MLF Experimental Report	提出日 Date of Report 2017.4.13
課題番号 Project No. 2016B0052 実験課題名 Title of experiment Investigation of excitations in Nd-based metallic materials exhibiting heavy-fermion natures 実験責任者名 Name of principal investigator Kazuaki Iwasa 所属 Affiliation Frontier Research Center for Applied Atomic Sciences & Institute of Quantum Beam Science, Ibaraki University	装置責任者 Name of responsible person Shinichi Itoh 装置名 Name of Instrument/(BL No.) BL12 (HRC) 実施日 Date of Experiment 2017.2.9 – 2.13 2017.2.21 – 2.26

試料、実験方法、利用の結果得られた主なデータ、考察、結論等を、記述して下さい。（適宜、図表添付のこと）
Please report your samples, experimental method and results, discussion and conclusions. Please add figures and tables for better explanation.

1. 試料 Name of sample(s) and chemical formula, or compositions including physical form.

$NdFe_4P_{12}$ single crystal

$NdRu_4P_{12}$ powder

$NdO_{0.5}F_{0.5}BiS_2$ powder

2. 実験方法及び結果（実験がうまくいかなかった場合、その理由を記述してください。）
Experimental method and results. If you failed to conduct experiment as planned, please describe reasons.

Filled-skutterudite compounds, $NdFe_4P_{12}$ (L. Keller et al., J. Alloys and Comp. **323-324**, 516 (2001)) and $NdRu_4P_{12}$ (H. Sugawara and C. Sekine, private communication, S. Masaki et al., PRB **78**, 094414 (2008)), exhibit ferromagnetic ordering at 1.9 and 1.6 K, respectively. The electrical-resistivity data of $NdFe_4P_{12}$ show an increment with decreasing temperature below approximately 20 K (H. Sato et al., PRB **62**, 15125 (2000)). This behavior is considered to be caused by the Kondo effect because the observed phenomenon is reproduced by a function of temperature, $-\log T$. A less significant anomaly in the resistivity was found for $NdRu_4P_{12}$ (T. Utsumi et al., Muroran Inst. Tech. Journal **49**, 93 (1999) (in Japanese)). We are also interested in $NdO_{0.5}F_{0.5}BiS_2$, which is a family of the layered BiS_2-based superconductors. The specific heat divided by temperature (C/T) reaches a high value of 7.5 J/(K^2 mol) at 0.3 K, and the magnetic susceptibility saturates in the low-temperature region (T. D. Matsuda, Y. Mizuguchi, Y. Aoki, private communication). In order to investigate electronic hybridization between rare-earth 4*f* electrons and conduction electrons in these compounds, we performed inelastic neutron scattering (INS) experiments at low-temperature region.

2. 実験方法及び結果（つづき） Experimental method and results (continued)

Figure 1 shows an intensity contour map in the Q–E space of $NdFe_4P_{12}$ at 5 K, which is obtained by subtracting the empty-sample-cell data from the sample measurement data. The incident neutron energy was 82 meV. A strong peak is located at 28 meV in the lower Q region below 3 Å^{-1}, This excitation is flat with respect to Q, and the intensity decreases with increasing temperature. Thus this excitation seems to be caused by magnetic scattering between crystalline-electric-field (CEF) levels. In addition, gradual change of scattering intensities in the same Q-region with decreasing the energy can be seen. These results may indicate that the broadening of the magnetic excitations in $NdFe_4P_{12}$, as a consequence of hybridization effect between the Nd 4f electrons and conduction electrons in the heavy-fermion (HF) state. On the other hand, we observed stronger intensities in the Q region above 3 Å^{-1}, which might be due to phonon contribution.

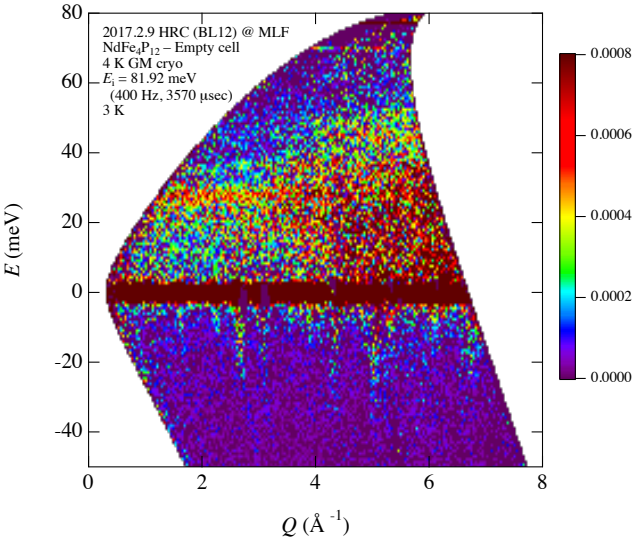

Fig. 1 Intensity contour map in the Q–E space of $NdFe_4P_{12}$ at 5 K.

Figure 2 shows an intensity contour map in the Q–E space of $NdO_{0.5}F_{0.5}BiS_2$ at 3 K. The incident energy was 51 meV. We observed Q-independent excitation peaks at 8.5 and 13 meV, the intensity of which decrease with increasing temperature. We also observed scattering intensities located at 23 meV, which are two-peak structure with respect to energy. The temperature dependence of this signal is not distinct between 3 and 100 K, but the Q-flat intensity is consistent with the CEF excitation. These excitations can be explained by transitions between the five CEF doublets expected from the local symmetry of the Nd ions in $NdO_{0.5}F_{0.5}BiS_2$. It is undertaken to identify the level scheme. In addition, spectral widths of these excitations are close to the instrumental resolution. This fact suggests that the 4f electrons are well localized to the Nd ion, in contrast to broad excitation peaks due to electronic hybridization often seen in conventional HF materials. It is attractive to investigate how the large value of C/T appears.

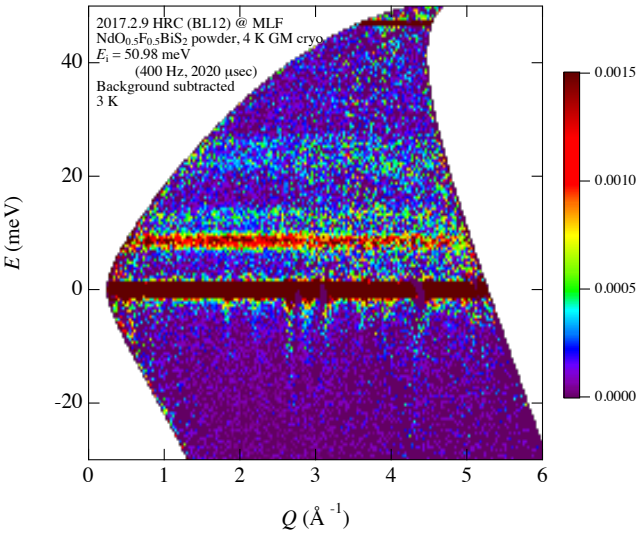

Fig. 2 Intensity contour map in the Q–E space of $NdO_{0.5}F_{0.5}BiS_2$ at 3 K.