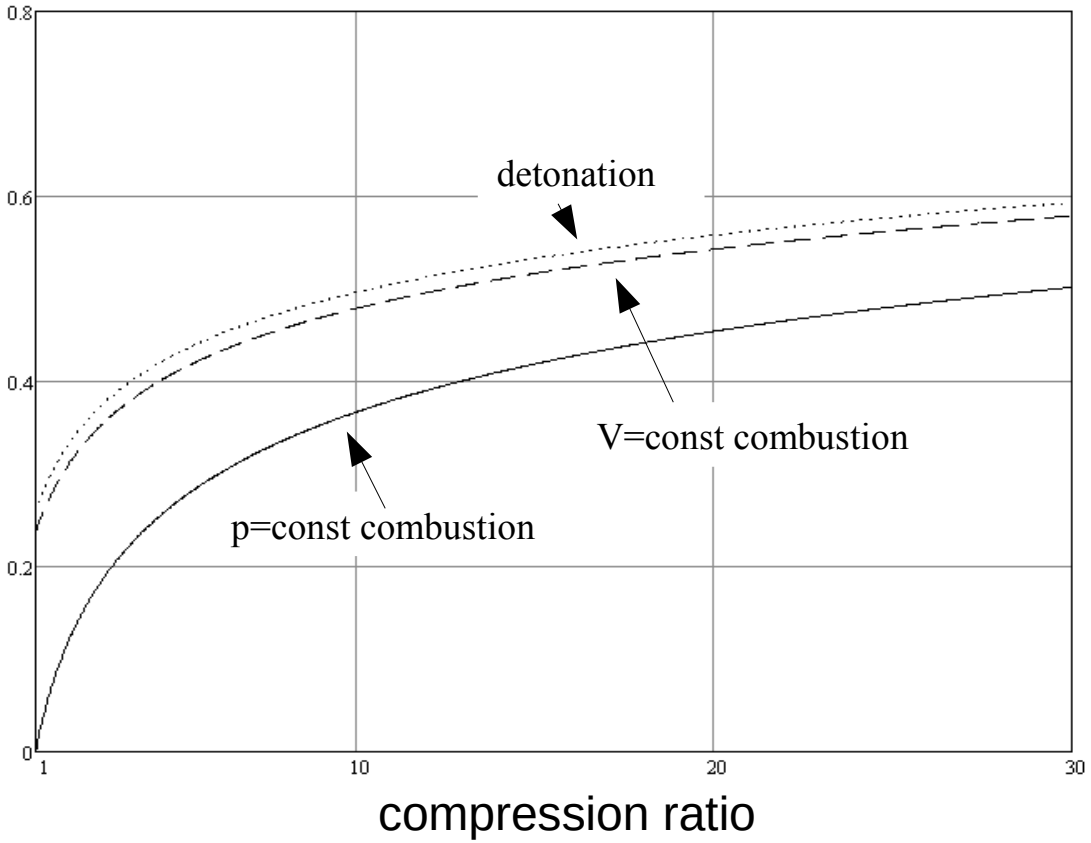
# Pulse detonation burner fueled with natural gas and air

*S. M. Frolov, V. S. Aksenov, K. A. Avdeev, A. A. Borisov, V. S. Ivanov, A. S. Koval, S. N. Medvedev,* ***V. A. Smetanyuk****, F. S. Frolov, I. O. Shamshin*

*Semenov Institute of Chemical Physics RAS, Russia*

# Thermodynamic efficient



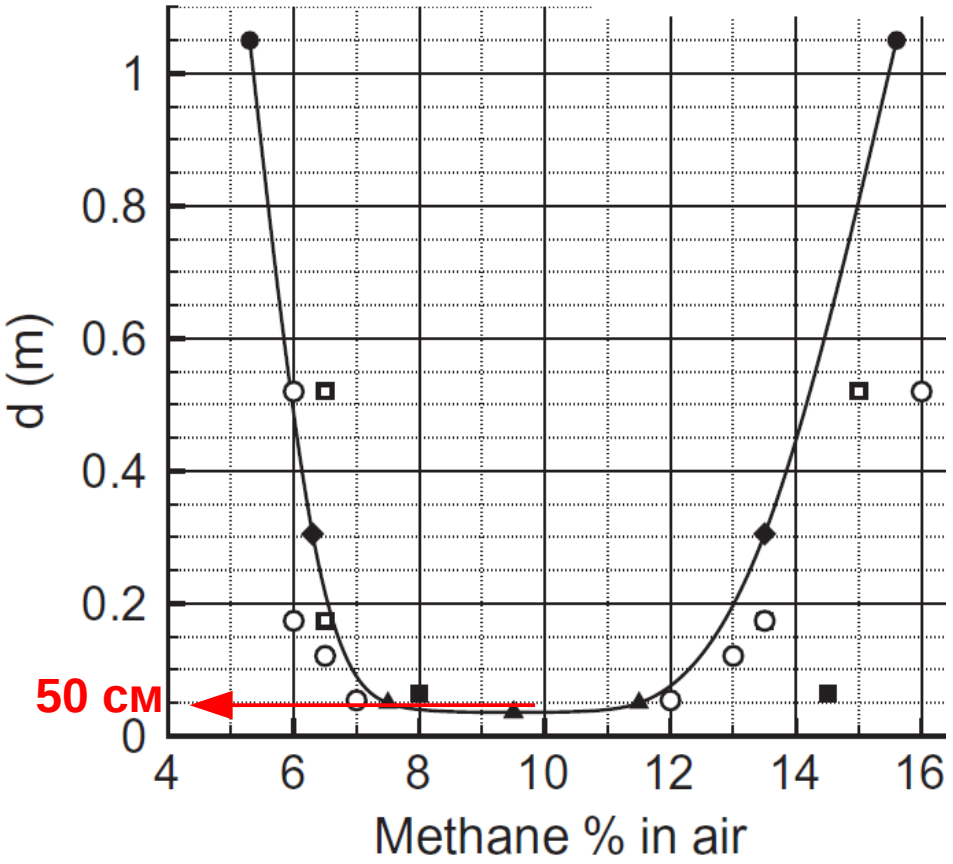




p=const (Brayton cycle), V=const (Humphrey cycle), detonation cycle

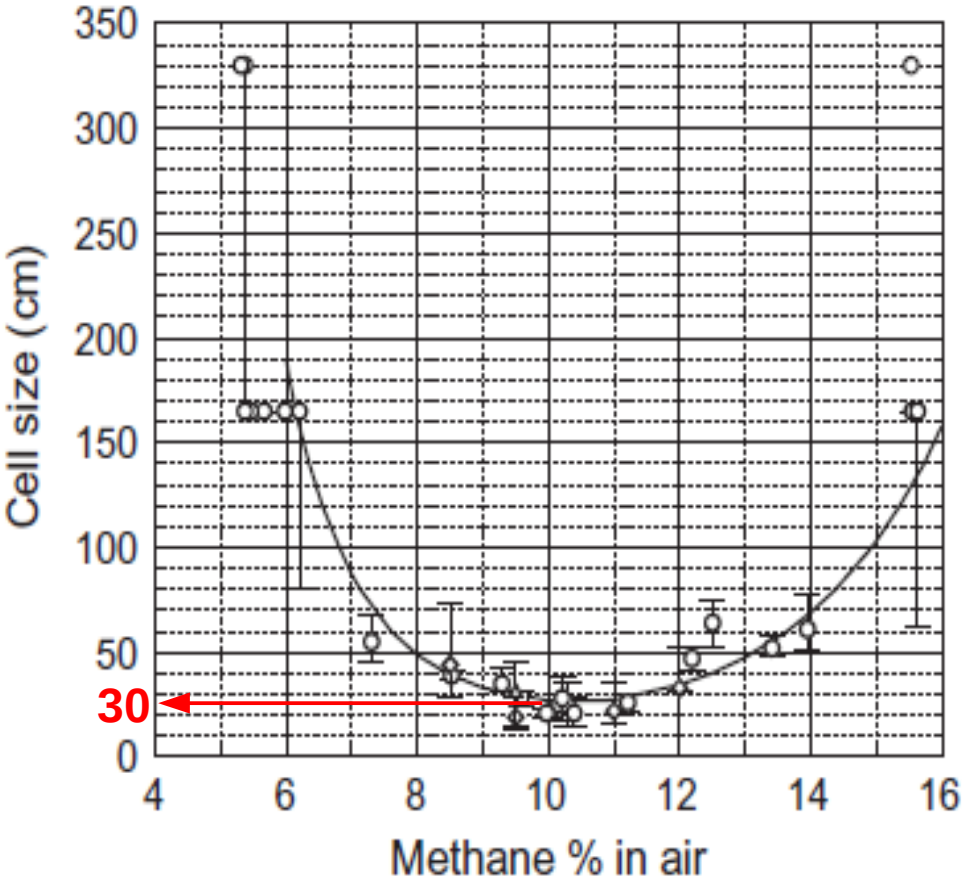


Zeldovich 1940+

# Motivation




Detonability limits measured for methane–air mixtures by different research groups in tubes of different diameters d




Detonation cell sizes measured and reported by Kuznetsov et al., Tieszen et al. and Moen et al.



Gamezo et al. 2012

# Contents

**DDT in natural gas — air mixture**

Previous work
- Tube 72 mm and 94 mm

Experimental setup description
- Air blow supply

Experimental registration technics and results

**Periodic (pulse) DDT operation mode**

Time characteristics
The operation frequency

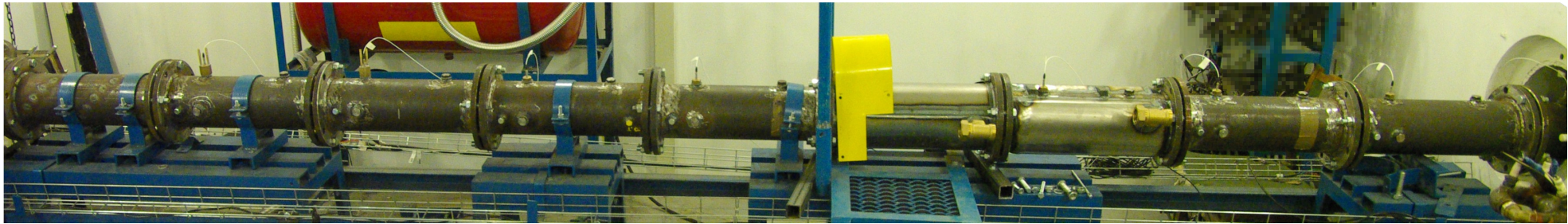
**Thermal characteristics of periodic DDT**

Experimental setup modification
Heated target
Temperature registration equipments
Temperature of the detonation tube

# PART I: DDT in natural gas — air mixture

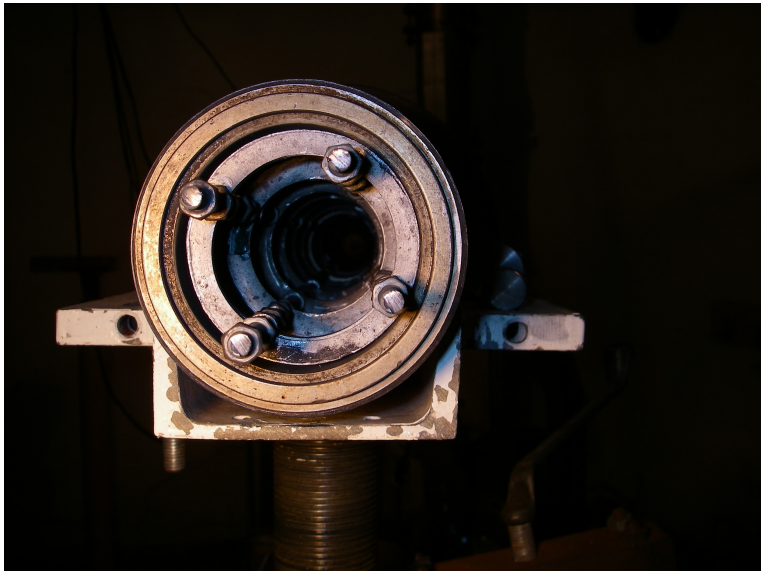
***objective:***

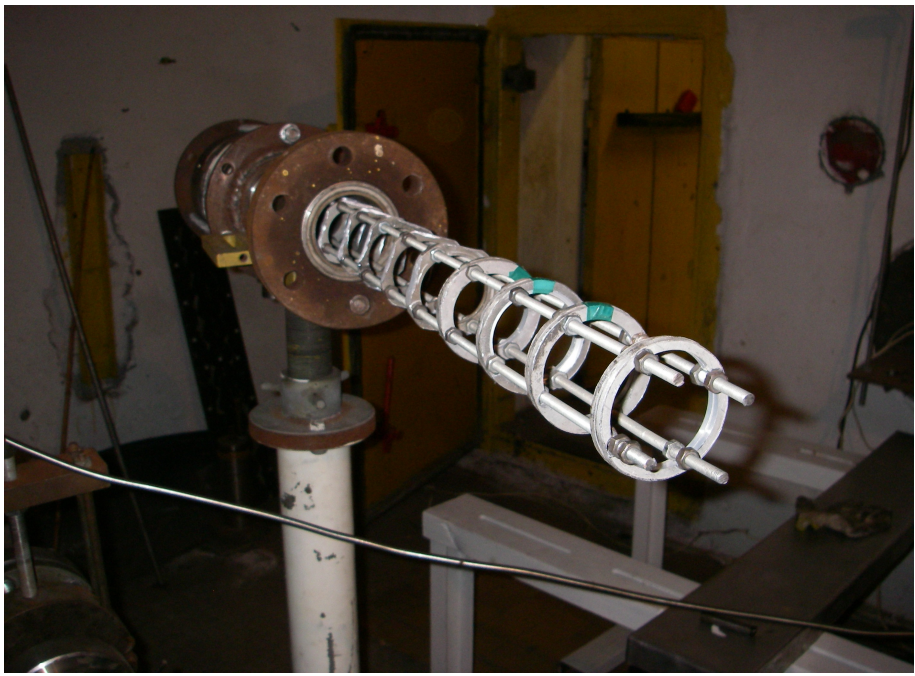
To get DDT in the natural gas — air mixture at 1 atm without high ignition energy supply



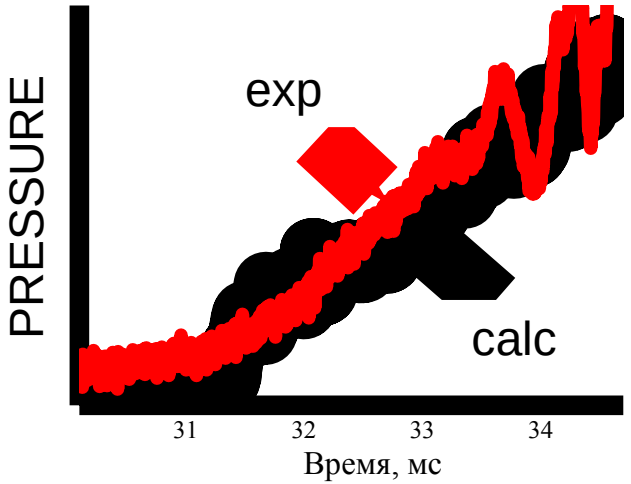
# Previous work: ~70 mm diameter tube 2 m

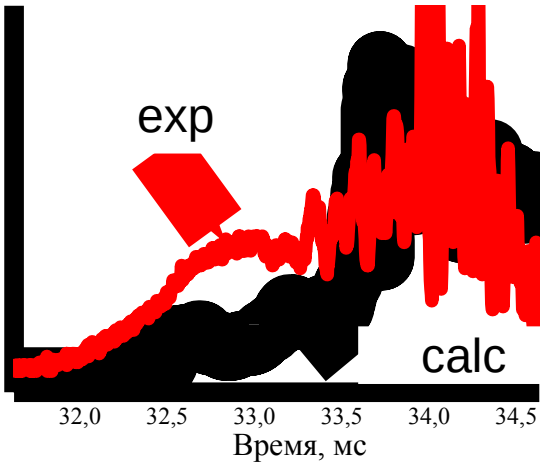
1)high energy ignition
2)perforated plates
3)regular ring obstacle

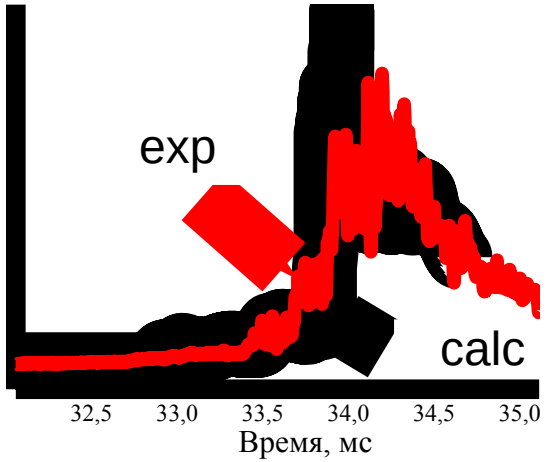


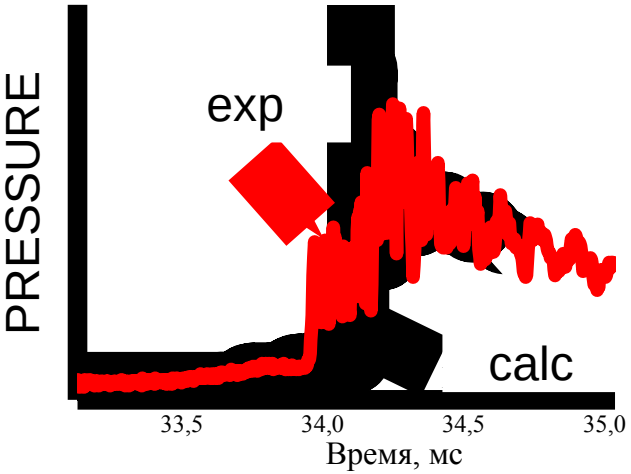


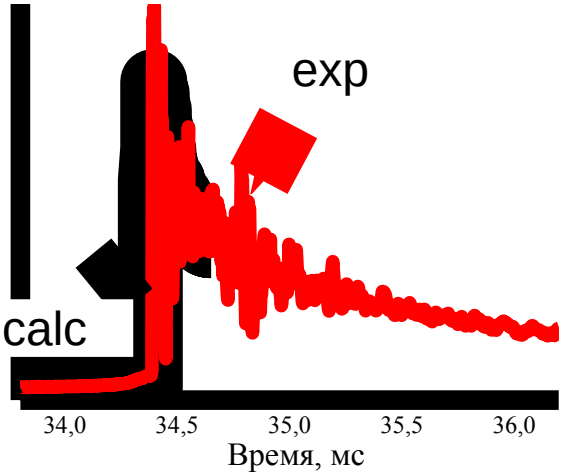
# Comparison with flame tracking model



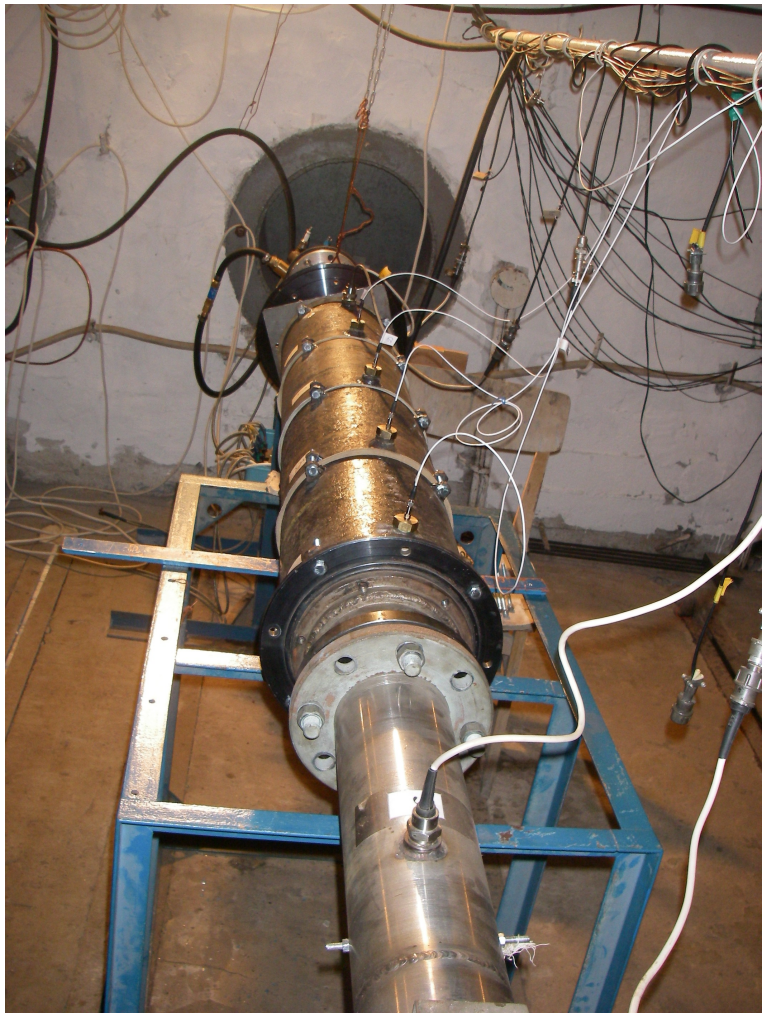



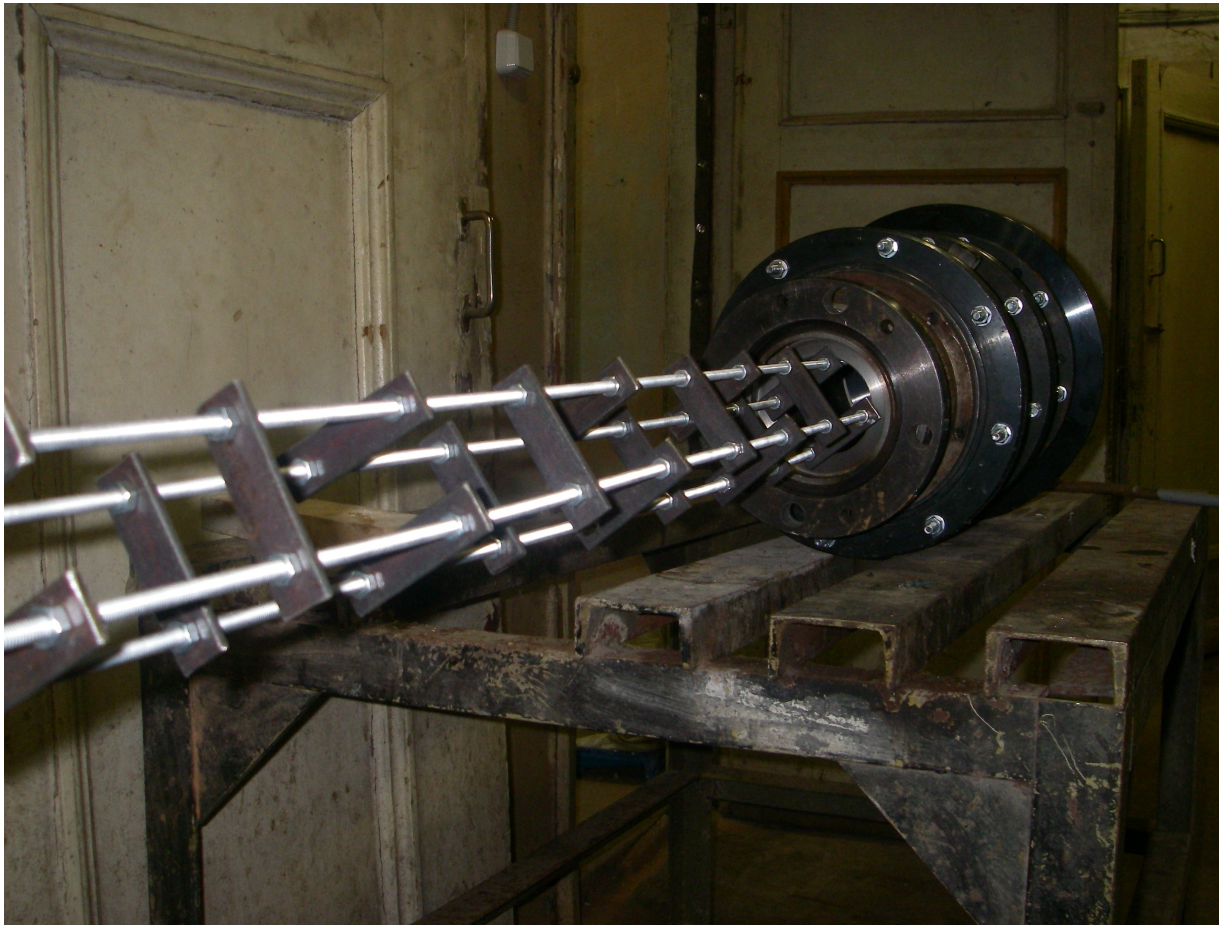






S. Frolov, V. Ivanov

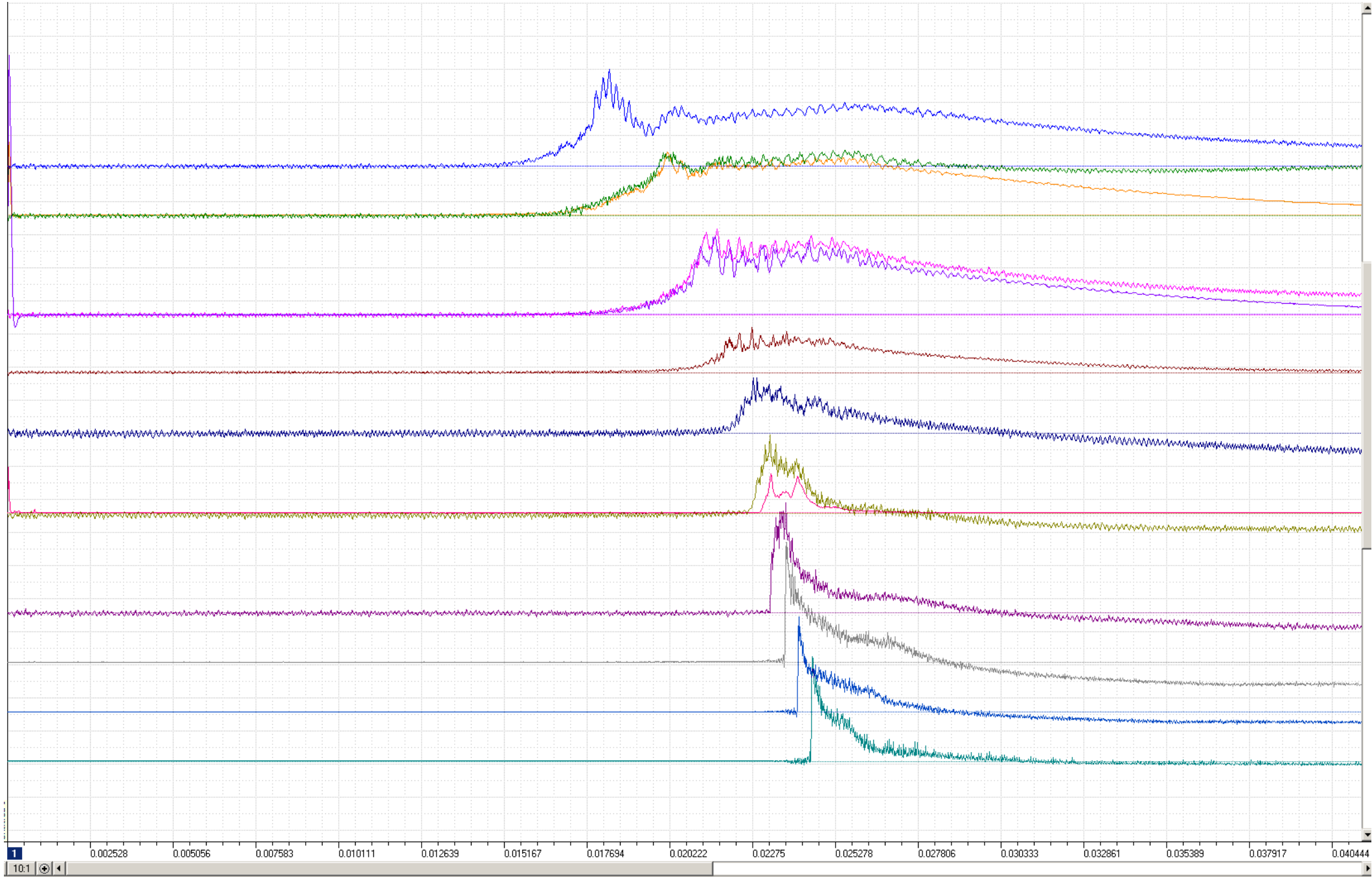
# Previous work: 94 mm diameter tube 3 m





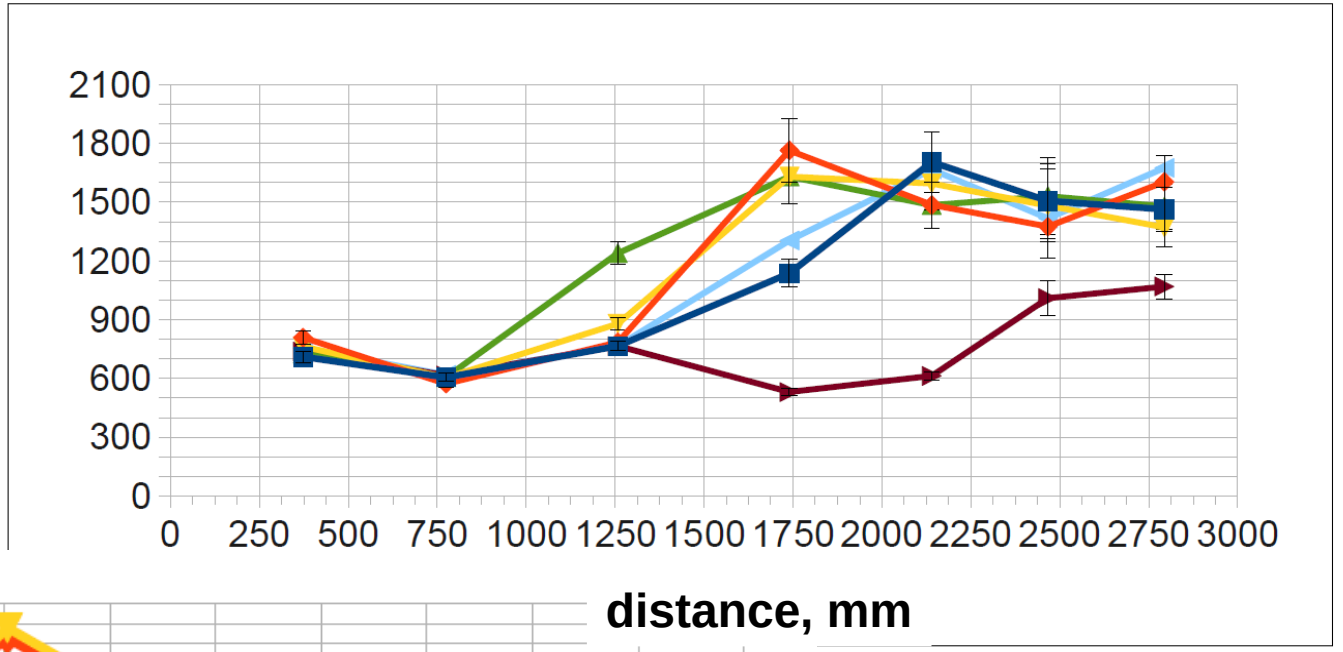
# Previous work: ~90 mm diameter tube 3 m

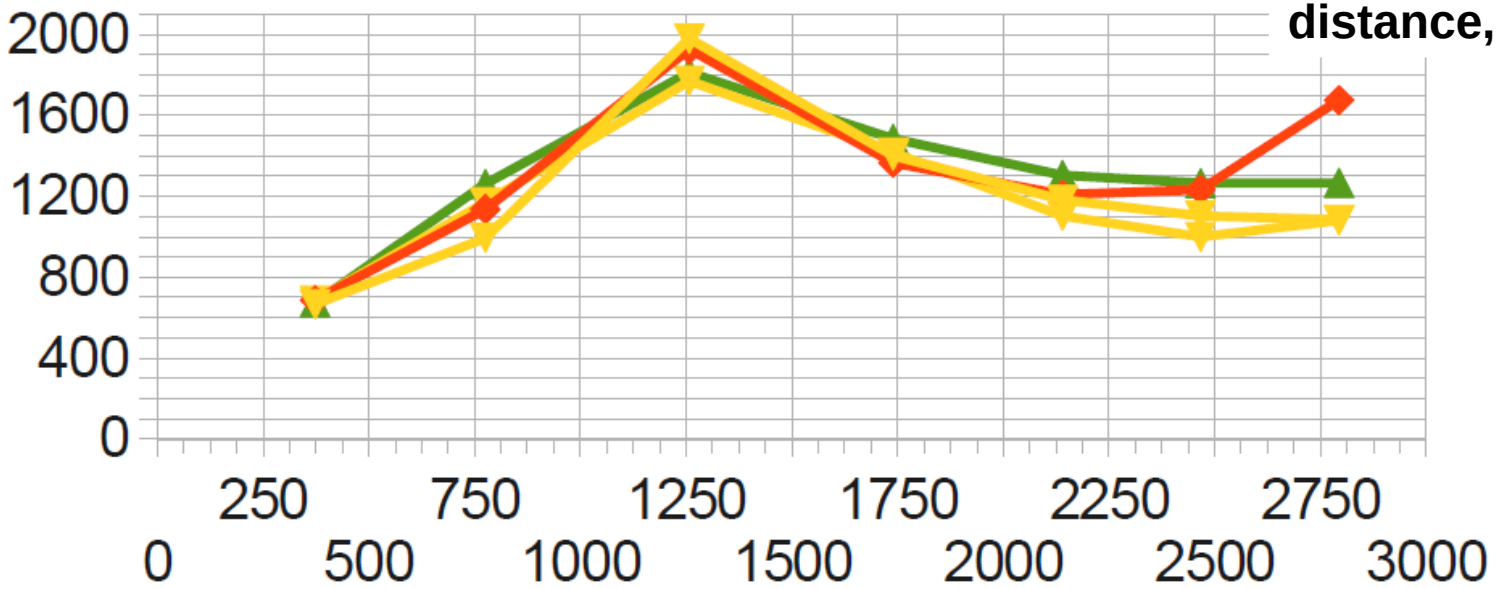
# Previous work: 94 mm diameter tube 3 m



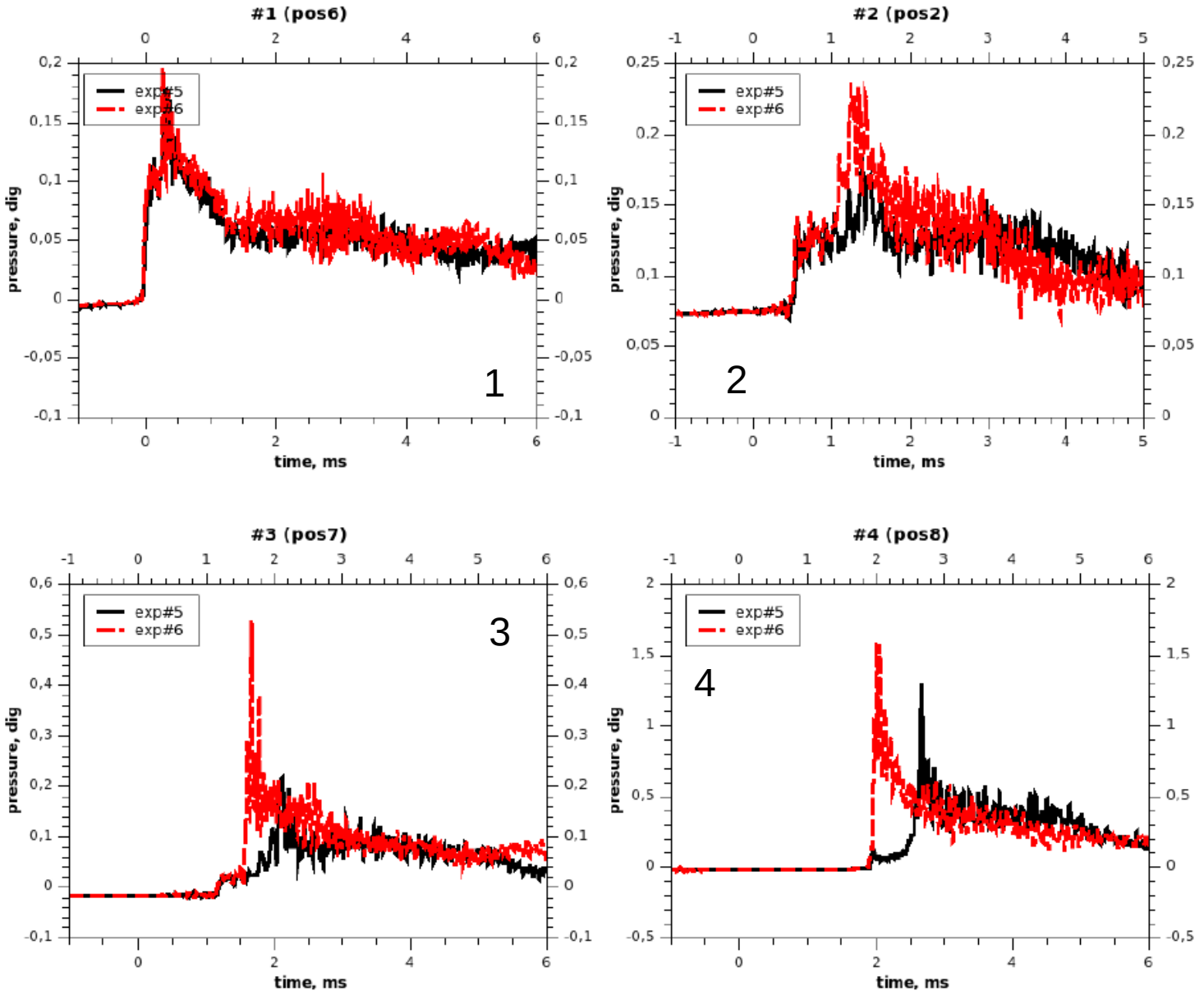
# Previous work: 94 mm diameter tube 3 m

$L_{DDT} = 20\ d_{tube}$



# non stable DDT for small diameter

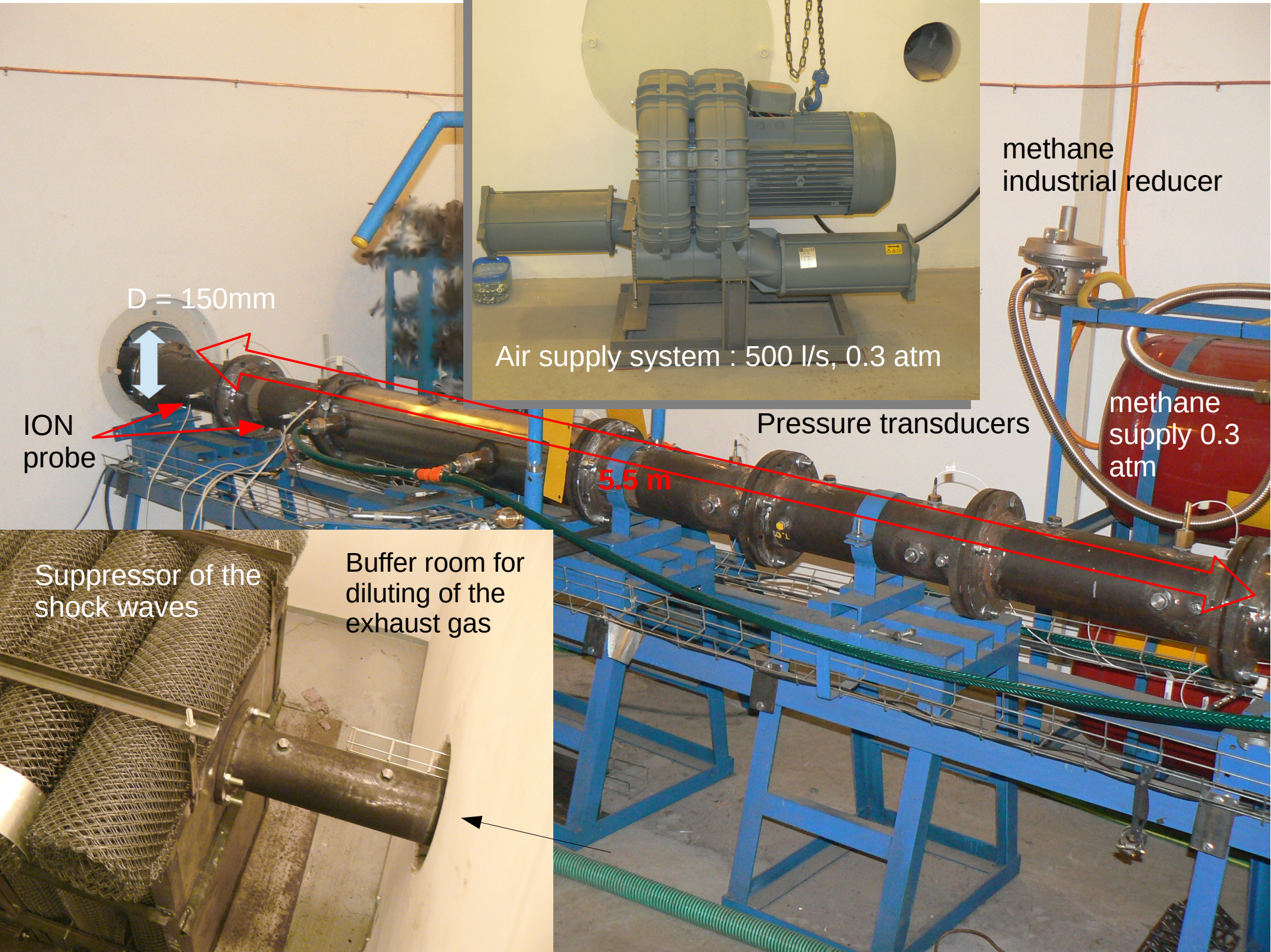


- tubes diameter 72 or 94 mm
- oxygen supply ignition or high energy spark plug
- premixed NG – air mixture
- non stable DDT

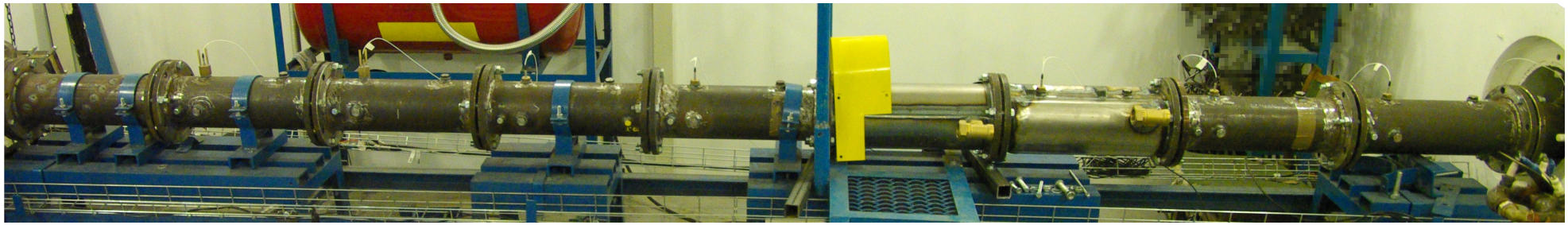
- not applicable for industrial use

# Current experimental setup

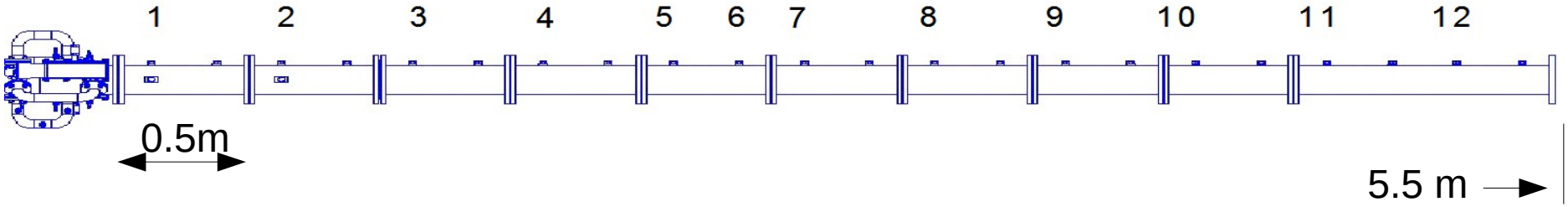
- Diameter 150 mm
- Length 5.5 m
- Air supply 500 l/s
- Fuel – natural gas
- No any additives
- Internal mixing
- Stoichiometry mixture


D = 150mm
ION probe
Air supply system : 500 l/s, 0.3 atm
methane industrial reducer
Pressure transducers
methane supply 0.3 atm
5.5 m
Suppressor of the shock waves
Buffer room for diluting of the exhaust gas

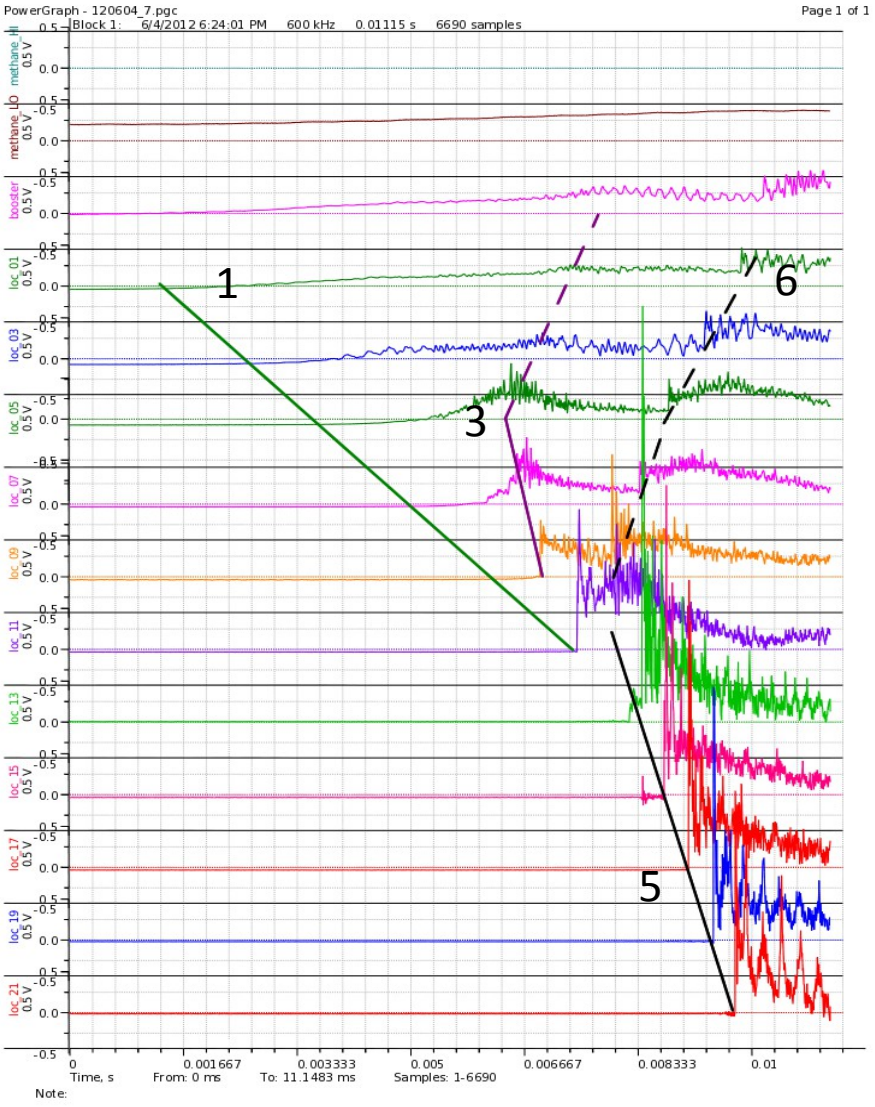
# 150 mm diameter tube: schematic representation of the setup

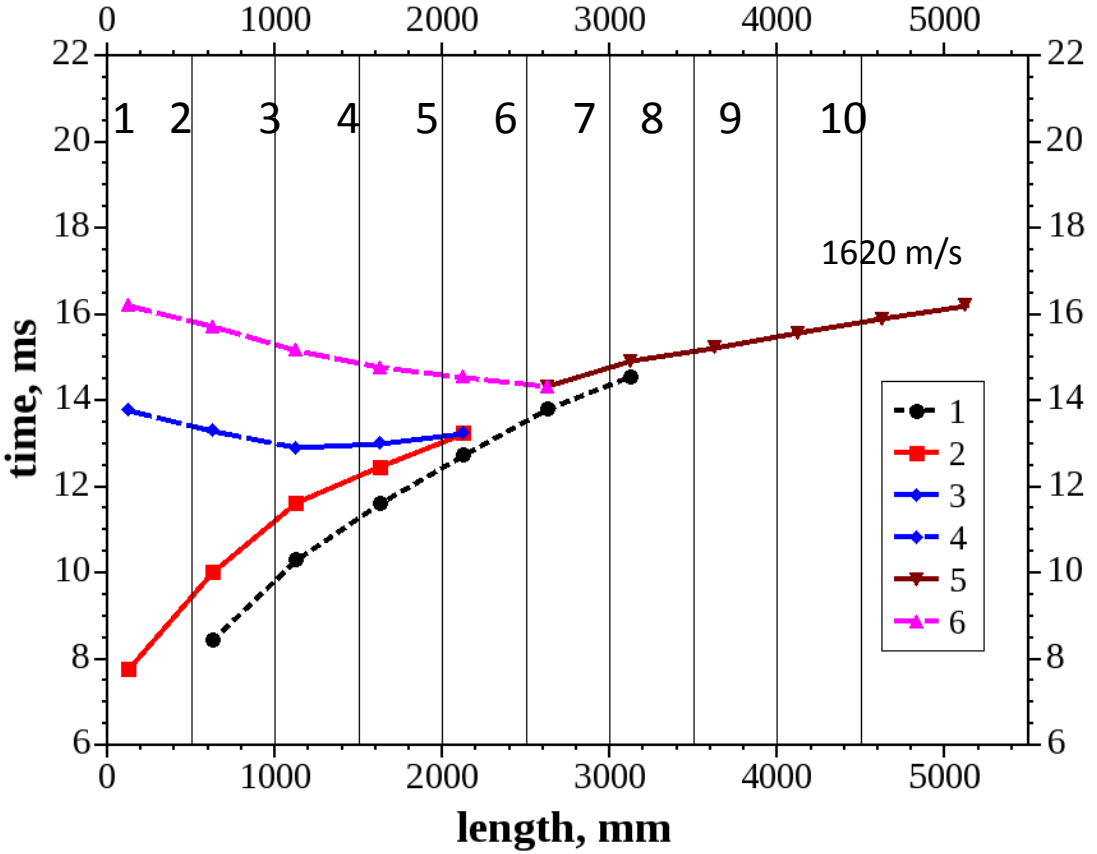


9 x 0.5 m section + 1.0 m section



# 150 mm diameter tube: first results




1 – acoustic wave from spark plug

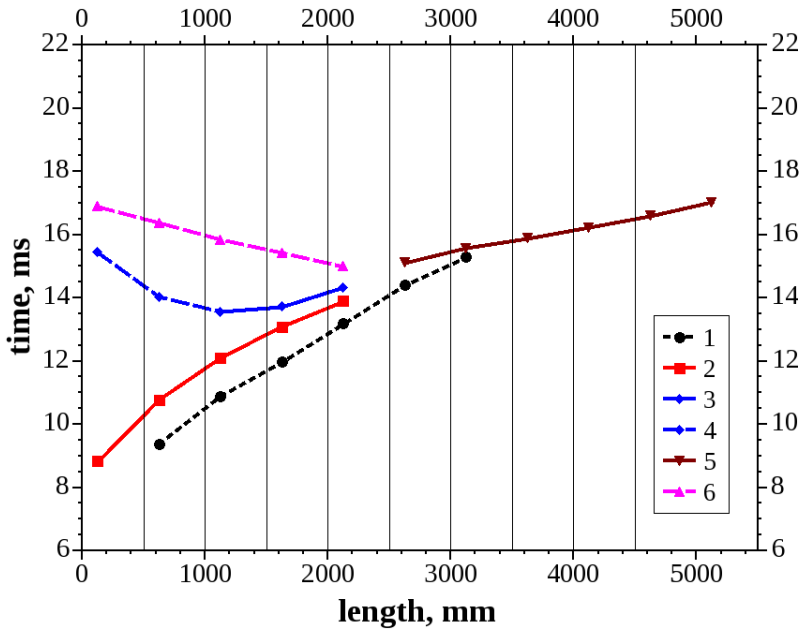
3 – accelerated flame front

4 – backward pressure wave

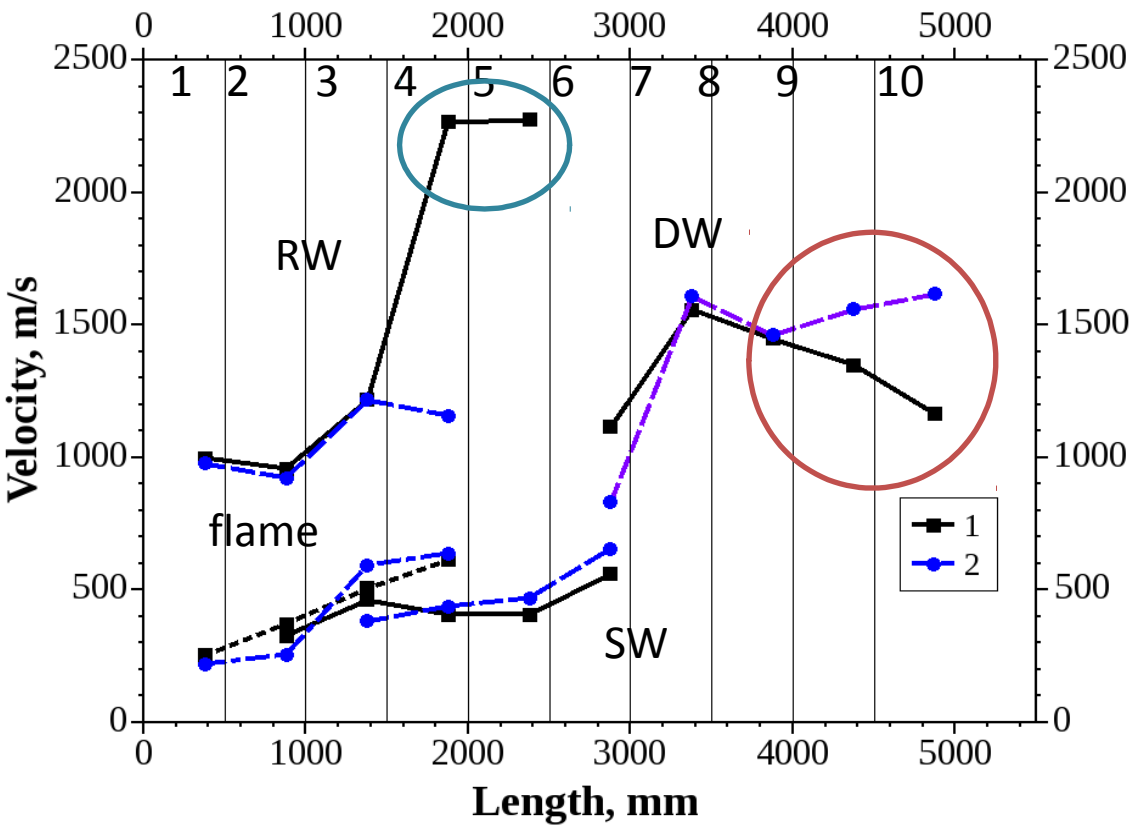
5 – strong shock wave

6 – retonation wave

X-t diagram



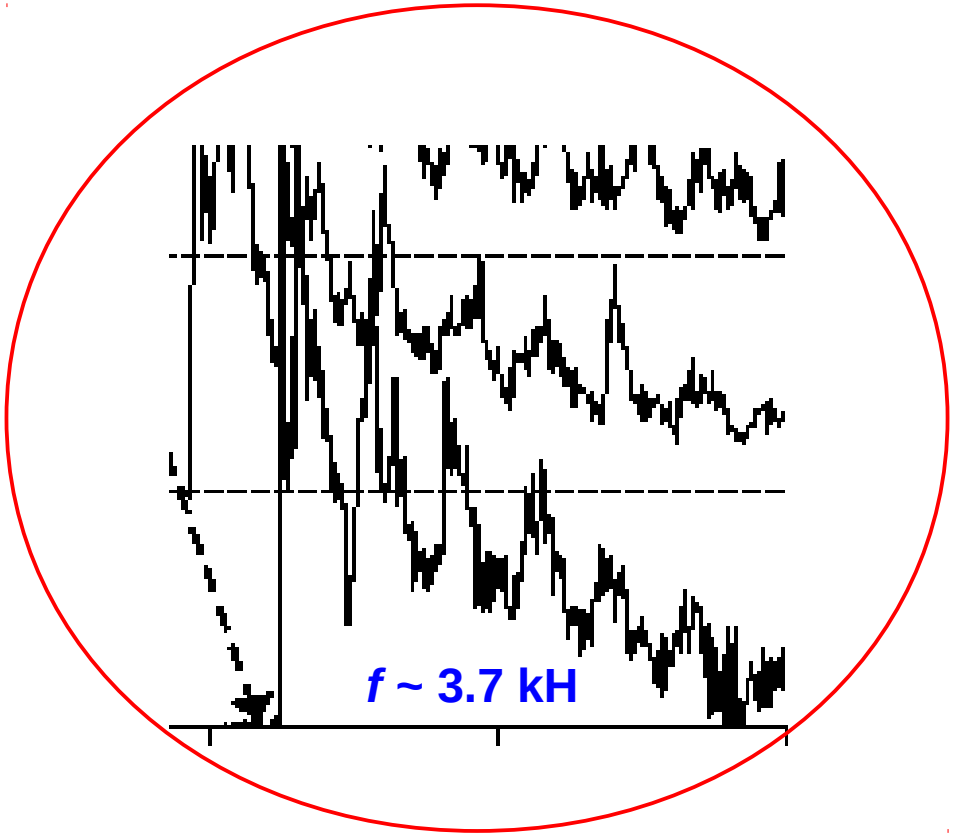

Velocity of the SW on the different distance




1 – not stable DW

2 – stable DW

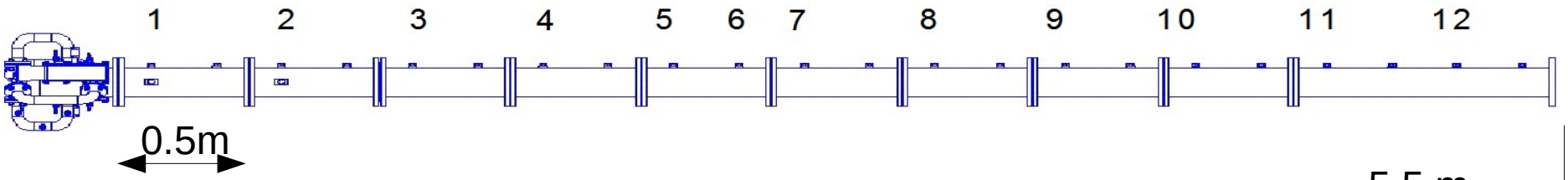
MP
a



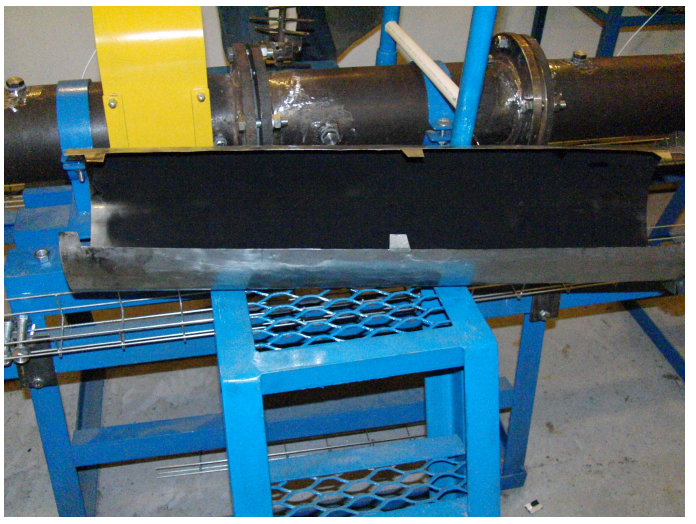

1 MPa

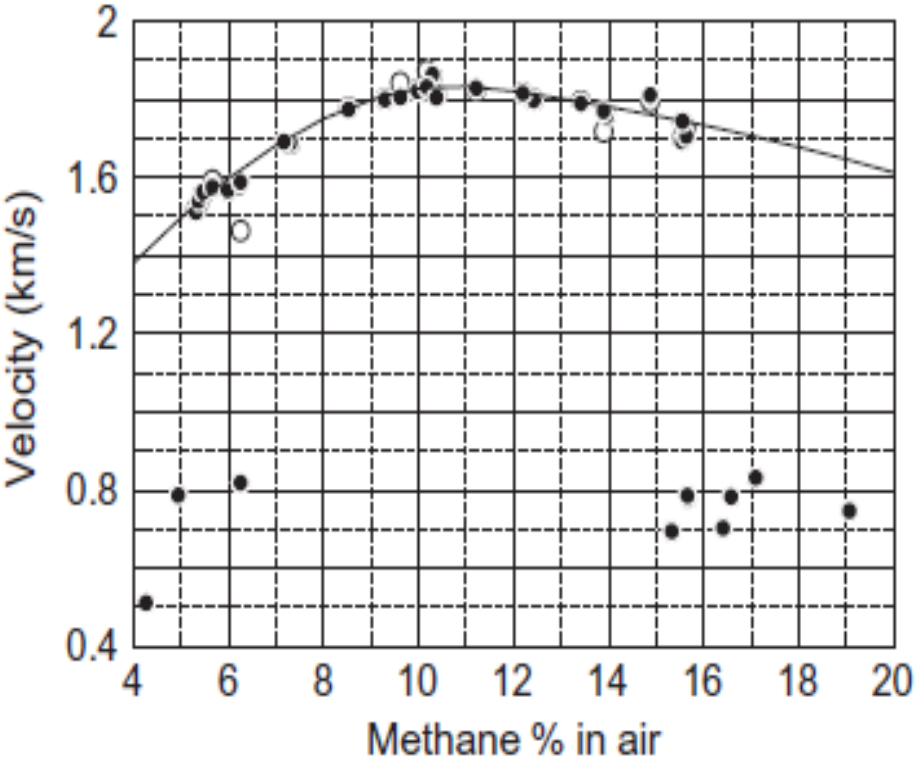
Spin detonation

Time , ms

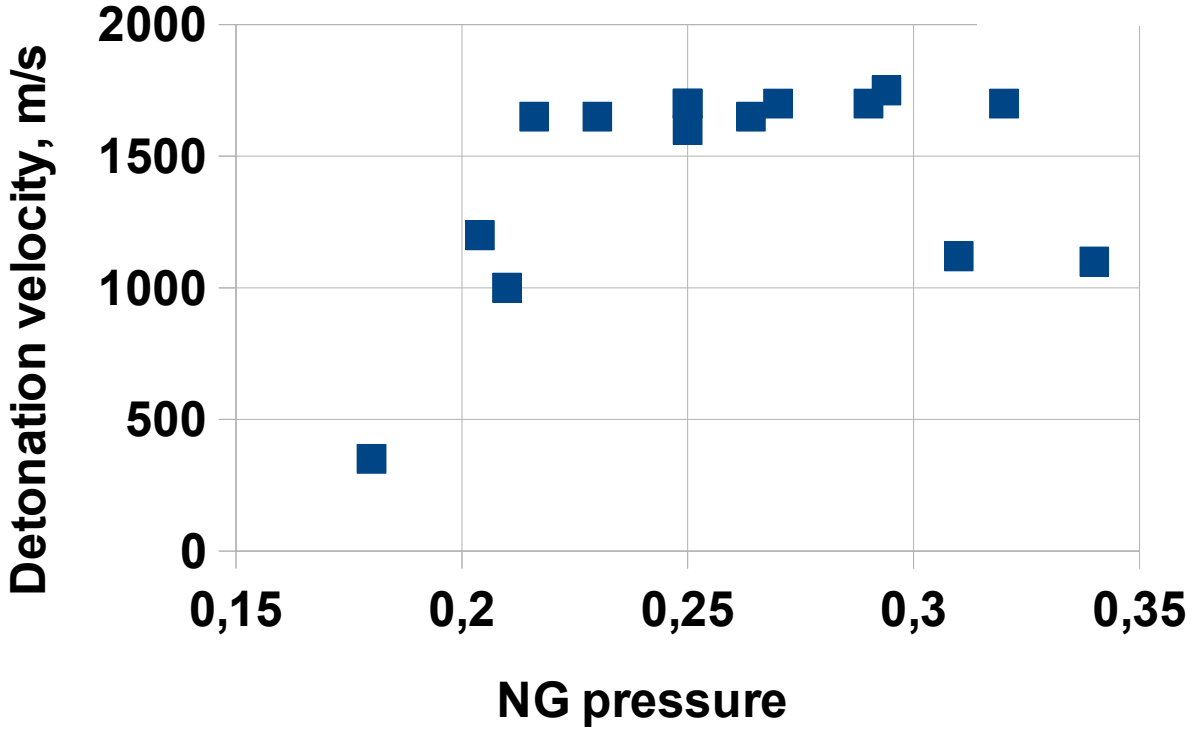


Smokfoil record




Gamezo et al., 2012
1050 mm diameter



# Interim conclusions 1(3)

1) Stable DDT in non-premixed NG-air mixture was obtained in the tube diameter 150 mm. Runup distance is 3 m.

2)

3)

**1/ DDT in natural gas — air mixture**

Previous our investigations

- Tube 74 mm and 92 mm

Experimental setup description

- Air blow supply
- Mixture ratio
- Ignition

Experimental regis
results

## 2/ Periodic DDT

- Time characteristics
- Remarks
- Efficiency of the detonation combustion
- Efficiency of the heat exchanging
- Requirements for burners

**3/ Thermal characteristics of periodic DDT**

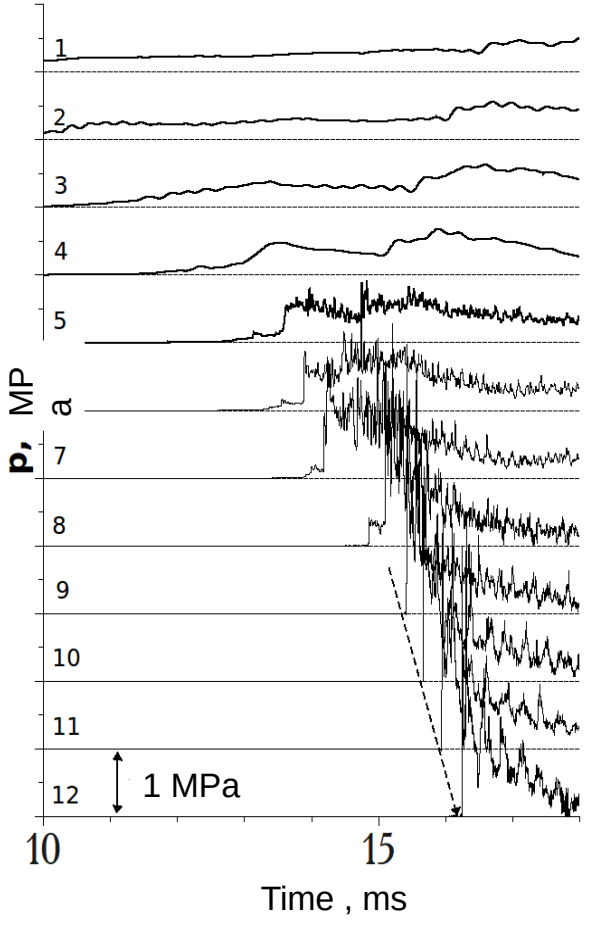
# PART 2: **Periodic DDT**

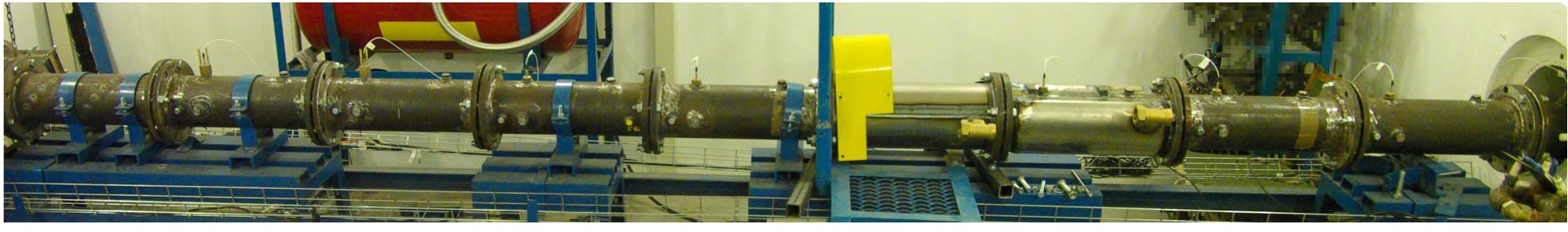
***objective:***

Determine the conditions for cycle DDT

cycle characteristics:

| | |
|---|---|
| 1. mixture filling | 350 ms |
| 2. detonation combustion | 20 ms |
| 3. production exhaust | <100 ms |
| **4. refreshing by air !!!** | **>100 ms** |

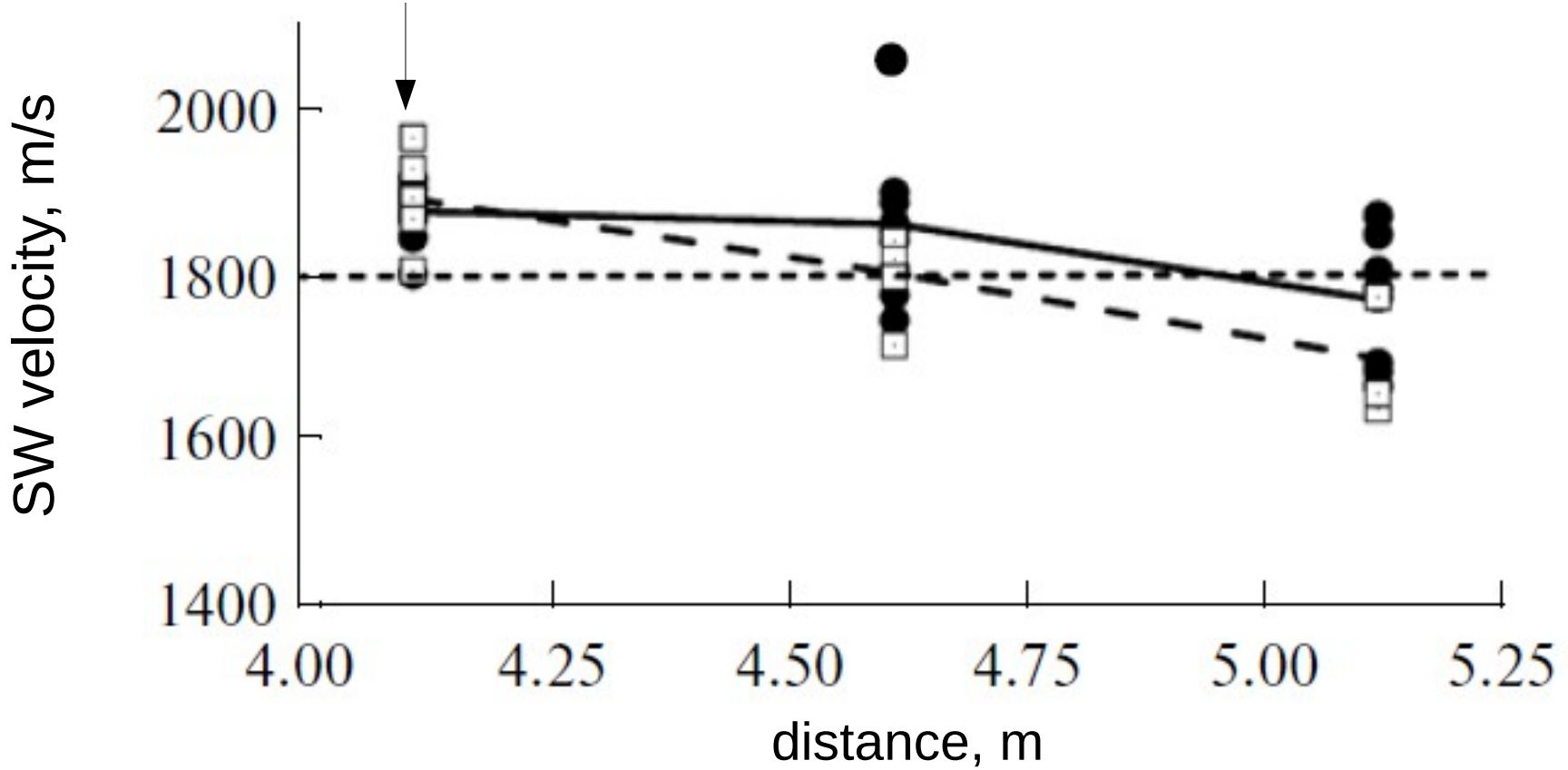


# DDT in the periodic mode

overdriven detonation

Different time of filling by fuel-air mixture




$$\eta = \max_{N} \left| \frac{D - \bar{D}}{\bar{D}} \right| \times 100\%$$

cycle to cycle instability < 10%

# Interim conclusions 2(3)

1) Stable DDT in premixed NG-air mixture was obtained in the tube diameter 150 mm

2) DDT occurs in the cycle mode with velocity deviation less then 10% at frequency 1.7 Hz

3)

# Contents

**1/ DDT in natural gas — air mixture**

Previous investigations
- Tube 74 mm and 92 mm

Experimental setup description
- Air blow supply
- Mixture ratio
- Ignition

Experimental registration technics and results

**2/ Periodic DDT**

Time characteristics
Remarks
Efficiency of the detonation combustion
Efficiency of the heat exchanging
Requirements for burners

**3/ Thermal characteristics of periodic DDT**

Experimental setup modification
Heated target
Water cooling jacket
Temperature registration equipments
Experimental results:
Temperature profiles

# Heat exchange during

- Heat exchange

$$Q = \alpha \cdot (t_c - t_ж) \cdot F.$$

- Nusselt number

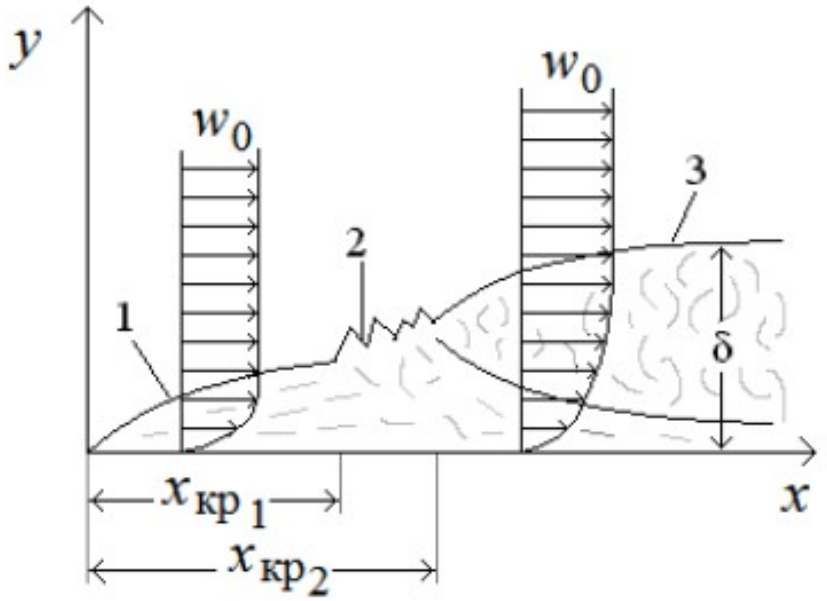
$$Nu = \frac{\alpha \times l_0}{\lambda}$$

- The dependency of  Nusselt number from velocity

$$\mathrm{Nu} = f(\mathrm{Re}, \mathrm{Pr})$$

- Local heat exchange coeeficient

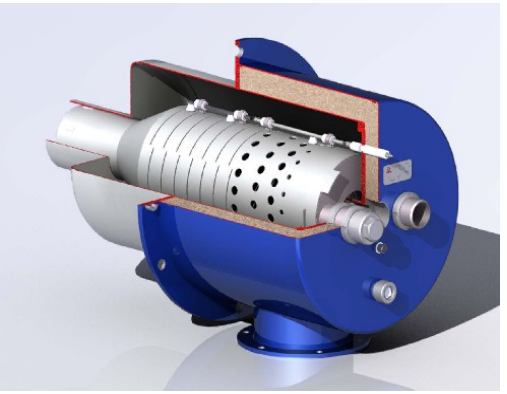
$$\mathrm{Nu}_{x\,ж} = 0{,}0296 \cdot \mathrm{Re}_{x\,ж}^{0{,}8} \cdot \mathrm{Pr}_{ж}^{0{,}43} \cdot \left(\mathrm{Pr}_{ж} / \mathrm{Pr}_{c}\right)^{0{,}25}$$



# Technical characteristics of the industrial gas burners

deflagration burner

- Thermal power of about 1000kW;
- Temperature of the gas in the output cross-section up to 2000 $^{o}$C;
- Maximum velocity of combustion products in the output cross-section of about 100 m/s;



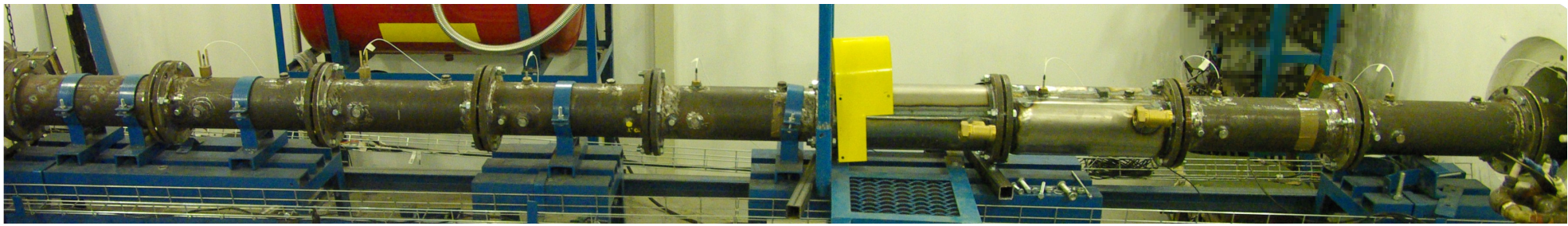
Impulse detonation burner

- Operating frequency up to 2 Hz;
- Velocity of combustion products 350-1000 m/s;
- Temperature of the gas in the output cross-section of up to 2500$^{o}$C;
- The energy of ignition- less than 1 J;
- The length of the burner tract is not more than 6 m;

# PART 3

***objective:***

determination of the thermal characteristics of the experimental setup

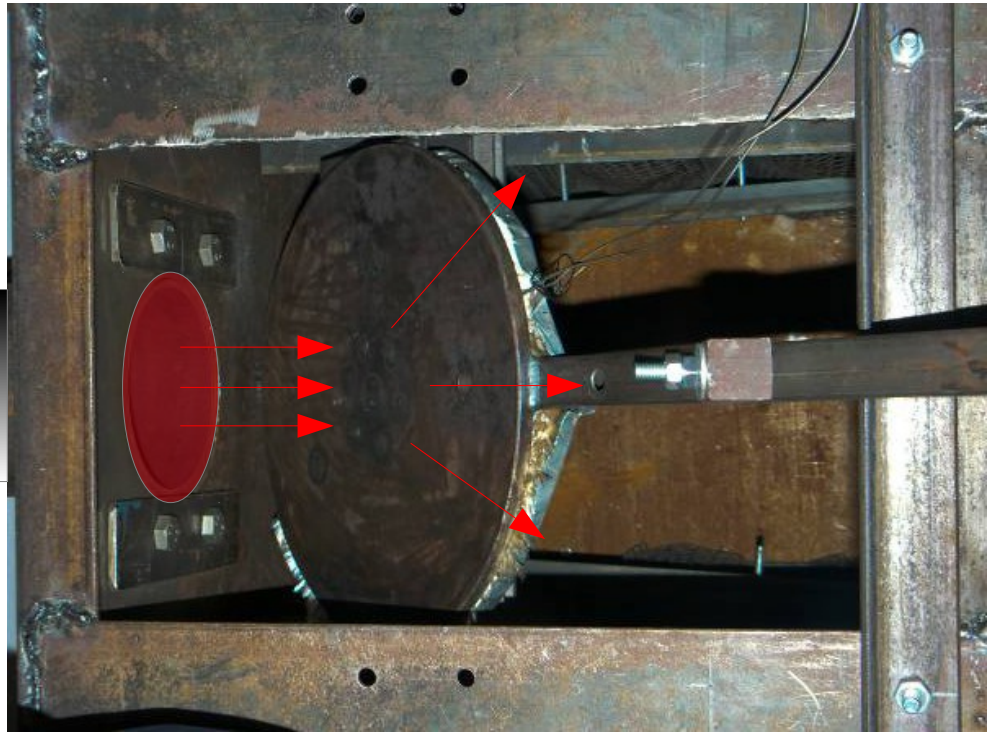


Experimental setup modification

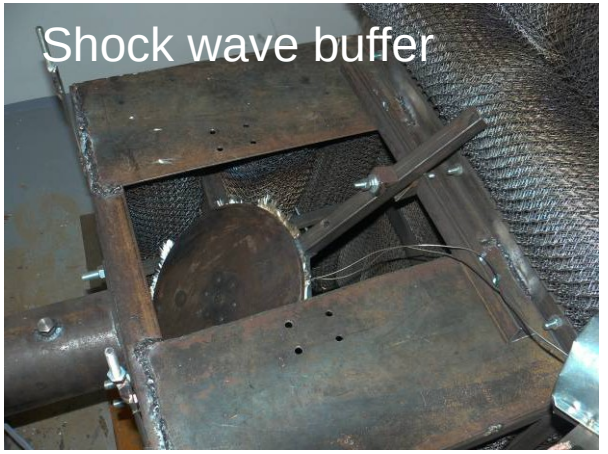
1. heated target
2. surface of burner
3. obstacles

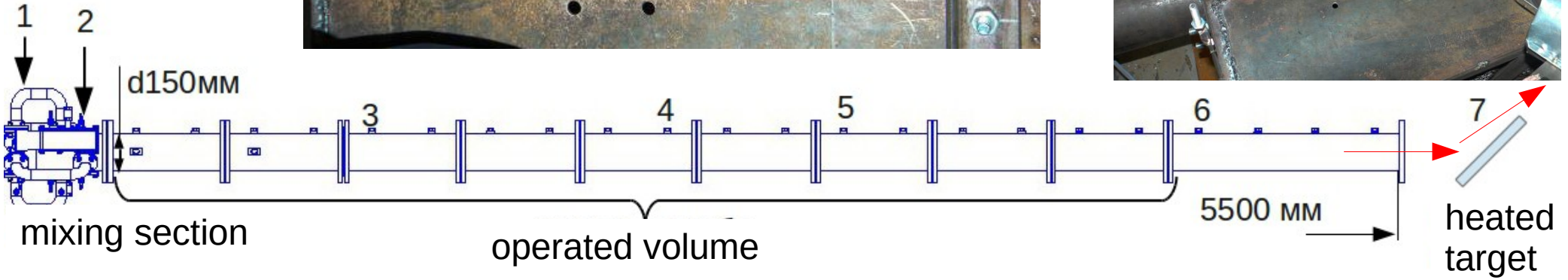
# Experimental setup

exhaust tube section



Heated target:
steel disk
thickness 2 cm
weight 3 kg



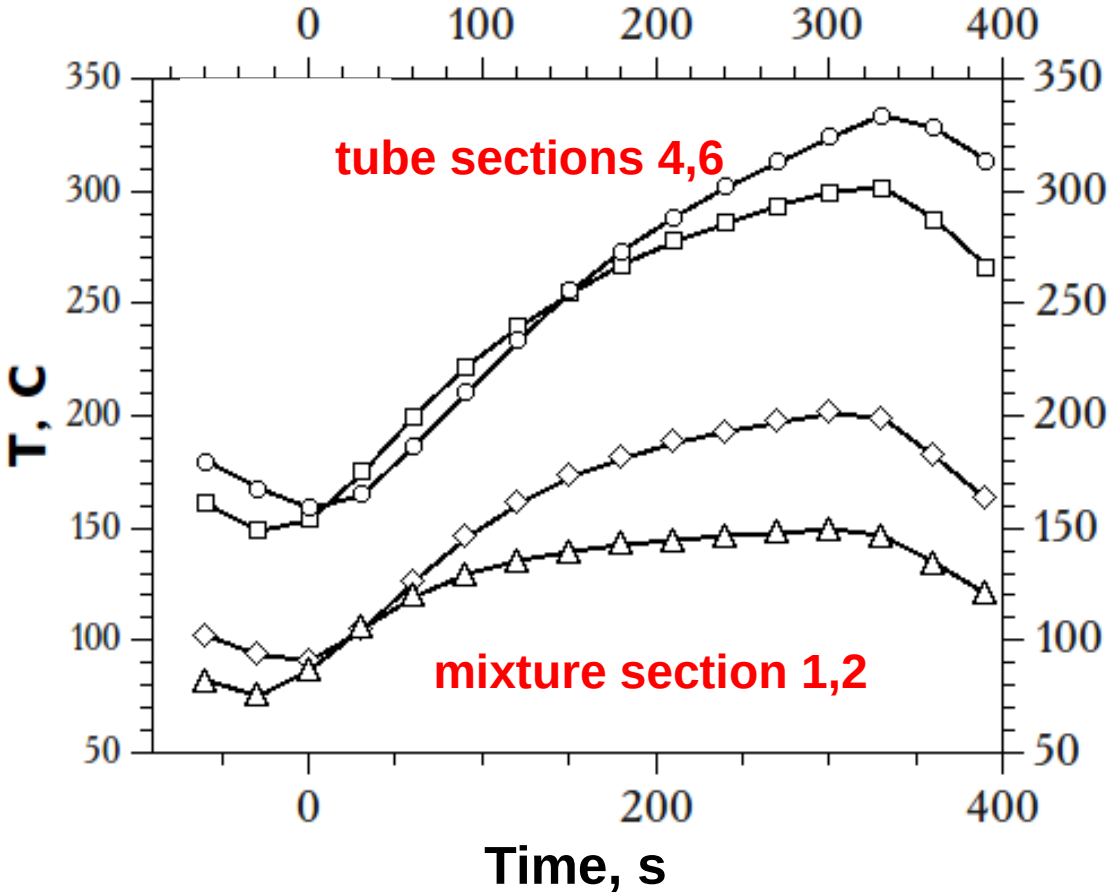

Registartion data points: 1 – igniter; 2 – mixter; 3, 5 – obstacles; 4, 6 – smooth sections; 7 – heated target

# Measuring technics

analog-digital converter — E 270

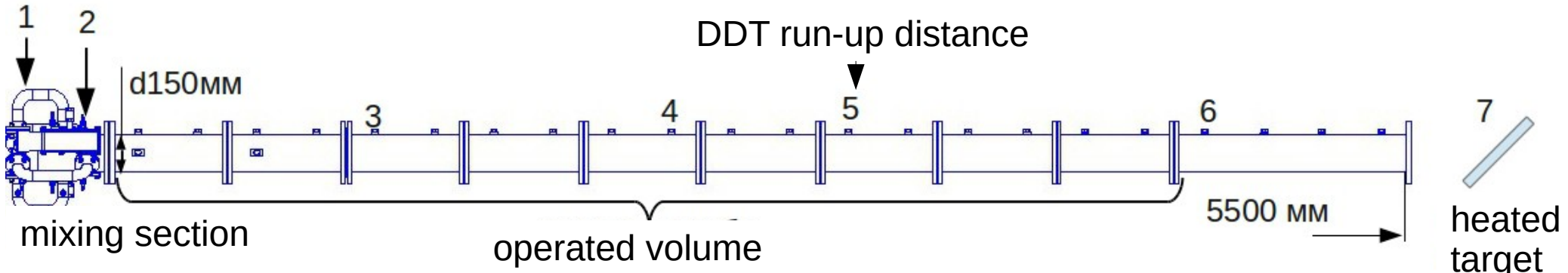

- sampling rate 10 Hz
- number of digits 14bit
- X-A thermocouples
- thermistor
- error of measurements <3 $^{o}$C
- thermal imager Testo

# Temperature profiles in the tube sections

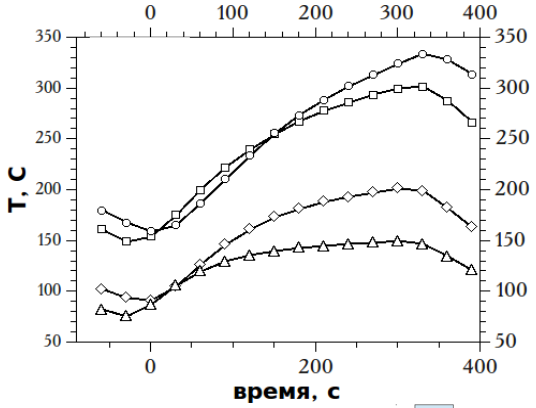



stationary temperature level ?

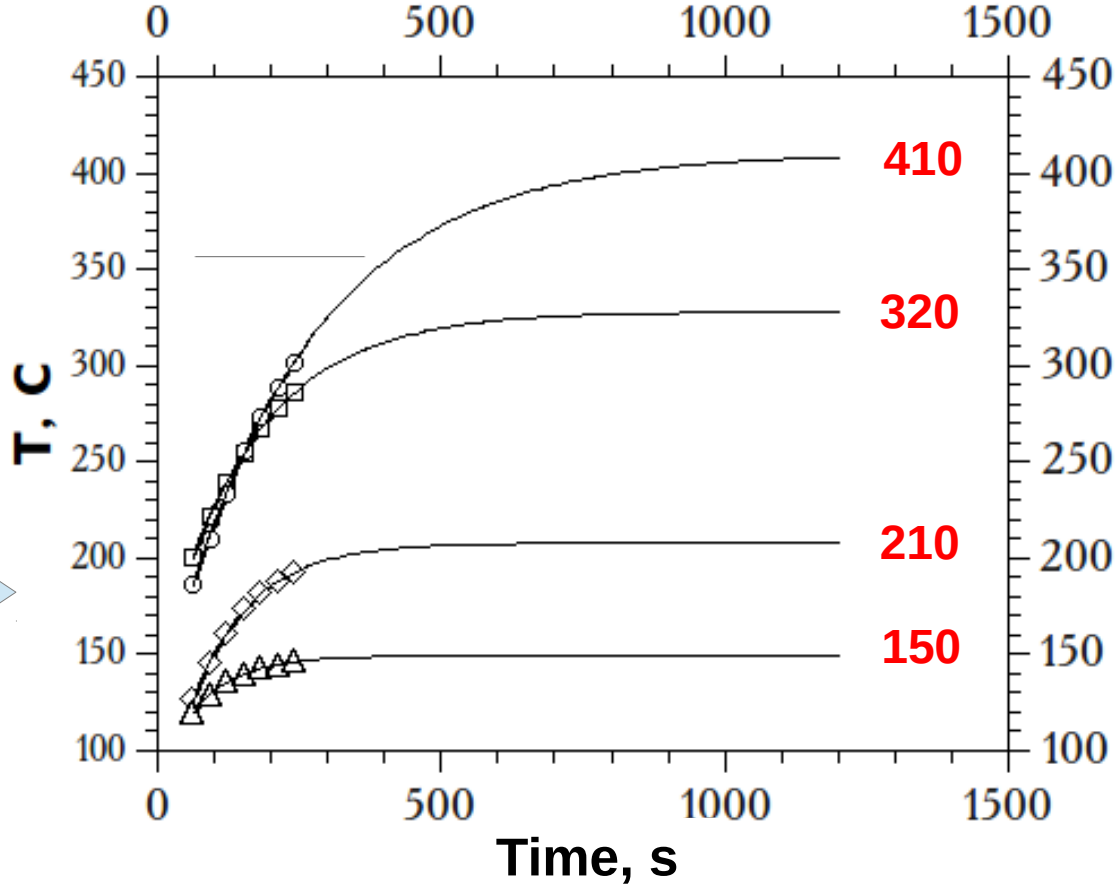
approximation function
T=A exp(-B/t)



# температура в различных точках установки




T=A exp(-B/t)



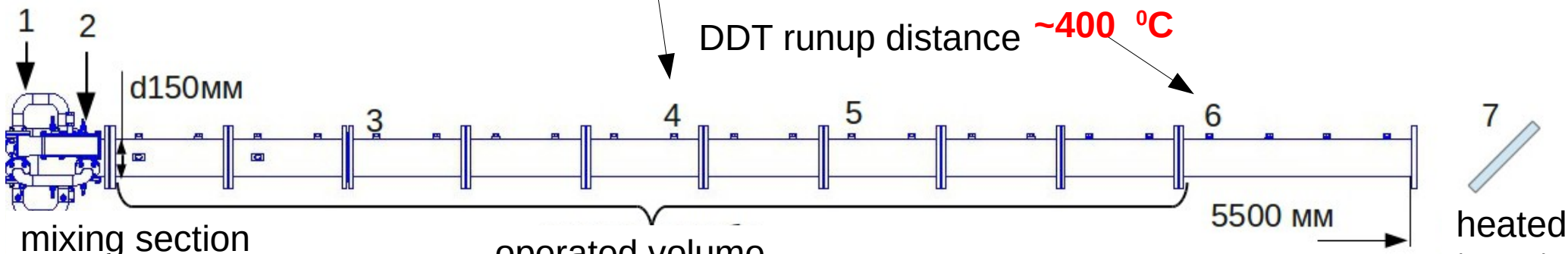

~200 °C

Time, s

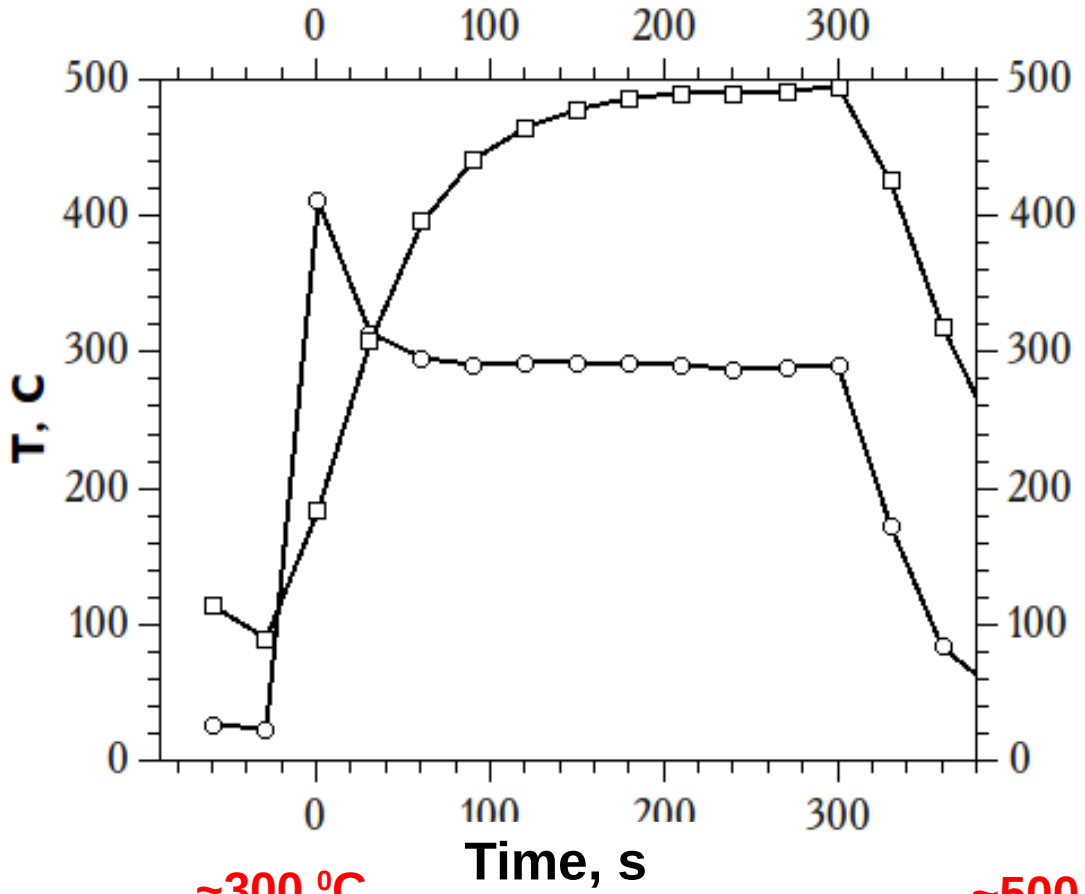
~300 °C

DDT runup distance

~400 °C

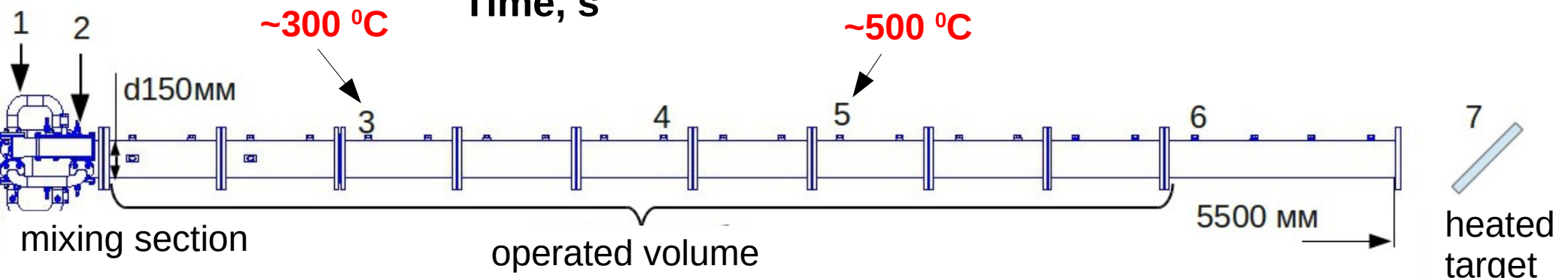


# Obstacles temperature profile

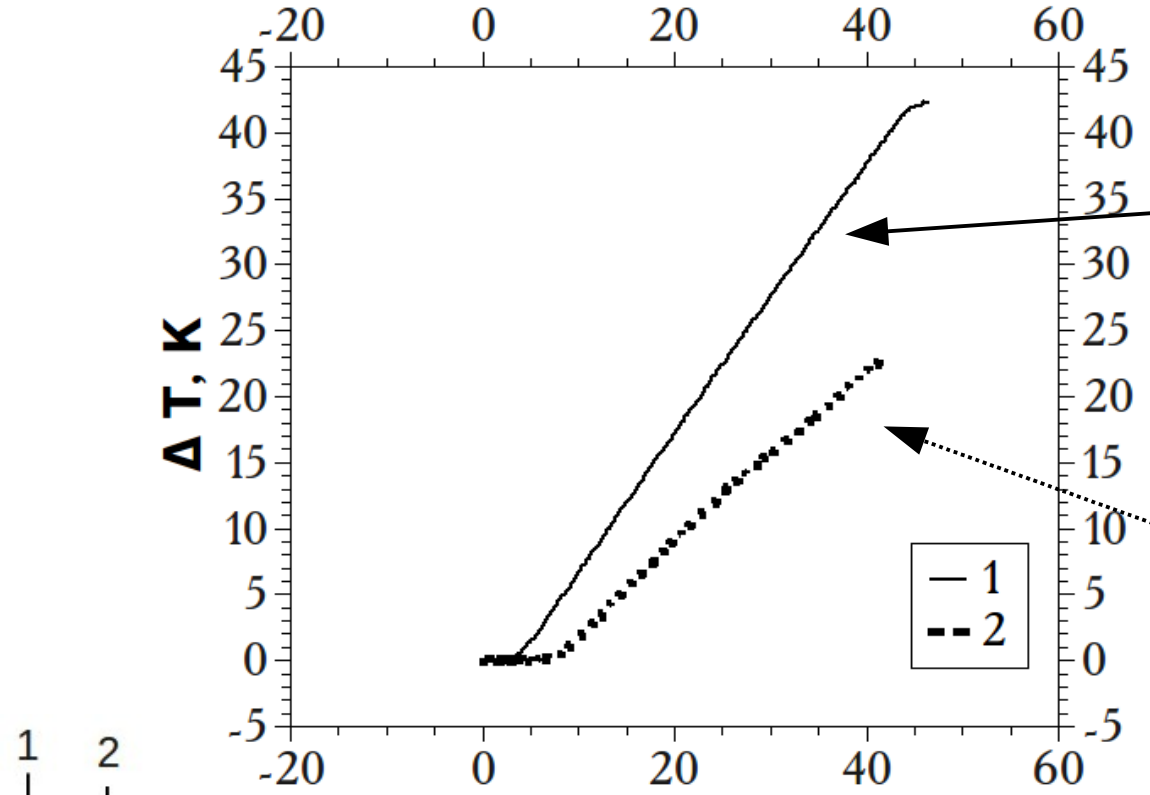



detonation region

combustion region

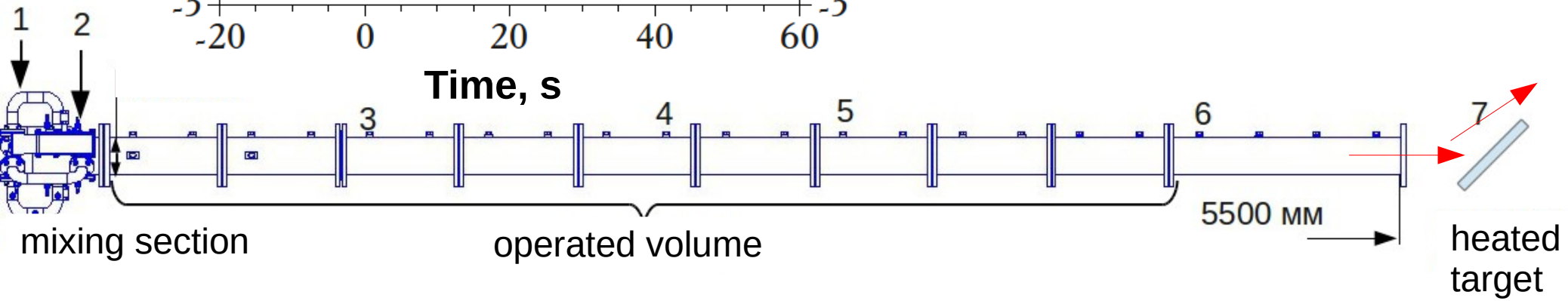


# Heated target temperature




impulse operation mode with DDT

impulse operation mode with combustion



# Contents

**DDT in natural gas — air mixture**

Previous work
- Tube 72 mm and 94 mm

Experimental setup description
- Air blow supply

Experimental registration technics and results

**Periodic DDT**

Time characteristics
The operation frequency

**Thermal characteristics of periodic DDT**

Experimental setup modification
Heated target
Temperature registration equipments
Temperature of the detonation tube

# Conclusions

1) Stable DDT in premixed NG-air mixture was obtained in the tube diameter 150 mm

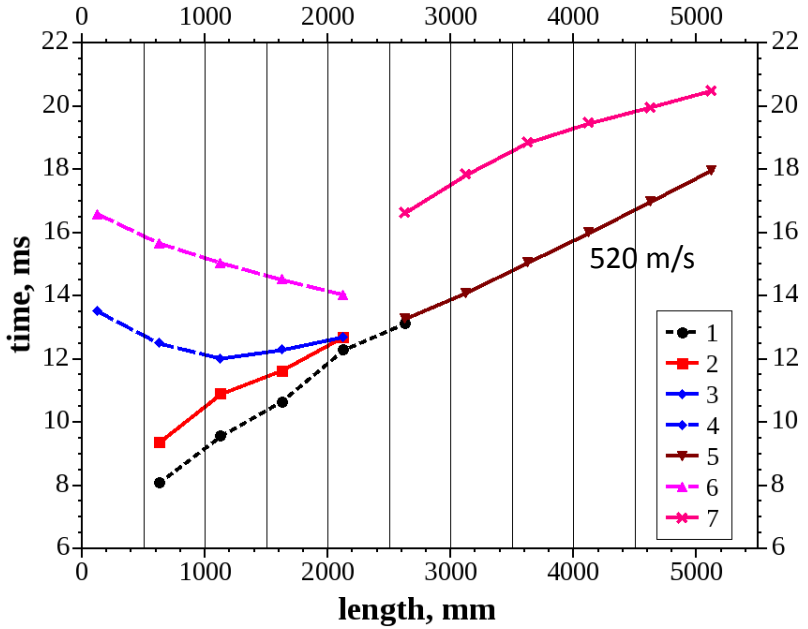
2) DDT occurs in the cycle mode with velocity deviation less then 10% at frequency 1.7 Hz

3) Thermal parameters of the detonation tube inside and on surface was determine.

Comparison of two mode (impulse detonation and impulse deflagration) demonstrate more high intensity of heat exchange in detonation mode

Работа выполнена в рамках Государственного контракта №16.526.12.6018 «Разаработка высокоскоростной энергосберегающей импульсно-детонационной газовой горелки для повышения эффективности тепловой работы промышленных печей и теплоэнергетических установок».

Нет ДВ, нет инициирования




1 – первичное возмущение(переходит в лидирующую УВ)
2 – начало фронта пламени(т.к. оно вытянуто)
3 – возмущение, распространяемое дальше по трубе от турбулизатора в секции №3
4 – возмущение, распространяемое обратно по трубе от турбулизатора в секции №3
5 – фронт УВ
6 – обратная волна, распространяющаяся от начала второй части ершей
7 – фронт горения.