Production of ^{83}Rb for calibration sources for dark matter and neutrino mass experiments

M. Šefčík, D. Vénos, R. Běhal, O. Dragoun, O. Lebeda, D. Seifert, J. Ráliš
Nuclear Physics Institute, Czech Academy of Sciences, 250 68 Řež, Czech Republic

Motivation

The isomeric state ^{83m}Kr ($T_{1/2}$ = 1.8 h) produced in the decay of the isotope ^{83}Rb ($T_{1/2}$ = 86.2 d) decays to the stable ground state of ^{83}Kr through a cascade of the 32.5 and 9.4 keV electromagnetic transitions.
The well known low energy monoenergetic electrons of internal conversion of these transitions are suitable for the test, calibration and systematic measurements of the detector systems used in the dark matter [1] and neutrino mass [2] experiments. The gaseous ^{83m}Kr is also used for the calibration of the Transition Radiation Detector in A large Ion Collider Experiment (ALICE) in CERN.

^{83}Rb production

The mother isotope ^{83}Rb is produced in the reaction of protons on the natural krypton gas. The abundances for A = 78, 80, 82, 83, 84, 86 amounts to 0.36, 2.3, 12, 12, 57, 17 %, respectively. The main contributing reaction is ^{84}Kr(p,2n)^{83}Rb. The excitation function for the formation of the ^{83}Rb on the natural krypton is presented in Fig. 1.
Smaller amounts of the accompanying radioactive isotopes ^{84}Rb ($T_{1/2}$ = 33 d) and ^{86}Rb ($T_{1/2}$ = 19 d) do not disturb in the ^{83m}Kr application because the intensity of their low energy electrons is weak.
For the irradiation of natural krypton with protons at the NPI cyclotrons a pressurised gas target is used.

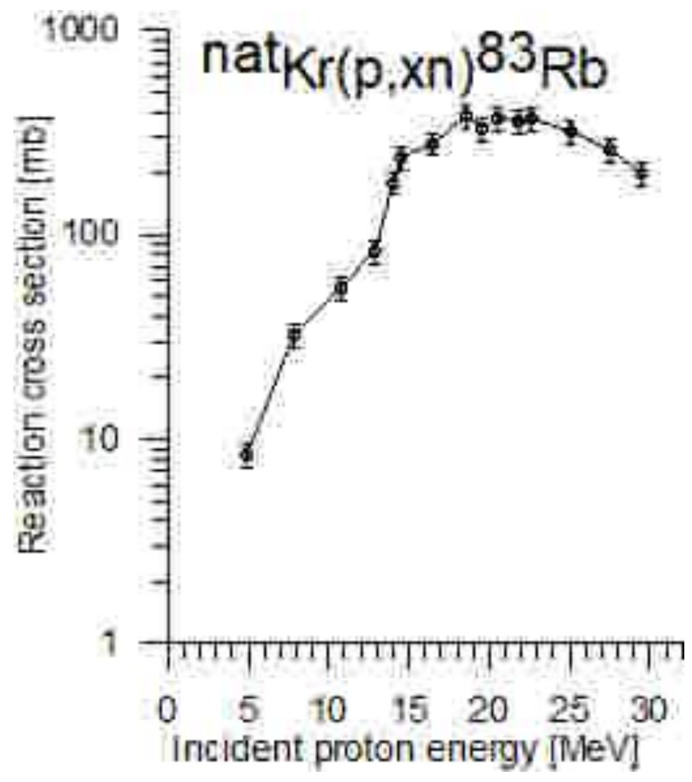

Fig. 1.^{83}Rb excit. function [3].

Further improvements of ^{83}Rb production

Up to now the most efficient target T4 was successfully used for the 12, 13 and 2 hour irradiations in which 1.7, 1.9 and 0.3 GBq of ^{83}Rb were produced. The share of ^{84}Rb and ^{86}Rb activities was 54% and 16%, respectively.
Further steps for production optimization:

- target length - to reduce ^{84}Rb and ^{86}Rb production,
- alloy with less Fe and Ni - to decrease the contamination with radioactive Co isotopes,
- try to irradiate at 25 MeV at TR-24 (needs a special cyclotron regime) - to reduce ^{84}Rb and ^{86}Rb production,
- larger defocusing of the proton beam at the target input windows to reduce their local thermal load.

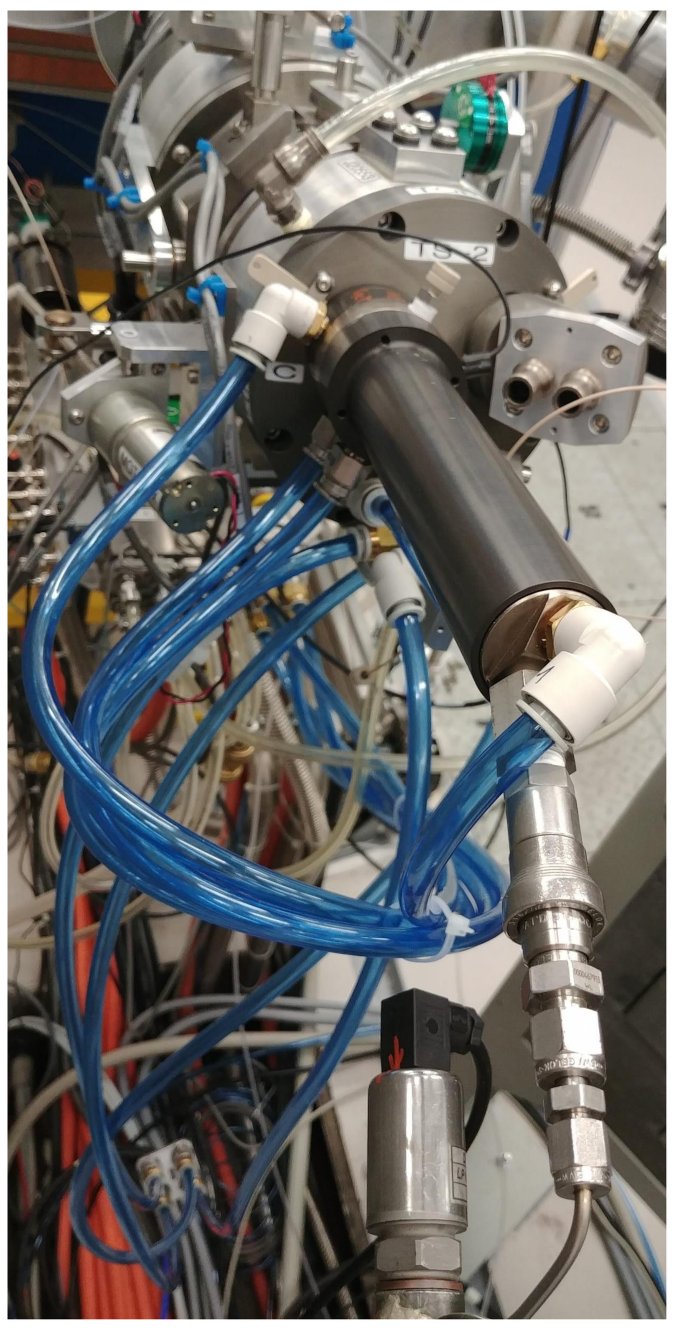

Fig. 3. Target T4 attached to TR-24 cyclotron Blue tubes – water (target body) and He (input windows) cooling, Black cable – proton current measurement, Cylindrical gauge – krypton pressure measurement

KATRIN and xenon experiments

At KATRIN, the ^{83m}Kr electrons are used to investigate the properties of the windowless gaseous tritium source and high-energy-resolution electrostatic electron spectrometers with adiabatic magnetic collimation, as well as to calibrate the measurements of the high voltage and monitor its stability.
Altogether 4 types of the electron sources based on ^{83m}Kr were developed and used in the neutrino mass experiment KATRIN: GKrS - Gaseous Krypton Source, IKrS - Implanted Krypton Source, CKrS - Condensed Kr source, EKrS - vacuum Evaporated Krypton Source.
At XENON dark matter experiment the ^{83m}Kr is dispersed in all regions of the xenon liquid detector enabling the uniform calibration of the energy scale. In this case the GKrS is used.

Targets development

For the cyclotron U-120M (E_p=26.5 MeV, I_p=15 µA), gradually three types of the targets from the aluminium alloy were developed and used within the period 2006-2020:

- T1 (water cooling, krypton pressure 7.5 bar, proton current 6 µA, rate 14 MBq/hour of ^{83}Rb, 8 irradiations accomplished),
- T2 (water + helium cooling of the proton input window, 13 bar, 15 µA, rate 52 MBq/hour, 21 irradiations),
- T3 (water+helium cooling, centering electrodes, 13 bar, 15 µA, rate 50 MBq/hour, 4 irradiations).

For the new cyclotron TR-24 (E_p=24 MeV, I_{pmax}=45 µA), the forth target was developed within the period 2019-2020:

- T4 (water+helium cooling, 10 bar, 45 µA, rate 150 MBq/hour, 3 irradiations).

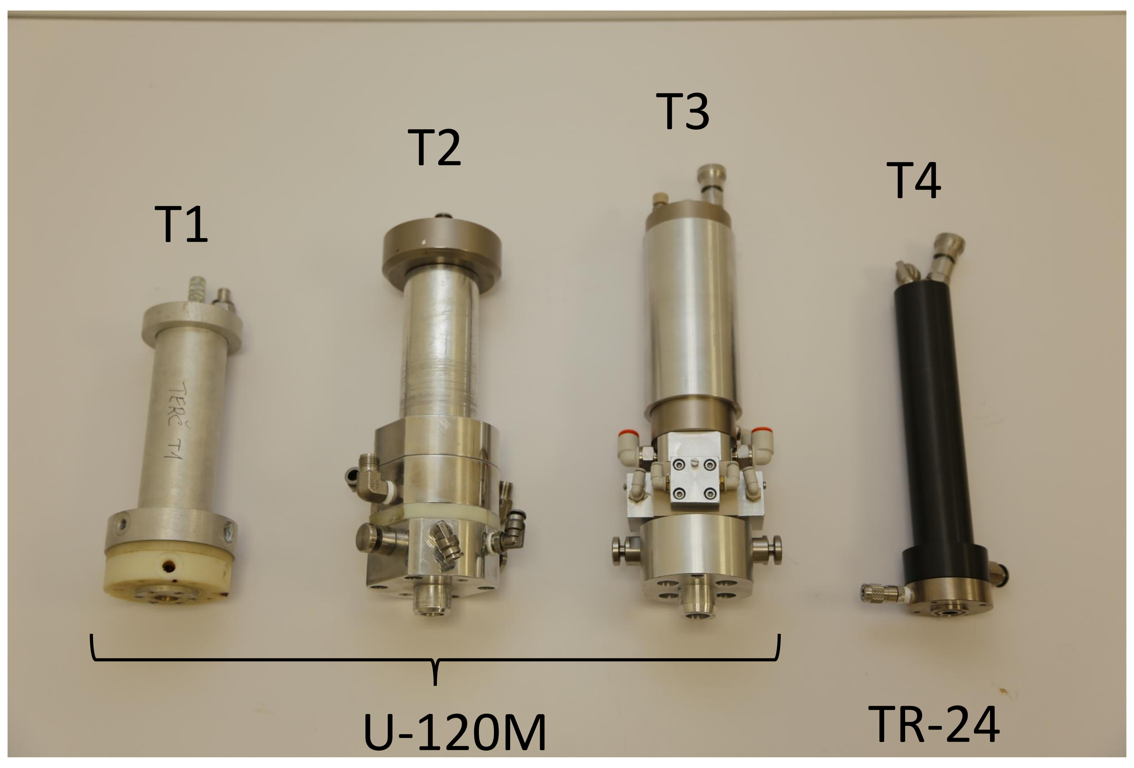

Fig. 2. Targets

References

[1] W.X. Xiong, M.Y.Guan, C.G. Yang, P. Zhang, J.C. Liu, C. Guo, Y.T. Wei, Y.Y. Gan, Q. Zhao, J.J. Li, *Calibration of liquid argon detector with ^{83m}Kr and ^{22}Na in different drift field*, arXiv 1909:02207v1, 5 Sep 2019.
[2] M. Arenz, W.J. Baek, M. Beck et al. (KATRIN collab.), *First transmission of electrons and ions through the KATRIN beam line*, JINST **13**(2018) No.4 P04020.
[3] Z. Kovacs, F. Tarkányi, S.M. Qaim, G. Stöcklin, *Excitation functions for the formation of some radioisotopes of rubidium in proton induced nuclear reactions on ^{nat}Kr, ^{82}Kr and ^{83}Kr with special reference to the production of ^{81}Rb(^{81m}Kr) generator radionuclide,* Appl. Radiat. Isot. 42(1991)No.4 392.

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