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MEASUREMENT OF NEUTRINO SOURCE ACTIVITY IN THE EXPERIMENT BEST BY CALORIMETRIC METHOD

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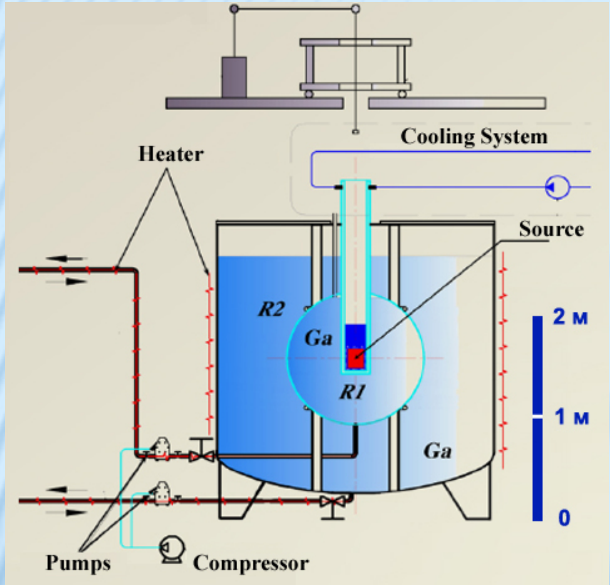
BAKSAN EXPERIMENT ON STERILE TRANSITIONS (BEST)



Two-zone Ga target

Internal spherical zone: 7,40 t Ga,
External cylindrical zone: 40,09 t Ga,
Neutrino path length in sphere: 53 cm,
Neutrino path length in cylinder: 55 cm.

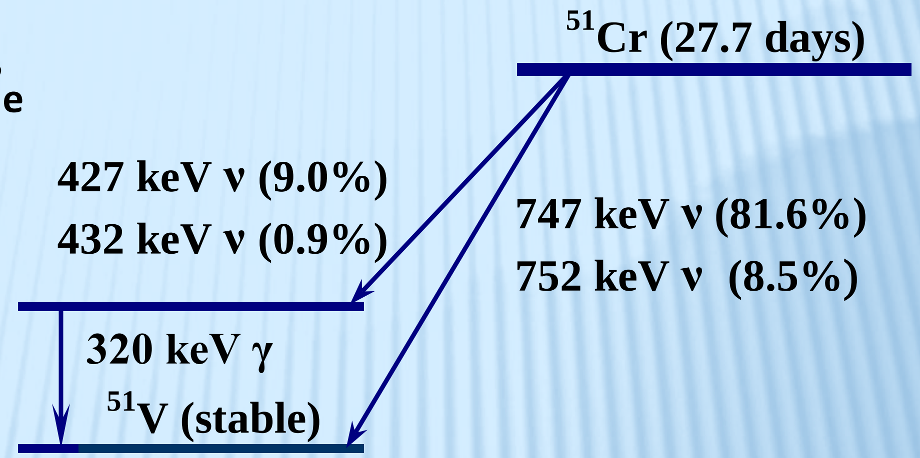
The evidence of nonstandard neutrino properties:

- there is a significant difference between the capture rates in the two zones
- the average rate in both zones is considerably below the expected rate

Uncertainty of activity measurement < 1%.

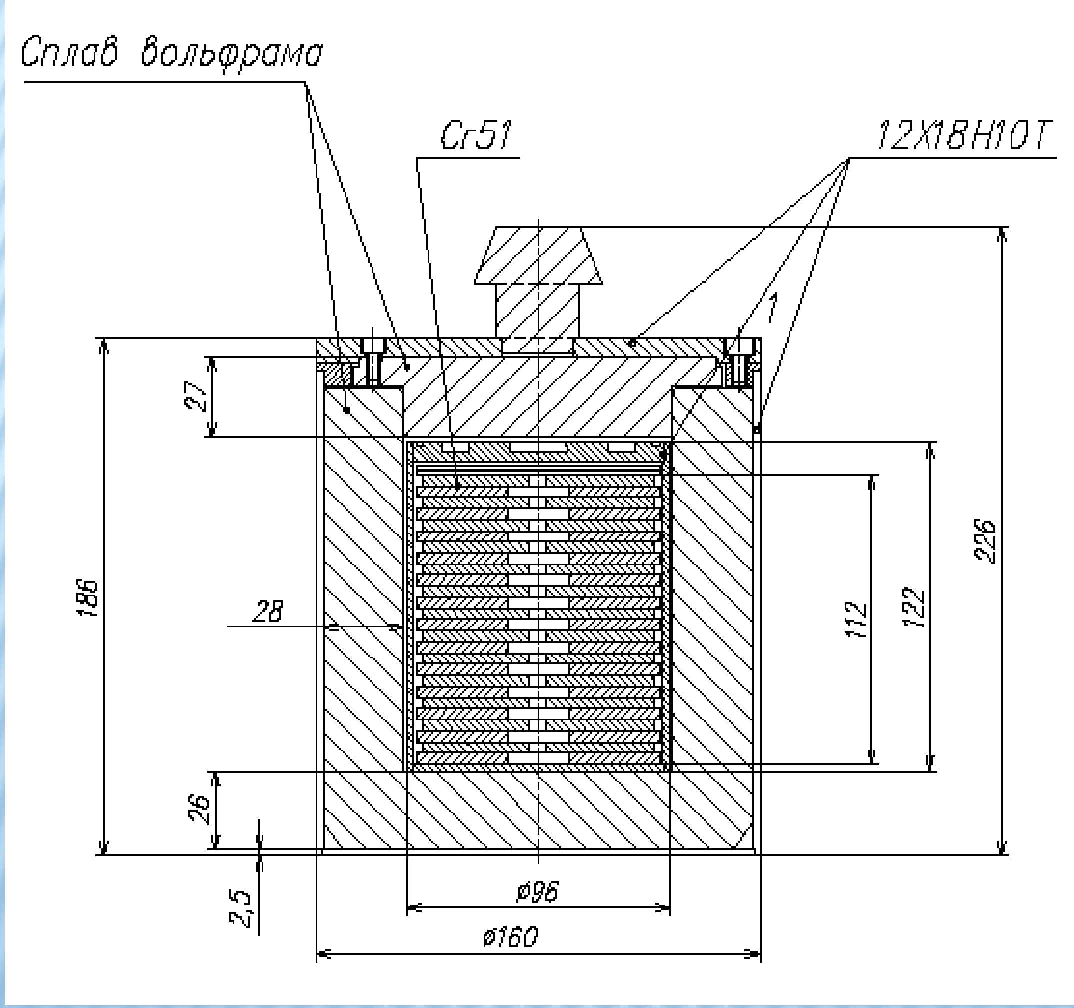
NUCLEAR DECAY SCHEME ^{51}Cr

$$^{51}Cr + e^- \rightarrow {}^{51}V + \nu_e$$



Type of energy release	Energy, keV	Contribution to ^{51}Cr decay	Energy release with ^{51}Cr decay, keV
Gamma rays	320,0835 (4)	0,0991 (2)	31,720 (64)
K-cupture	5.465	0,8919 (17)	4,874 (9)
L-cupture	0,628	0,0927 (14)	0,0582 (9)
M-cupture	0,067	0,0154	0,001
inner bremsstrahlung	751 (max)	$3,8\times10^{-4}\times0.902$ (±10%)	0,096 (10)
inner bremsstrahlung	430 (max)	$1,2\times10^{-4}\times0.0983$ (±10%)	0,001
Total			36,750 (84) - 0.23%

NEUTRINO SOURCE BASED ON ^{51}CR

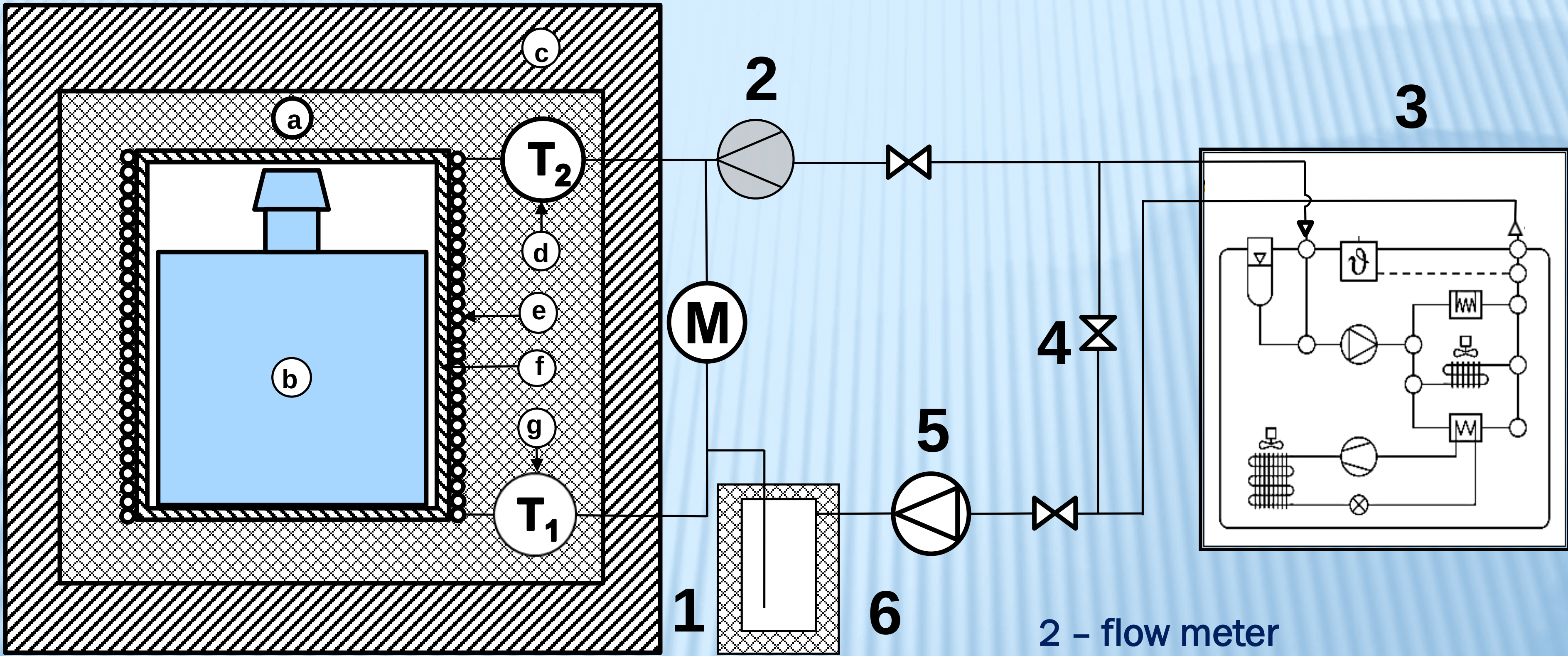


4 kg 97%-enriched ^{50}Cr,
26 chrome metal disks
h = 4 mm, ∅ 84 and 88 mm.

Biological shield 30 mm
(W - 98%, Ni - 2%, Cu - 1%)

Energy losses due to gamma-rays escaping < 0.03%.

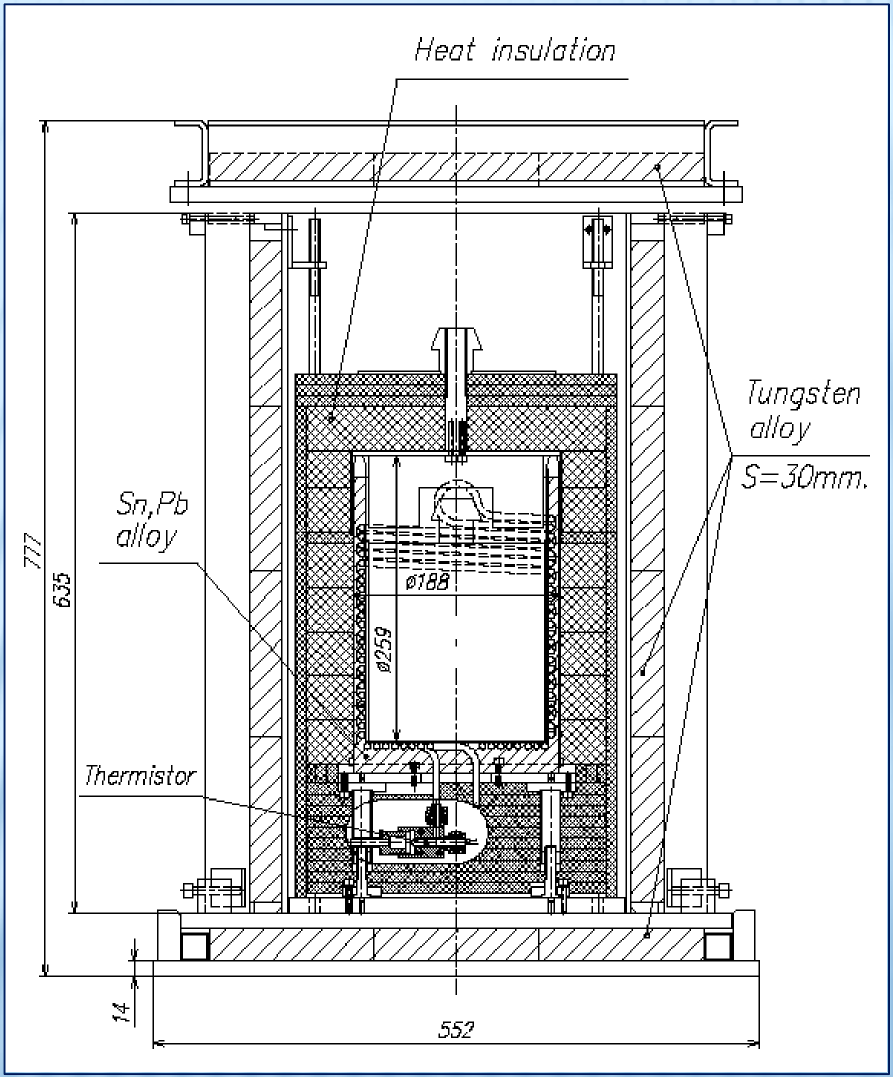
SCHEME OF THE CALORIMETRIC SYSTEM



1 – MEASUREMENT CELL
a – thermal insulation
b – neutrino source
c – biological shield
d – output thermistor
e – heat exchanger
f – container
g – input thermistor

2 – flow meter
3 - thermostat
4 - bypass
5 - gear pump
6 – temperature damper
M – differential manometer

MEASURING CELL OF CALORIMETER



FRAGMENT OF THE BEST INSTALLATION

Laboratory GGNT BNO INR RAS, 4700 m.w.e.

Neutrino registration by gallium detector

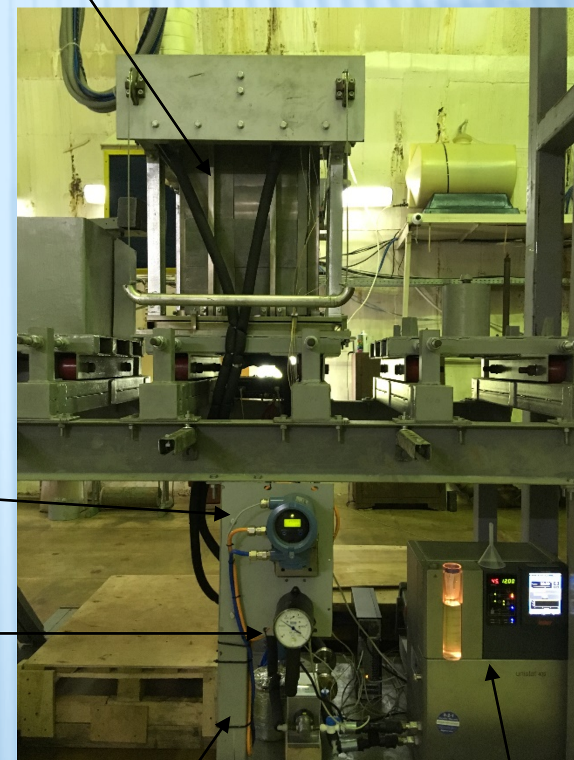
$$^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$$

1. Exposure of Ga target - 10-9 d
2. Chemical extraction of ^{71}Ge, activity measurement, gamma-ray spectrometry - 1 d
3. Counting of ^{71}Ge decay - 60 -150 d

Time for calorimetric measurement $\leq$ 20 h.

CALORIMETRIC SYSTEM

Measurements cell with neutrino source



Temperature meter

Flow meter

Differential manometer

Power supply

Multimeter

Control computer

Temperature damper

Thermostat

USED EQUIPMENT

- **Platinum thermistors PTV-2-1 (VNIIFTRI)**
  (with temperature uncertainty less than 0.002 K).
- **Coriolis mass flow meter Micro Motion (±0.05%).**
- **Cooling thermostat Unistat (±0,01 K).**
- **Gear pump Ismatec Reglo-Z Digital (± 0,05 %).**
- **Power supply Sorensen XHR 300-3,5.**
- **Two-channel digital multimeter ADVATEST R6452E (0,01 V).**
- **Shunt (R= 52,15 ± 0,01 mOhm).**

SOFTWARE OF THE CALORIMETRIC SYSTEM

Software is based on LabVIEW Package (National Instruments).
Software ensures reading and storing of the following data:

- **mass flow rate, density, total mass and temperature of the coolant through the flow meter;**
- **input and output temperatures of coolant;**
- **voltage on the heat simulator and the shunt.**

The basic characteristic of flow calorimeter is the total heat removal from heat source to heat-transfer liquid (deionized water).

The heat release is proportional to the difference between the output and input temperatures of the coolant and it can be expressed by equation:

$$N = k \times Q \times (T_{out} - T_{in}),$$

where

***N* – heat release of the source, W.**

***k* - the proportionality factor, which in the absence of heat loss is equal to the specific heat capacity of the coolant, J/(kg x K).**

Q - the coolant flow rate, kg/s.

T_{out} – the temperature at the outlet of the heat exchanger, K.

T_{in} - the temperature at the inlet to the heat exchanger, K.

It is necessary to take into account:

- **heat release from the impurity radioactive nuclides in neutrino source.**
- **heat release due to the liquid friction in heat exchanger.**
- **heat loss in the environment.**
- **change of the heat release due to ^{51}Cr decay.**

RADIONUCLIDE COMPOSITION OF THE NEUTRINO SOURCE

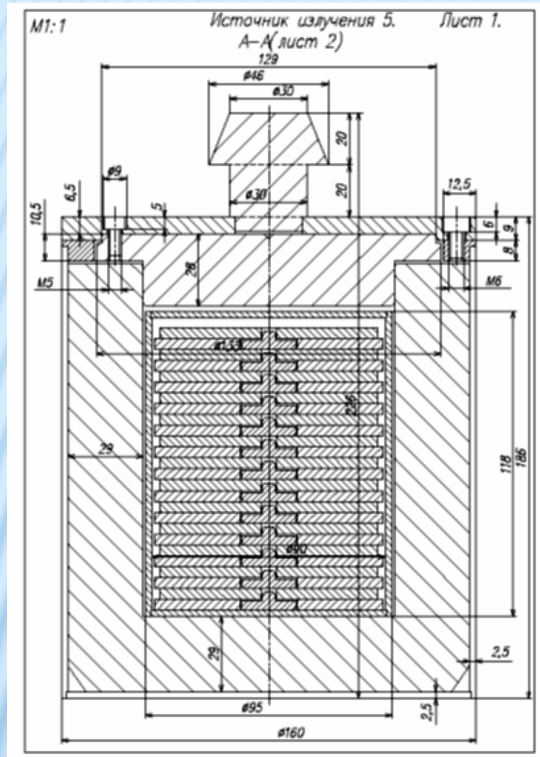
(V.V. Gorbachev "Estimation of radioactive impurities in the ^{51}Cr source from photon radiation measurements in the BEST experiment"

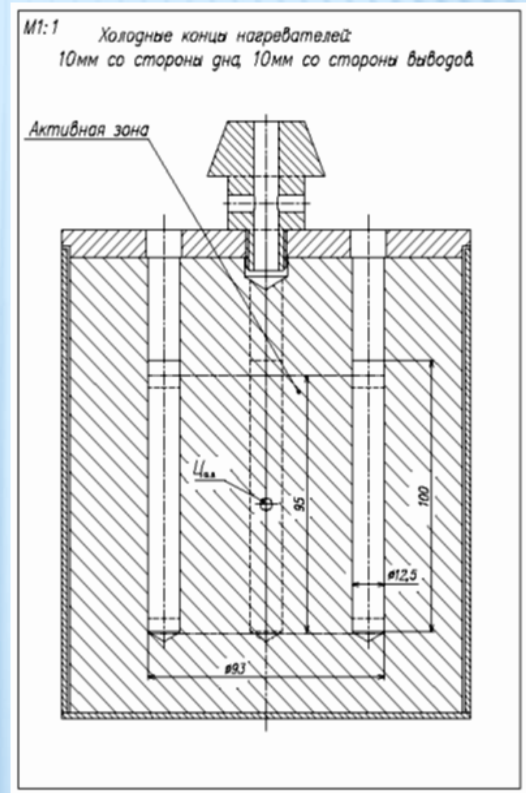
XXXV International Conference on Equation on State for Matter, Elbrus, KBR, Russia, 1-6 March 2020)

	Isotope, $T_{1/2}$	Energy, keV	Line output, %	Activity (5.07.2019), mCi	Heat release, mW
1	^{137}Cs 30.05 y	662	85	8.5× (1±0.23)	0.06
2	^{95}Zr 64 d	724 757	11.1 54.38	60×(1±0.12)	2.1
3	^{95}Nb 35 d	766	99.8	87×(1±0.04)	
4	^{134}Cs 2.06 y	796	85.5	3.3×(1±0.18)	0.041
5	^{58}Co 70.85 d	811	99.44	6.0×(1±0.27)	0.08
6	^{54}Mn 312 d	835	100	13×(1±0.05)	0.10
7	^{46}Sc 83.8 d	889 1120	100 100	5.2×(1±0.10)	0.07
8	^{59}Fe 44.5 d	1099 1291	57 43.2	23×(1±0.07)	0.22
9	^{60}Co 5.27 y	1173 1332	100 100	6.6×(1±0.03)	0.11
10	^{124}Sb 60.2 y	1690 2091	47.5 5.5	5.8×(1±0.06)	0.10
11	^{154}Eu (?) 8.6 y	1274 1595	34.9 1.8	0.86×(1±0.18)	0.010
Σ					2.9

- **Total heat release from impurity radionuclides – 2,9 ± 0,5 mW.**
- **Impurity radionuclide contribution to heat release of 3.0 MCi ^{51}Cr source (~650 W) is ~ $4{\cdot}10^{-6}$ and can be neglected.**

CALORIMETER CALIBRATION

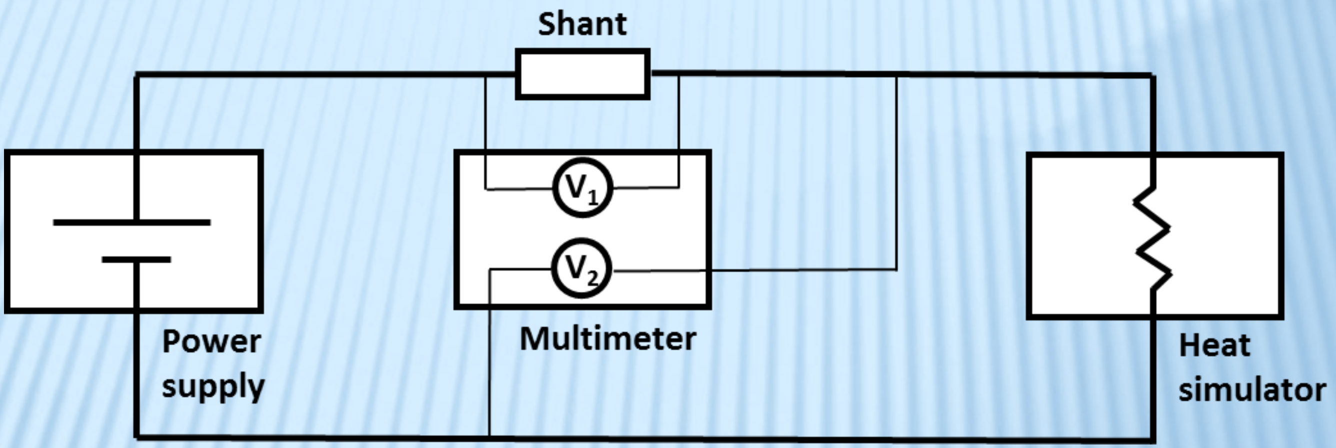




Neutrino source based ^{51}Cr
- heat capacity - 9862 J/K
- heat conduction of the tungsten alloy - 163 W/m·К

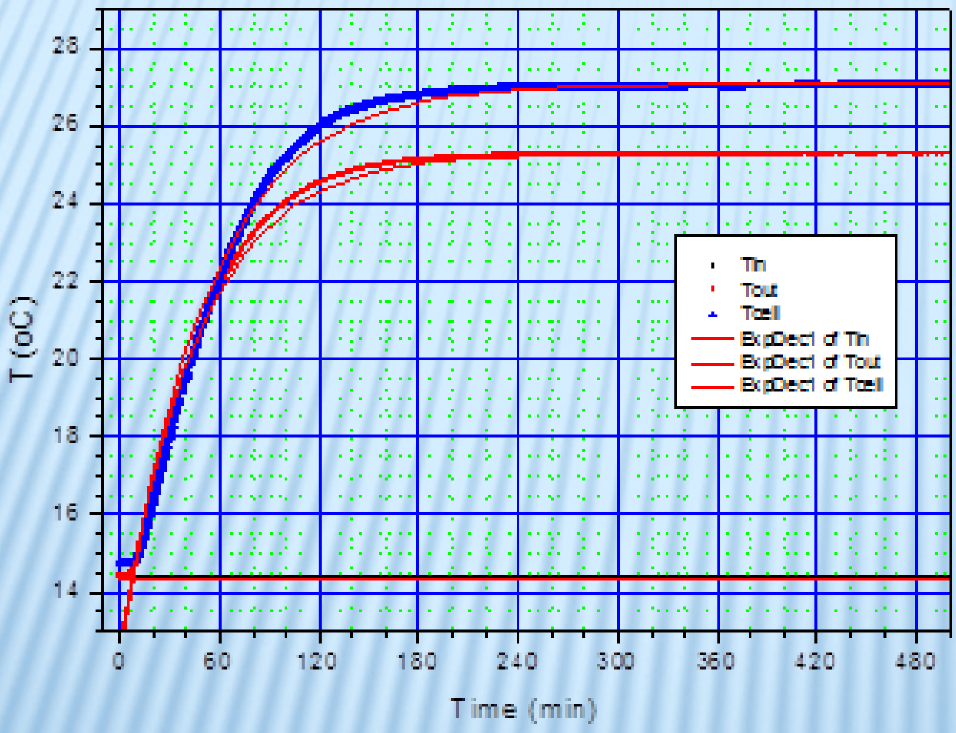
Heat source simulator
- heat capacity - 10031 J/K
- heat conduction of duralumin - 160 W/m·К

ELECTRC POWER MEASUREMENT



$$P = \frac{U1 \times U2}{Rshunt}, \delta = 0.03\%$$

ATTAINMENT OF THE HEAT EQUILIBRIUM



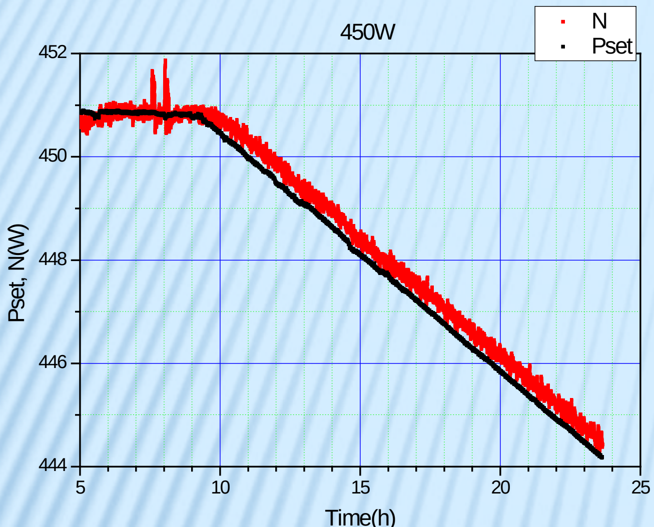
$T = T1*exp(-x/t1) + T0$

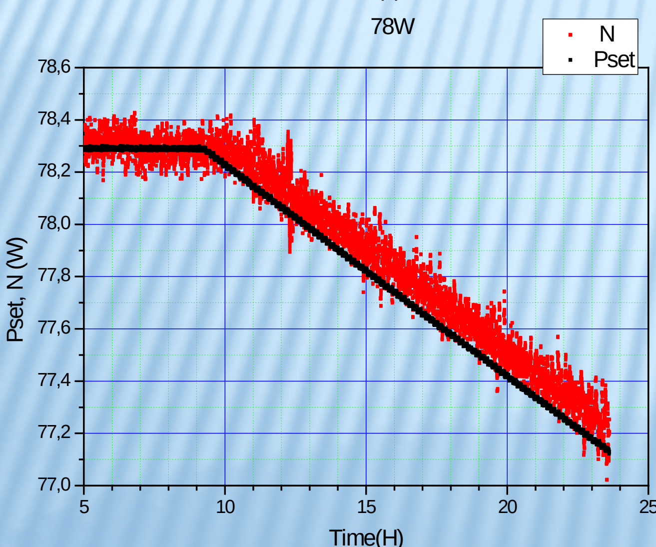
T_{in}: t1 = 51 min

T_{out}: t1 = 47 min

T_{cont}: t1 = 53 min

CALORIMETER CALIBRATION

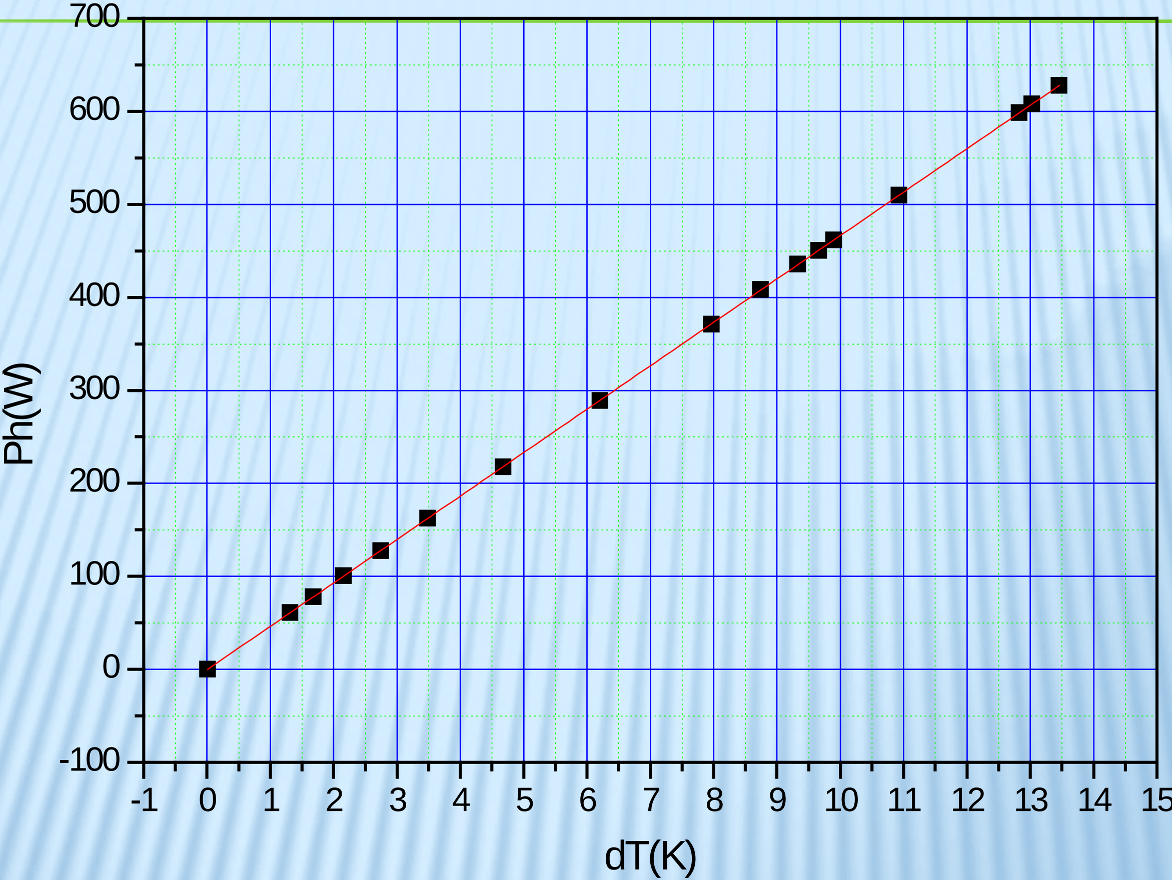




$t_{shift} = (1/b)*\ln(P0/N0)$

№ п/п	1	2	3	4	5	6	7	8	9	10	
T_{in}, °C	12.398	14.840	15.326	15.330	17.781	19.252	19.837	20.218	20.506	20.701	20.601
T_{out}, °C	25.427	24.501	23.291	21.541	22.458	22.740	22.580	22.375	22.182	22.013	20.610
dT, K	13.029	9.661	7.965	6.211	4.677	3.488	2.743	2.157	1.676	1.312	0.008
T_{cont}, °C	26.419	25.137	24.274	22.197	22.882	23.081	22.850	22.470	22.209	22.059	20.617
T_{room}, °C	21.480	21.66	21.30	21.38	21.86	21.89	21.89	21.117	20.69	20.77	20.686
Q, kg/h	38.13	40.07	37.85	37.85	39.19	40.72	40.48	40.03	40.08	39.93	41.501
Ph, W	579.47	450.89	351.10	273.47	213.23	165.20	129.05	100.54	78.29	60.99	0
Ncalk,W	577.26	449.65	350.20	273.11	212.93	164.95	128.96	100.30	78.04	60.84	0.402
Nfr, W	0.31	0.36	0.32	0.32	0.35	0.38	0.38	0.36	0.37	0.37	0.404
Nhl, W	2.52	1.57	1.21	0.67	0.65	0.63	0.46	0.60	0.62	0.52	0.002
l, W/K	0.509	0.453	0.408	0.83	0.63	0.528	0.481	0.446	0.407	0.404	-0.03
Phnorm,W	607.81	450.13	371.08	289.03	217.63	162.30	127.51	100.46	78.13	61.11	0
t_{shift}, min	39	53	55	71	81	85	68	84	71	89	

CALORIMETER CALIBRATION



N(dT) = (46,69 ± 0,02) × dT + (-0,41 ± 0,15), correlation coefficient: R^2 = 1

N = c_pQdT, c_p = 4202,0 Дж/кг·К,

$C_p^{табл}$ = 4184,1 Дж/кг·К [CRC Handbook of Chemistry and Physics. 97^{th} ed. W.M. Haynes, CRC Press, 2017, 2643pp.]

MEASUREMENT OF NEUTRINO SOURCE ACTIVITY

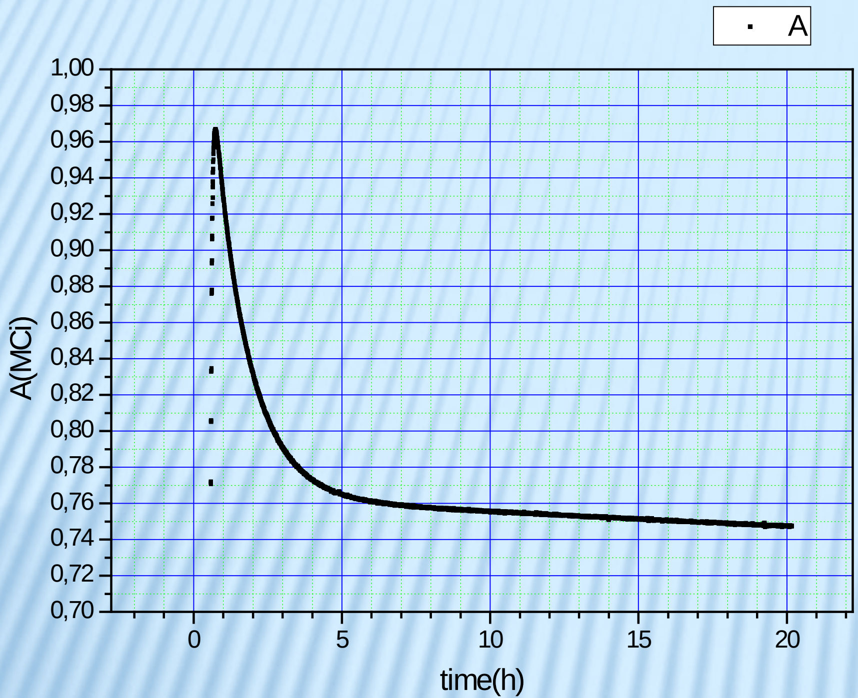
Calculating method:

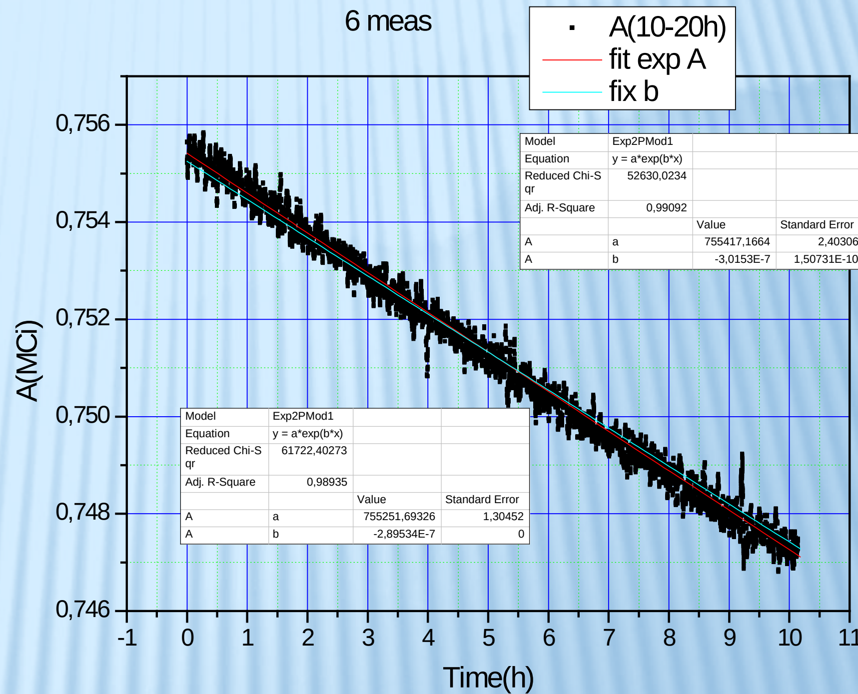
$$A_1 = [N_{heat} + N_{loss} - N_{resist}]/f =$$

$$[Qc_p(T_{out} - T_{in}) + l_i(T_{cont} - T_{room}) - 1,76 \cdot 10^{-5} \cdot \Delta p \cdot Q/\rho]/f, \quad (2)$$

where A_1 – the source activity, MCi,
N_{heat} – the transferring coolant heat, W,
N_{loss} - the heat losses, W,
N_{resist}– heat release due to hydraulic resistance in heat exchanger, W,
Q – the coolant flow rate, kg/h,
T_{out} – the coolant temperature at the outlet of the heat exchanger, °C.
T_{in} - the coolant temperature at the inlet to the heat exchanger, °C.
f – the scaling factor, 217,857 W/MCi,
c_p – the specific heat capacity of the coolant, J/(kg · K).
l_i – the heat loss coefficient (obtained from i-calibration experiment), W/K,
T_{cont} – the temperature of container side, °C,
T_{room} – room temperature, °C,
Δp – hydraulic resistance in heat exchanger, mbar,
ρ - the coolant density, kg/m^3.

SOURCE ACTIVITY MEASUREMENT BY CALCULATING METHOD





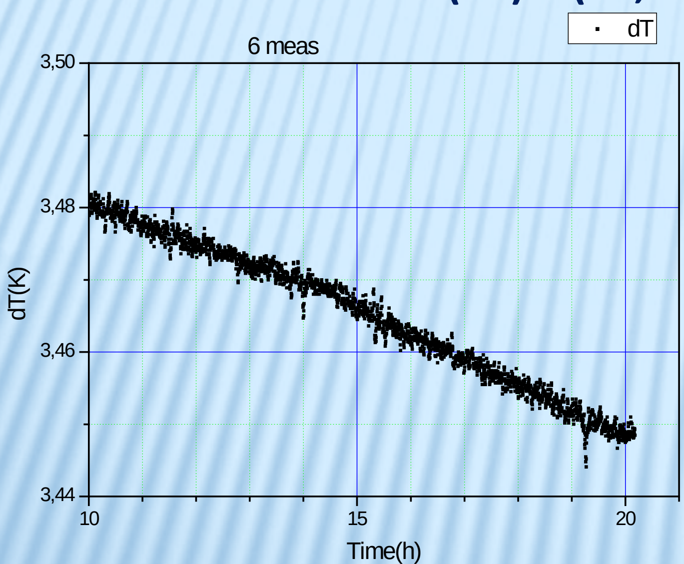
№ meas	1	2	3	4	5	6	7	8	9	10	A_0, MCi	$T_{1/2}$, d
Date, time	15.07.19 23-56	26.07.19 03-23	05.08.19 00-20	14.08.19 23-16	25.08.19 01-02	03.09.19 23-05	13.09.19 23-58	23.09.19 23-45	03.10.19 23-58	13.10.19 23-34	05.07.19 14-02	
A_1, MCi	2.62362	2.03722	1.59104	1.23251	0.96249	0.75133	0.58438	0.45531	0.35423	0.27582	3.403 ±0.002	27.665

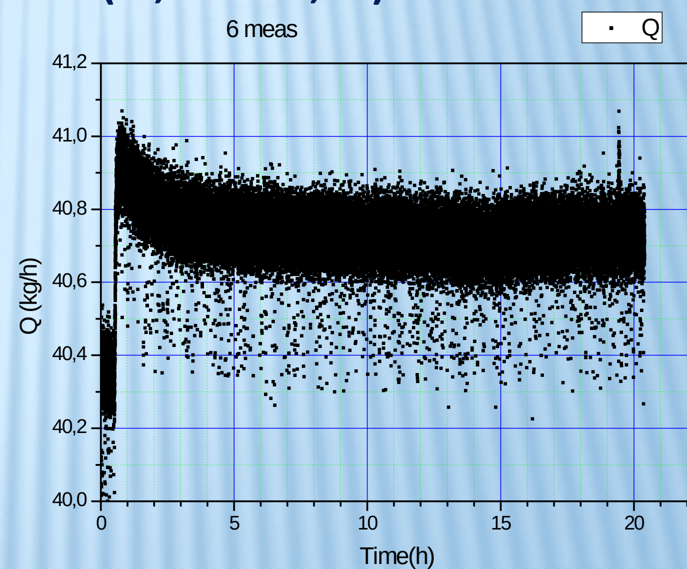
SOURCE ACTIVITY MEASUREMENT BY CALIBRATION METHOD

$$A_2 = [kQ(T_{out} - T_{in})/f],$$

where k – the calibration coefficient, J/kg·K,
Q – the coolant flow rate, kg/h,
T_{out} – the coolant temperature at the outlet of the heat exchanger, °C,
T_{in} - the coolant temperature at the inlet to the heat exchanger, °C,
f - the scaling factor, W/MCi.

$$N(dT) = (46{,}69 \pm 0{,}02) \times dT + (-0{,}41 \pm 0{,}15)$$



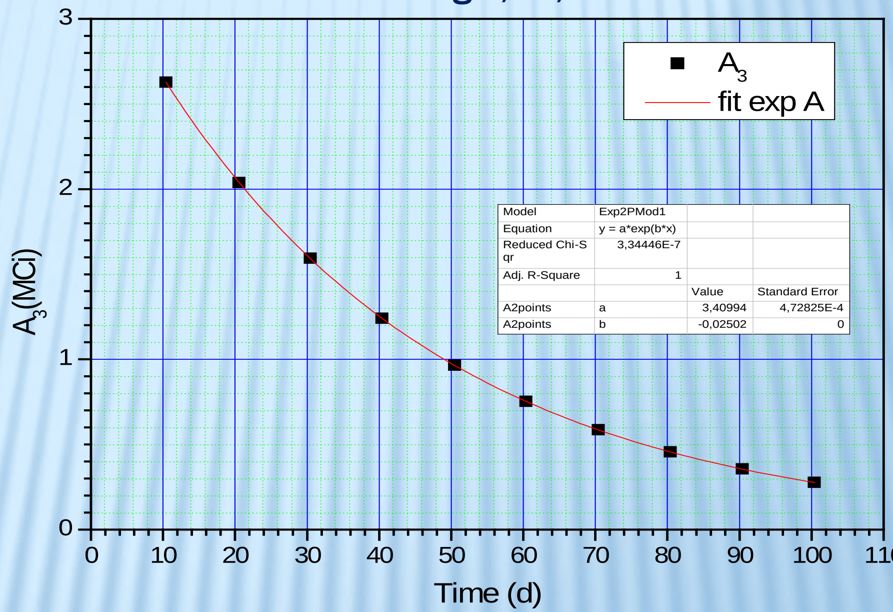


№ meas	1	2	3	4	5	6	7	8	9	10	A_0, MCi	$T_{1/2}$, d
Date, time	15.07.19 23-56	26.07.19 03-23	05.08.19 00-20	14.08.19 23-16	25.08.19 01-02	03.09.19 23-05	13.09.19 23-58	23.09.19 23-45	03.10.19 23-58	13.10.19 23-34	05.07.19 14-02	
A_2, MCi	2.62824	2.04044	1.59542	1.24415	0.96671	0.75386	0.58634	0.45561	0.35464	0.27580	3.4125 ±0.0009	27.720

SOURCE ACTIVITY MEASUREMENT USING CALIBRATION AT PARTICULAR HEAT RELEASE

$$A_3 = [k_i Q(T_{out} - T_{in})/f],$$

k_i – the calibration coefficient in i-measurement, J/kg·K,
Q – the coolant flow rate, kg/h,
T_{out} – the coolant temperature at the outlet of the heat exchanger, °C,
T_{in} - the coolant temperature at the inlet to the heat exchanger, °C,
f - the scaling factor, W/MCi.



№ meas	1	2	3	4	5	6	7	8	9	10	A_0, MCi	$T_{1/2}$, d
Date, time	15.07.19 23-56	26.07.19 03-23	05.08.19 00-20	14.08.19 23-16	25.08.19 01-02	03.09.19 23-05	13.09.19 23-58	23.09.19 23-45	03.10.19 23-58	13.10.19 23-34	05.07.19 14-02	
A_3, MCi	2.62787	2.03809	1.59378	1.24188	0.96523	0.75319	0.58569	0.45556	0.35587	0.27699	3.4099 ±0.0005	27.709

NEUTRINO SOURCE ACTIVITY

№ meas	1	2	3	4	5	6	7	8	9	10	A_0, MCi	$T_{1/2}$, d
Date, time	15.07.19 23-56	26.07.19 03-23	05.08.19 00-20	14.08.19 23-16	25.08.19 01-02	03.09.19 23-05	13.09.19 23-58	23.09.19 23-45	03.10.19 23-58	13.10.19 23-34	05.07.19 14-02	
A_1, MCi	2.62362	2.03722	1.59104	1.23251	0.96249	0.75133	0.58438	0.45531	0.35423	0.27582	3.403 ±0.002	27.666
A_2, MCi	2.62824	2.04044	1.59542	1.24415	0.96671	0.75386	0.58634	0.45561	0.35464	0.27580	3.4125 ±0.0009	27.723
A_3, MCi	**2.62787**	**2.03809**	**1.59378**	**1.24188**	**0.96523**	**0.75319**	**0.58569**	**0.45556**	**0.35587**	**0.27699**	**3.4099 ±0.0005**	**27.715**

The neutrino source activity, taking into account the uncertainty of heat release (0.015%) and energy release (0.23%) was on 14-02 05.07.2019

3.410 ± 0.008 MCi

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PHOTON SPECTRUM FROM NEUTRINO SOURCE