Spectroscopic measurements of L X-rays with a TES microcalorimeter for a non-destructive assay of transuranium elements

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Introduction

Spectroscopic measurement of L X-ray is one of important techniques for a **non-destructive assay** of transuranium (TRU) elements because L X-rays of the energy ranging from 10 keV to 25 keV are emitted following internal conversion after the α-decay of TRU elements. High purity germanium (HPGe) semiconductor detectors have been used in spectroscopic measurement of L X-rays emitted from TRU elements so far. However, the accurate identification of L X-ray peaks is difficult due to the insufficient energy resolution of the HPGe detector. For identification of L X-ray peaks of TRU elements, the energy resolution of the detector is required to be **lower than 100 eV of the full width at half maximum (FWHM)**.

Recently, transition-edge-sensor (TES) microcalorimeters have been developed for measuring X-rays and gamma-rays with ultra-high energy resolution. We had previously fabricated a TES microcalorimeter for spectroscopic measurements of L X rays emitted from TRU elements. In this work, the TES microcalorimeter was employed for spectroscopic measurements of L X rays emitted from **Np–237 and Cm–244 sources** of typical TRU elements.

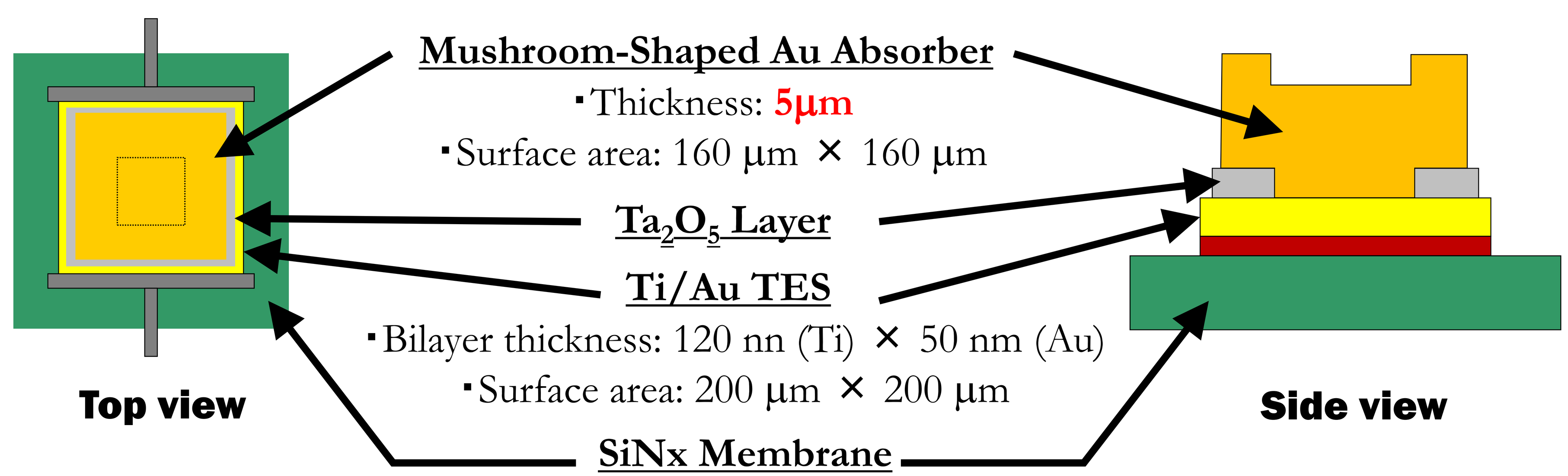
Energy of L X-ray photons emitted from Np-237 and Cm-244

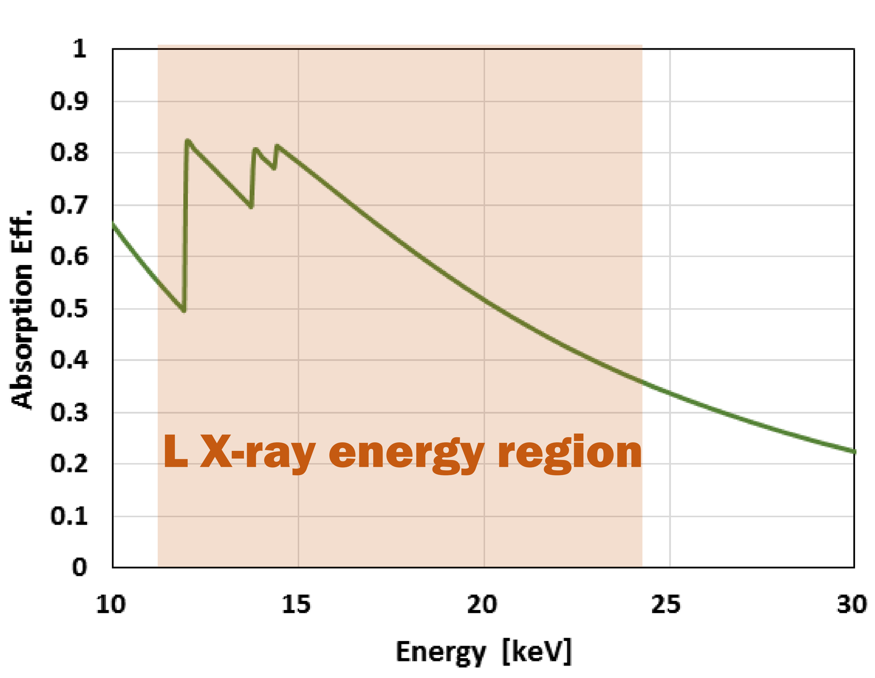
L X-ray	Np-237	Cm-244
$L_{\alpha 2}$	13.13	14.09
$L_{\alpha 1}$	13.29	14.28
$L_{\beta 2,15}$	16.01	17.24
$L_{\beta 4}$	16.10	17.56
$L_{\beta 5}$	16.64	17.95
$L_{\beta 1}$	16.71	18.30
$L_{\beta 3}$	16.93	18.54
$L_{\gamma 1}$	19.57	21.42
$L_{\gamma 6}$	20.22	22.15

Materials and Methods

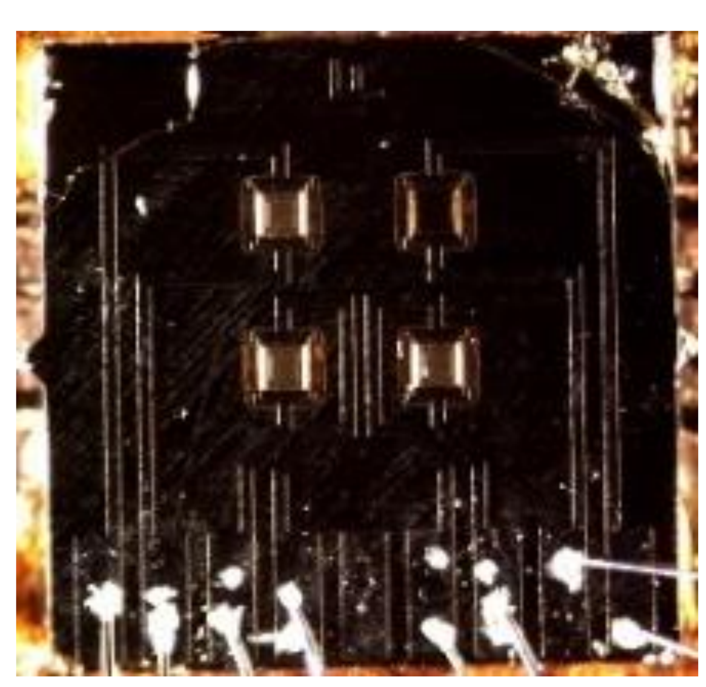
4 pixel TES microcalorimeter

The TES sensor comprised a bilayer of Au and Ti, and its superconducting transition temperature was approximately 130 mK. Due to its sufficient absorption efficiency, a **5-μm-thick Au absorber** that provides **an absorption efficiency of 35%–80%** with an energy range of 10–25 keV was deposited on the TES. The absorber shape was similar to a **"mushroom"** so as to minimize the effect of the dependence on the energy deposition position in the absorber.





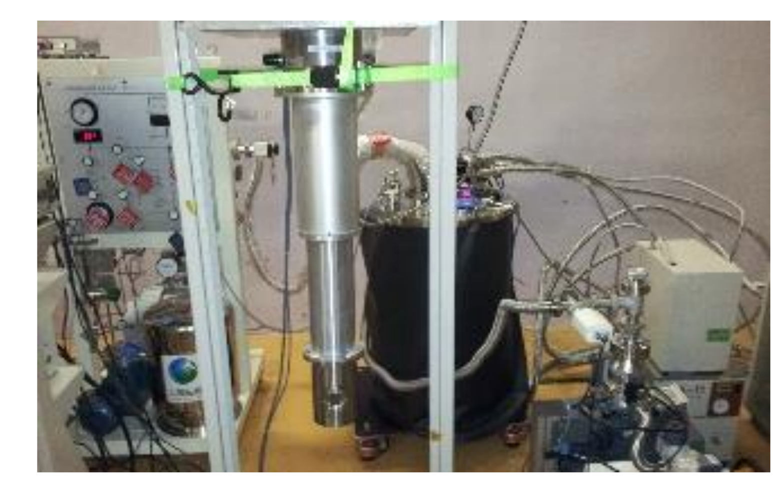
Absorption Efficiency of 5μm Au



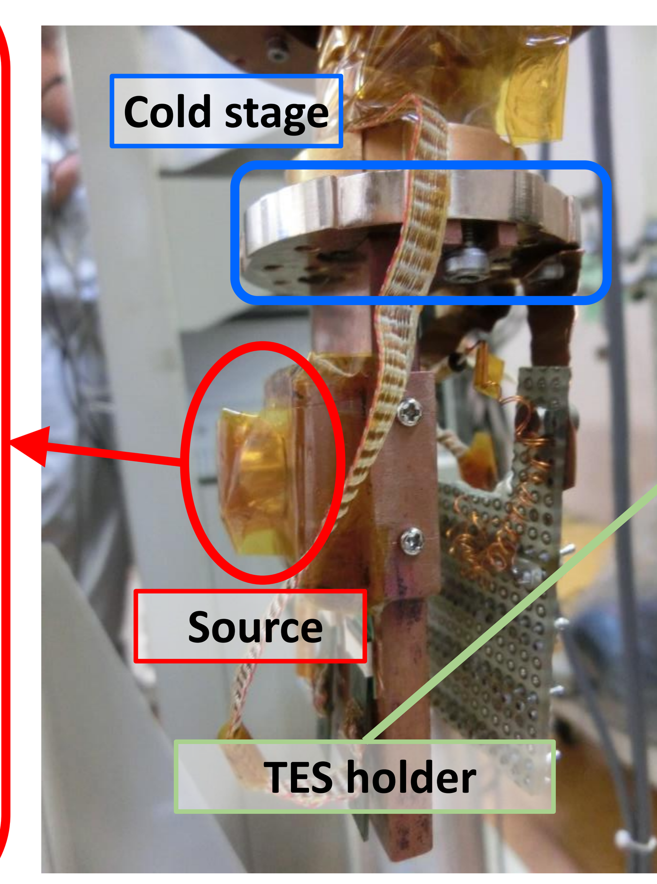
4-pixel TES microcalorimeter chip

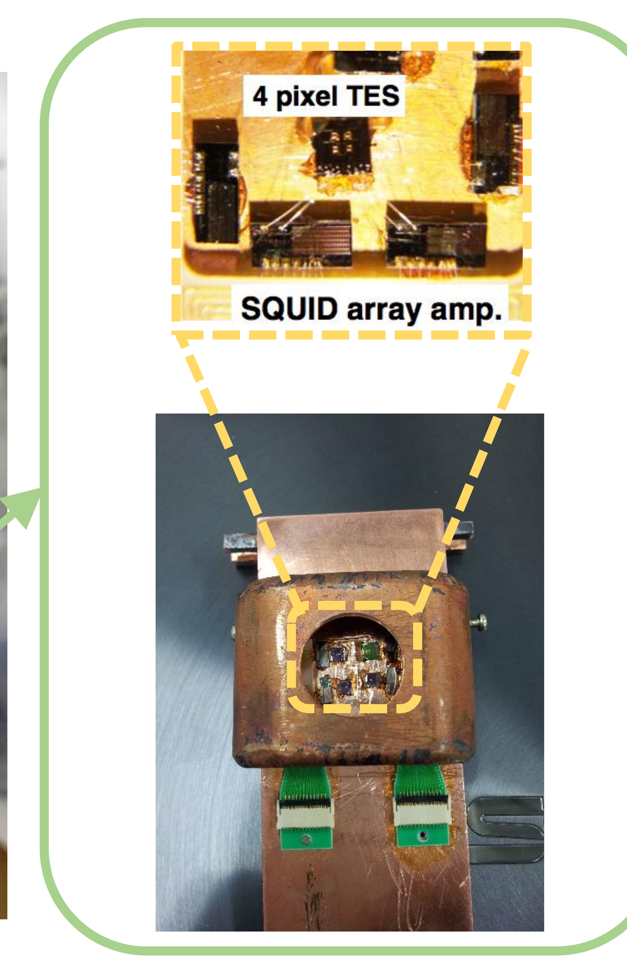
Experimental setup

Because it is difficult to use liquid helium in a laboratory for handling TRU elements, a Gifford-McMahon cryocooler split-type **dry ^3He-^4He dilution refrigerator** using a remote helium cooling loop system was employed to maintain the operating temperature of the TES microcalorimeter.



- Electrodeposited source
- Active Diameter: 5mm
- Backing: Platinum
- Cover: 100μg Am/cm²



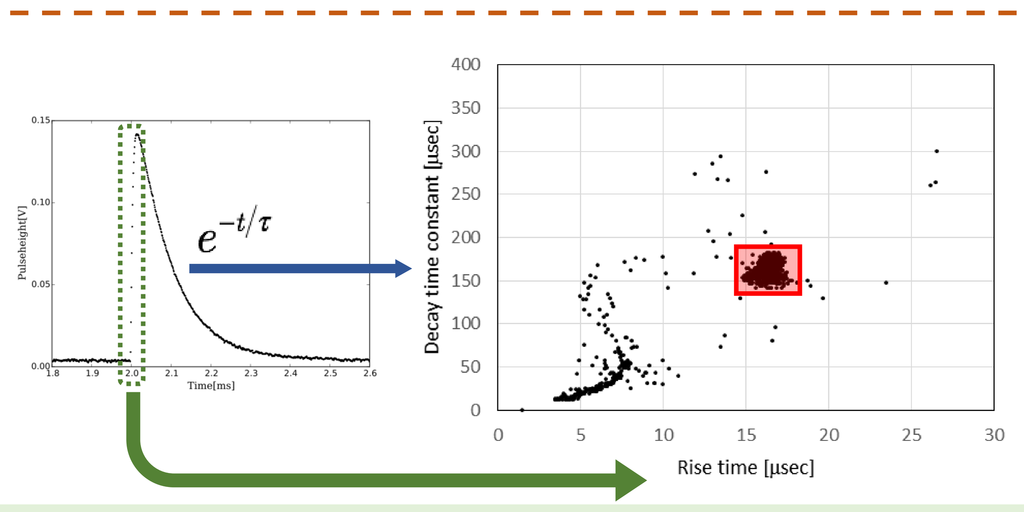


The four pixel TES microcalorimeter and the SQUID array amplifier chips were glued on the holder attached to the cold stage of the dilution fridge. For spectroscopic measurements of L X rays emitted from **Cm-244 and Np-237 sources**, electroplated radioactive sources were used for placing inside the vacuum chamber of the fridge. The surface of the source was covered with a polyimide tape for stopping alpha particles.

Result

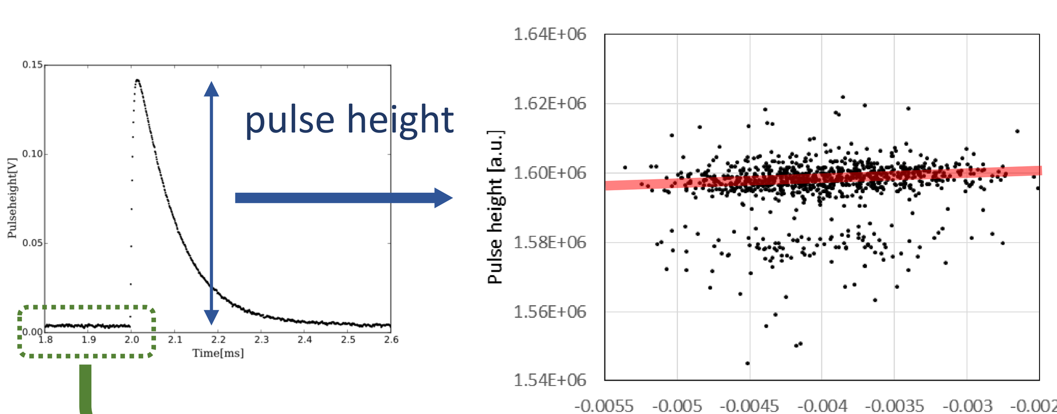
Flow of pulse analysis

- Accumulated pulse data
- ⇩ **Pulse shape selection**
- ⇩ Optimal filter method
- ⇩ **Correction of temperature fluctuation**
- ⇩ Pulse-height spectrum
- ⇩ Peak search & identification
- ⇩ **Energy calibration**
- ⇩ Energy spectrum



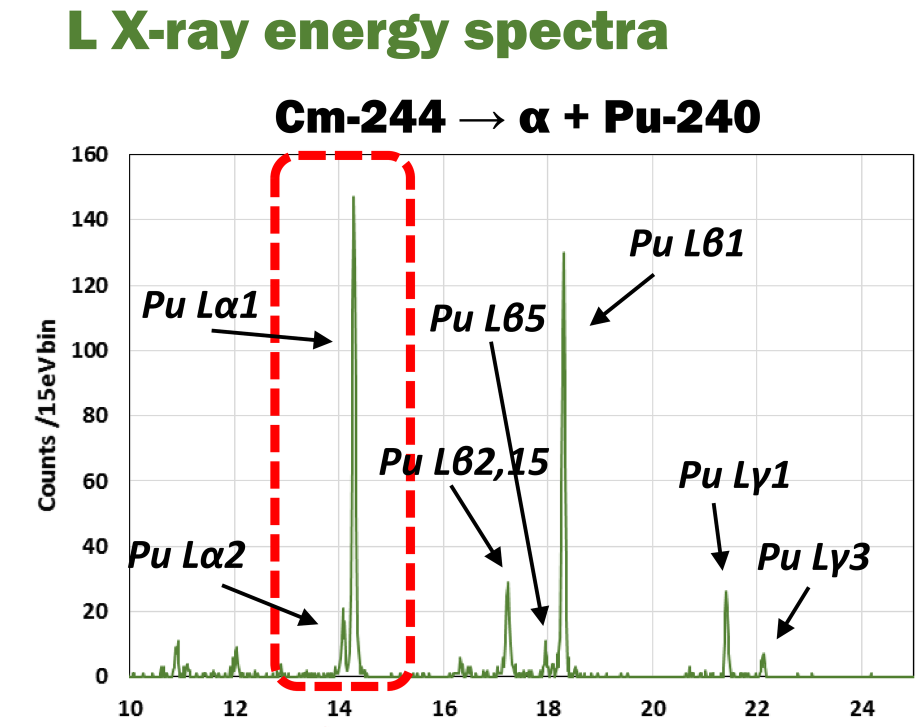
The relationship between the rise time and decay time constant

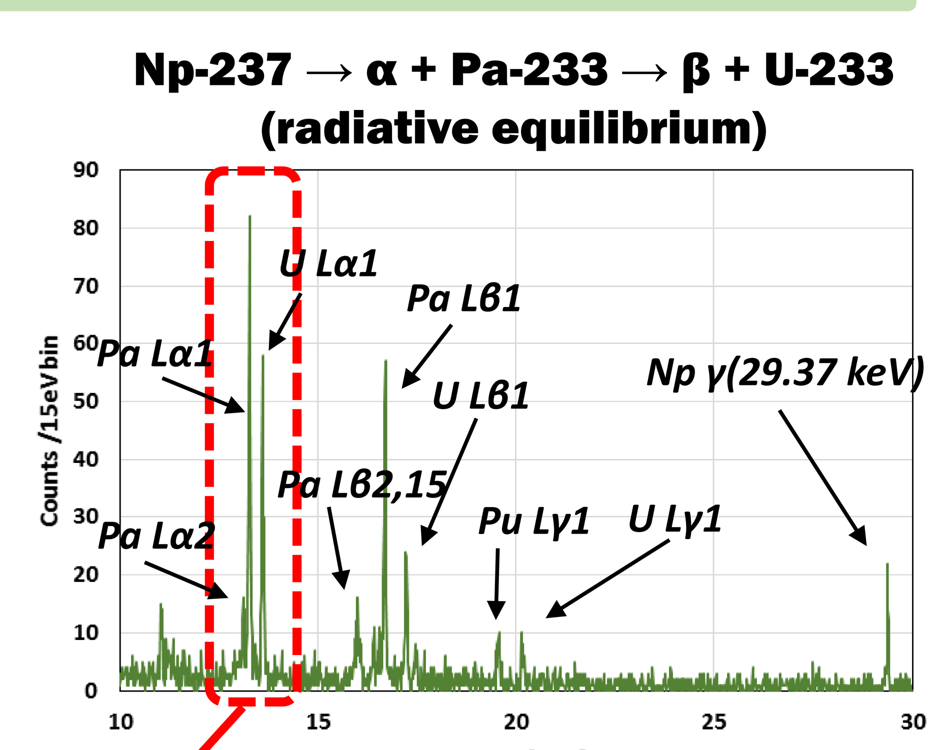
- **The events in red colored area: Absorber events**
- The others: Abnormal events such as TES events

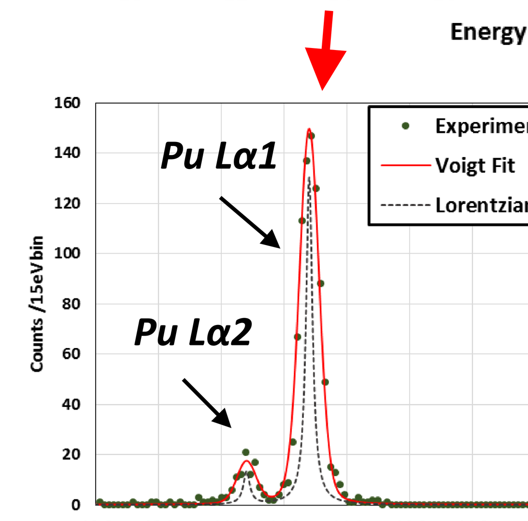


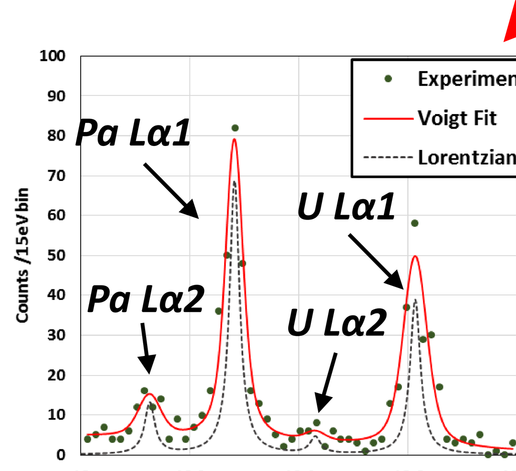
A bath temperature fluctuation was observed in the long-term operation of the fridge. Since the TES operation temperature depends on the bath temperature, the bath temperature fluctuation affects the TES sensitivity. ***The base-line voltage of the signal pulse indicates the operating temperature of TES.*** Therefore, we corrected the signal pulse height by using the base line voltage.

L X-ray energy spectra









Nuclide	L X-ray	Energy [keV]	Natural width [eV]	ΔE_{FWHM} [eV]
Cm-244	Pu $L_{\alpha 2}$	14.09	12.27	63.8
	Pu $L_{\alpha 1}$	14.28	12.20	69.5
Np-237	Pa $L_{\alpha 2}$	13.13	11.16	43.2
	Pa $L_{\alpha 1}$	13.29	11.12	29.7
	U $L_{\alpha 1}$	13.62	11.47	45.4

Summary

A TES microcalorimeter with a 5-μm-thick Au absorber was fabricated to measure L X-rays emitted from TRU elements. L X-rays emitted by a Np-237 and Cm-244 sources were detected by operating the TES microcalorimeter. L X-ray energy spectra were obtained by analyzing detection signal pulses with high energy resolution below 100 eV at FWHM for L X-rays. We demonstrated high-precision L X-ray spectroscopic measurements using the TES microcalorimeter