FABRICATION of REACTOR TARGET from ENRICHED 50Cr for ARTIFICIAL NEUTRINO SOURCE

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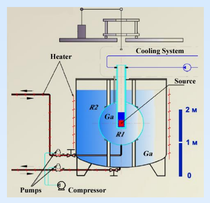
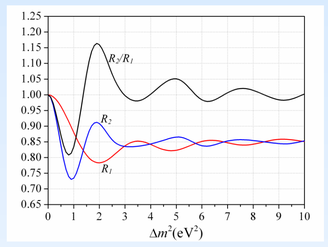
The current state of fabrication of the enriched 50Cr target for the artificial 51Cr neutrino source with activity > 3 MCi for the experiment BEST is presented. The processes of obtaining a target in the form of disks with a thickness of 4 mm and a diameter of 84 and 88 mm required to achieve the necessary activity using the reactor SM-3 are considered, including: enrichment of natural chromium in the form of oxyfluoride by gas centrifugation, electrolytic reduction and refining of metallic chromium, as well as the formation of chromium disks by spark plasma sintering.

Baksan Experiment on Sterile Transitions (BEST)



$$P_{ee} = 1 - \sin^2 2\theta \sin^2(1.27\Delta m^2(\mathrm{eV}^2)\frac{\mathrm{L(m)}}{\mathrm{E\,(MeV)}})$$



Ratio of measured capture rate to predicted rate in the inner (*R1*) and outer (*R2*) zones and their ratio *R2/R1* as a function of Δm^2 for the case of $\sin^2 2\theta = 0.3$.

Two-zone Ga detector:

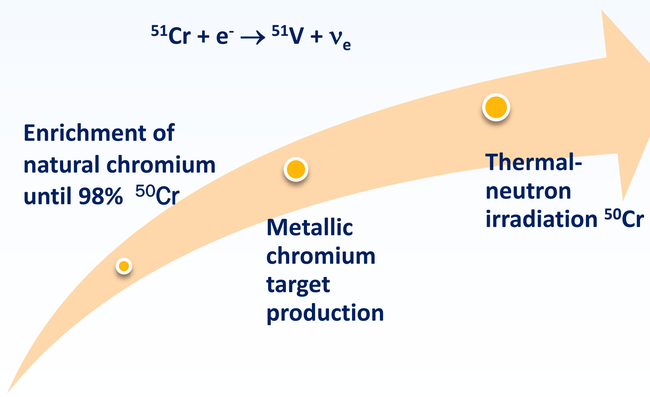
50 т metallic Ga
Masses of the zones:
7.5 t and 42.5 t
Path length in each zone:
<L> = 55 cm

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

Stages of ^{51}Cr source fabrication

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



	Natural Cr
^{50}Cr	4,35 %
^{52}Cr	83,79 %
^{53}Cr	9,50 %
^{54}Cr	2,36 %

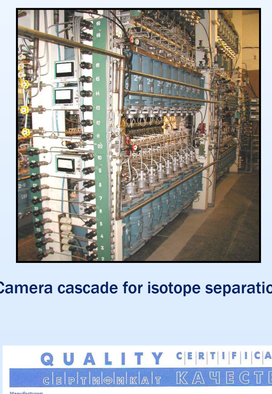
^{50}Cr enrichment of natural chromium in the oxyfluoride (CrO_2F_2) form using by the gas centrifugation.

CrO_2F_2 properties

- rather high saturation vapor pressure at room temperature (> 5-10 mm Hg);
- inactivity with respect to equipment materials;
- existence of the only one stable isotope of oxygen and fluorine;
- thermal and chemical stability (no transition in nonvolatile substances)

CrO_2F_2 Production

370 kg of oxyfluoride (99,97%) was synthesized by the technology created in the National Research Center "Kurchatov Institute", which is based on the reaction of molecular fluorine with chromium trioxide at elevated temperature in the flow system.



^{50}Cr Enrichment

The Joint Stock Company “Production Association “Electrochemical Plant” (JSC “PA ECP”) Zelenogorsk, Krasnoyarsk region

Camera cascade for isotope separation


QUALITY CERTIFICATE
сертификат КАЧЕСТВА
Manufacturer: Stock Company «Production Association «Electrochemical Plant»
Производитель: Акционерное общество «Производственное объединение «Электрохимический завод»
ECP
Performer of analysis: Stock Company «Production Association «Electrochemical Plant» Central Analytical Laboratory JSC «PO «Electrochemical Plant»
Исполнитель анализа: Центральная заводская лаборатория АО «ПО «Электрохимический завод»

CERTIFICATE No. 53/5000
СЕРТИФИКАТ №

Name of Product: Chrome enriched in stable isotope Cr-50, as chromic anhydride
Наименование продукта: Хром, обогащенный по стабильному изотопу Cr-50, в виде хромового ангидрида

Contract No. 13/8178-Д
Договор №
Lot No. 3703
Партия №
Addendum No.
Доп. соглашение №
Packages № 1÷4
Упаковки №№

CHARACTERISTICS OF PRODUCT
ХАРАКТЕРИСТИКИ ПРОДУКТА

1. Weight of Product CrO_3
Масса продукта
Net weight* 4485.31 g Element weight 2271.00 g
Масса нетто Масса элемента

2. Isotopic composition Cr
Изотопный состав

Isotopes Изотопы	50	52	53	54
Atomic fraction, % Атомная доля, %	98.19	1.80	0.005	0.005

3. Remark: Radiologically safe
Примечание: Не радиоактивный
Mass fraction of chromic anhydride ≥ 99.2 %
Массовая доля хромового ангидрида
Mass fraction of F < 0.030 %
Массовая доля фтор-иона


QUALITY CERTIFICATE
сертификат КАЧЕСТВА
Manufacturer: Stock Company «Production Association «Electrochemical Plant»
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ECP
Performer of analysis: Stock Company «Production Association «Electrochemical Plant» Central Analytical Laboratory JSC «PO «Electrochemical Plant»
Исполнитель анализа: Центральная заводская лаборатория АО «ПО «Электрохимический завод»

CERTIFICATE No. 53/4999
СЕРТИФИКАТ №

Name of Product: Chrome enriched in stable isotope Cr-50, as chromic anhydride
Наименование продукта: Хром, обогащенный по стабильному изотопу Cr-50, в виде хромового ангидрида

Contract No. 13/8178-Д
Договор №
Lot No. 3702
Партия №
Addendum No.
Доп. соглашение №
Packages № 1÷4
Упаковки №№

CHARACTERISTICS OF PRODUCT
ХАРАКТЕРИСТИКИ ПРОДУКТА

1. Weight of Product CrO_3
Масса продукта
Net weight* 4389.53 g Element weight 2229.00 g
Масса нетто Масса элемента

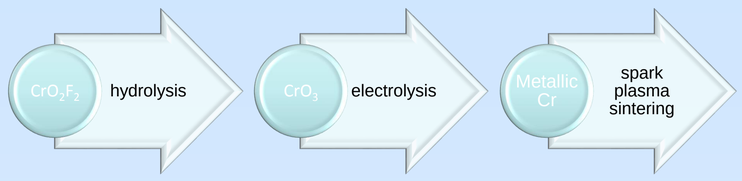
2. Isotopic composition Cr
Изотопный состав

Isotopes Изотопы	50	52	53	54
Atomic fraction, % Атомная доля, %	98.725	1.26	0.01	0.005

3. Remark: Radiologically safe
Примечание: Не радиоактивный
Mass fraction of chromic anhydride ≥ 99.5 %
Массовая доля хромового ангидрида
Mass fraction of F < 0.030 %
Массовая доля фтор-иона

$M(CrO_3)$ – 8874,84 g
$M(Cr)$ – 4499,00 g

Metallic chromium production

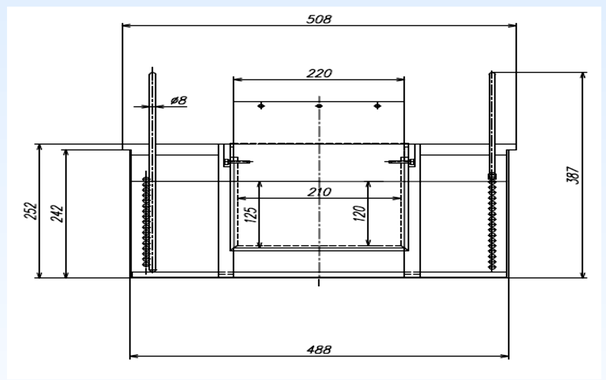


$CrO_2F_2 + H_2O \rightarrow CrO_3 + 2HF$
(JSC “PA ECP”)

water solution of sulphuric acid (INR RAS)

- thermal refinement in hydrogen (JSC “POLEMA”)
- chips grinding (FSUE “IREA”)
- spark plasma sintering (MSTU “STANKIN”)

Electrolysis of CrO_3



Electrolyzer – water-cooled titanic cell with lead anode and steel cathode.

- Electrolyte composition: aqueous solution CrO_3 and H_2SO_4.
- I - 30-40 A, U - 4,5-6 V, T - 18-23 ºC
- Average efficiency – 15 g/h.
- 4 kg metallic chromium will be obtained in 2 weeks.

Electrolytic chromium flakes (unrefined)

Thermal refinement in high purity hydrogen

Temperature refinement:	1300±100 °C.
Hydrogen consumption:	1,5 m^3 per 1 kg Cr.
Phydrogen dew point:	63 °C.
Metallic chromium yield:	97,8%

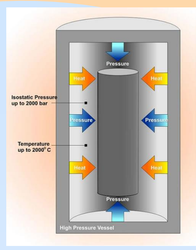
Electrolytic chromium flakes (refined)

Element	Critical concentration, ppm	Concentration before anneling, ppm	Concentration after anneling, ppm
C		26	31
N		50	20
O		5400	22
Na	1	5.0	12.0
Ca	80	< 2.0	2.0
Sc	0.5	< 0.5	< 0.5
Ti	8	2.8	2.5
Fe	50	50	90
Co	0.3	< 0.1	< 0.05
Cu	10	< 1.0	1.2
Zn	5	< 1.0	2.1
Ga	5	< 0.5	< 0.2
Y	0.5	< 0.2	< 0.2
Ag	0.5	< 0.05	< 0.05
Cd	5	< 0.05	< 0.05
Sb	2	16.0	5.7
La	0.1	< 0.05	< 0.05
Ta	0.5	< 0.05	< 0.05
W	10	1.0	< 1.0
Th	0.5	< 0.05	< 0.05
U	50	< 0.05	< 0.05

Grinding of flakes of refined metal chromium will be carried out in IREA using a mechanical mortar RM200 to a powder with a particle size of up to 500 microns.

Chromium powder pressing

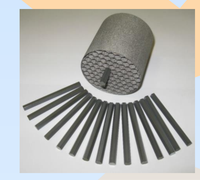
(previously proposed technology)



HIP uses the high isotropic pressure (160 Mpa) at temperature (1220°C) (below melting temperature) to compact metal powder by means of the plastic deformation and diffusion bonding.

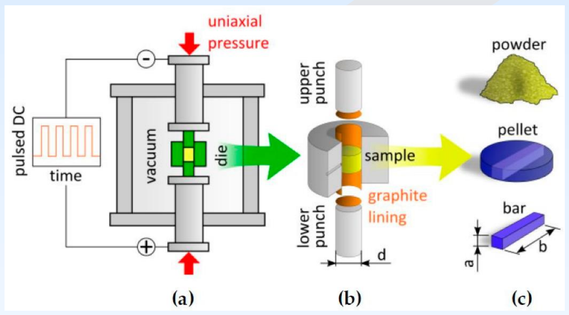
Chromium bar after HIP and mechanical operation

Electrical discharge machining of Cr bar

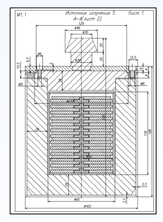


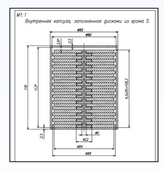
Chromium hexagonal rods and titanium separator

Spark plasma sintering



The process uses pulsed high electrical current to rapidly heat a conductive powder under simultaneous uniaxial pressure. With no heating elements extremely rapid heating and cooling of the sample is possible, enabling high density materials to be sintered with ultra-fine or even nano-sized grain structures.

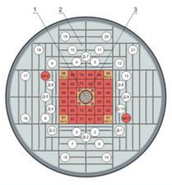




Neutrino source:
26 chrome disc assembly with a thickness of 4 mm and a diameter of 84 and 88 mm (with inner hole diameters of 6 and 22 mm, respectively) in sealed steel container and biological tungsten shielding.

Thermal-neutron irradiation ^{50}Cr

High-Flux Reactor SM JSC «SSC RIAR», Ulyanovsk region, Dimitrovgrad

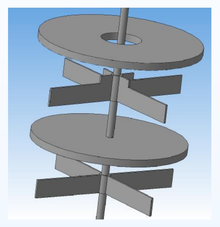


Core arrangement

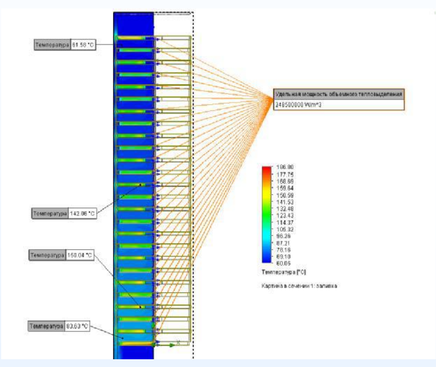
thermal neutron flux in central core – up to 5.0×10^{15} neutron/($sm^2 \cdot s$)

irradiation time - 75 days.

The maximum total activity of 26 ^{51}Cr disks with total mass about 4 кг - 3.9 MKi.



Part of irradiation fitment with chrome discs



The design of the irradiation fitment provides acceptable cooling conditions and simplifies the process of assembling the source.

Conclusions

- The design of the artificial neutrino source based on 51Cr for BEST project was developed. Neutrino source will be consisted of 26 chromium disks in sealed steel container and biological tungsten shielding.
- Technology of 51Cr source production includes the stages of natural chromium enrichment, production of metal chromium target and irradiation with thermal neutrons.
- Currently, the gas centrifugation of CrO_2F_2 was carried out and 50Cr enrichment is 98%.
- Technology of metal chromium target fabrication (electrolytic metal chromium reduction, thermal refinement in hydrogen, chips grinding, spark plasma sintering of metal disks) is developed and tested.