FEASIBILITY STUDY FOR ACCELERATION OF FISSION FRAGMENTS WITH AVF CYCLOTRON

T. Itahashi and M. Kondo

Research Center for Nuclear Physics, Osaka University
Mihogaoka 10-1, Ibaraki, Osaka 567, Japan*

and

T. Yamagata

Department of Physics, Konan University, Higashinada, Kobe 658, Japan

ABSTRACT

This study demonstrates the possibilities to accelerate or decelerate fission fragments with a cyclotron using alpha particles from ^{241}Am. An ^{241}Am source (3.33×10^6 Bq) was positioned on a radially movable probe in the median plane of the AVF cyclotron. Matching condition in the transverse phase space for acceleration of alpha-particle was investigated by varing the radial position of the source in the cyclotron. Accelerated alpha particles were detected with a solid state nuclear detector at the first focal point in the beam transport line. The observed rate of alpha particles were less than 1/20 of that expected from an alpha source intensity. Total efficiency of the acceleration of alpha particles would be increased by optimization of the source geometry.

1. INTRODUCTION

Studies of exotic nuclei far from the stability (F.F.S.) are quite interesting in nuclear and astrophysics. These exotic nuclei are produced mainly via projectile fragmentation reaction with high energy heavy ion beam using various types of accelerators. For example LISE spectrometer in GANIL delivers various exotic nuclei for nuclear physics experiments and HISS at Bevalac in Berkeley delivers these beams of energy up to 2.1 GeV/nucleon[1,2]. Many new isotopes were discovered in these facilities and the mass and lifetimes of these exotic nuclei were measured.

On the other hand, very neutron rich nuclei have been investigated by using the primary fission of several spontaneous fissioning elements. Light and heavy fission fragments of ^{252}Cf are useful candidates to be explored in FFS region.

Study of the acceleration of such radio active nucleus has just started in several facilities ; Louvain-La-Neuve will deliver ^{13}N ions by using two cyclotrons, and ESR+SIS at GSI will offer the radio-active beam in quite wide energy range with synchrotron acceleration or deceleration technique[3,4].

We studied the possibilities to accelerate or decelerate the nuclei of fission fragments from the spontaneous fissioning elements by using AVF cyclotrons. Since cyclotron has an advantage for a stringent selection for mass to charge, for example, ^{106}Tc (q=43, m=106) from ^{252}Cf would be accelerated up to about 2000 MeV with the RCNP AVF cyclotron. As the first step, we try to accelerate alpha particle emitted from an ^{241}Am source.

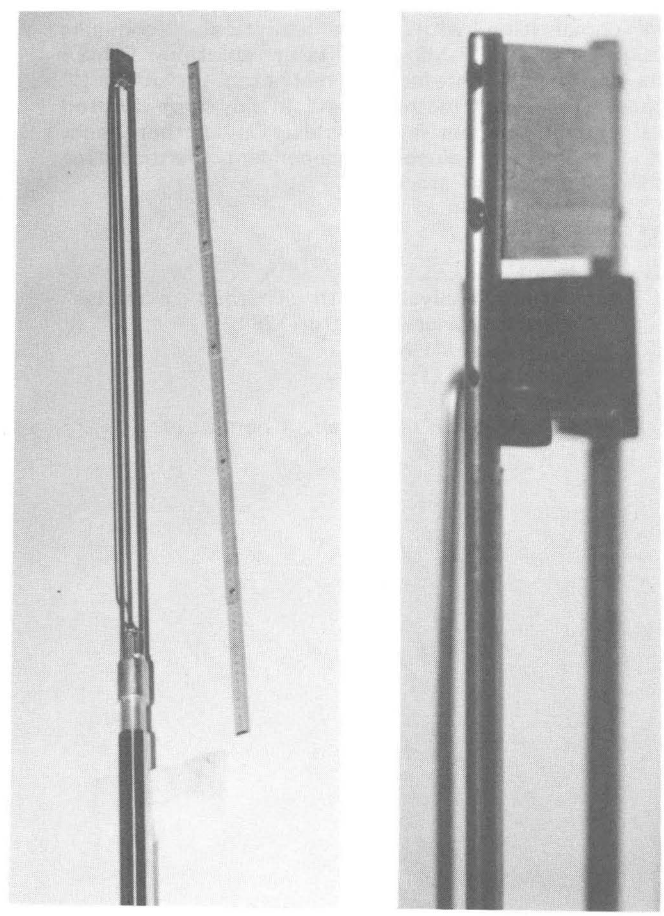


*Fig.*1. Photographs source-probe and source holder attached to the probe between two rods.

2. INSTRUMENTS

2.1 Accelerator

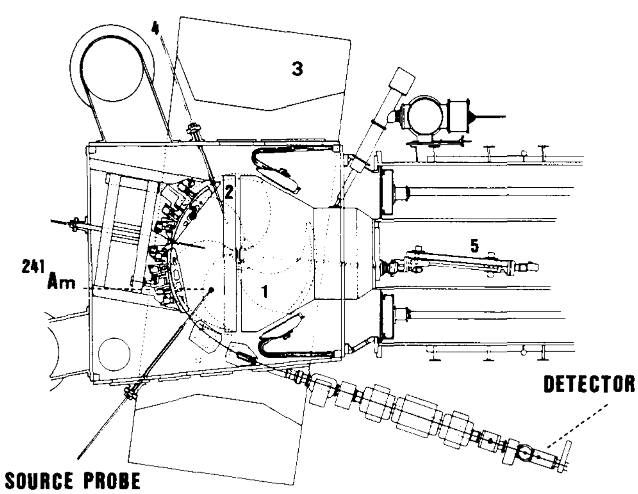
The cyclotron used for the present experiment is a three-sector single dee machine to accelerate various particles over a wide range of energies. The beam energy is available up to the magnet rigidity limit of 120 q^2/A MeV for all ions except for protons. The extraction radius is 100 cm and other specification is shown in the compilation of the cyclotrons[5].

2.2 Source

The alpha particles emitted from ^{241}Am (3.33×10^6Bq) was used as a source of the accelerator. The active source area of alpha's is 7×7 mm^2 and has overall dimension of $20\phi\times1.0$ (t) (mm) as a source backing. This source is housed in a holder with several types of source slits ; 8 mm ϕ aperture slit was placed at 7.5 mm from the source surface for this experiment.

2.3 Probe

Figure 1 shows the source holder fitted to the top of the probe and the probe stem; the alpha source holder is mounted between two solid rods to avoid beam hitting at the median-plane of the cyclotron. These rods are connected to the stem of the current probe (deflected-beam probe), at about 1 m apart from the source. The radial source position can be varied from 150 mm to the maximum cyclotron radius and azimuthal source angle can be tilted at the head of the rods. Median-plane plan dipicting the source position is shown in Fig. 2.



1-DEE ELECTRODE, 2-DUMMY DEE ELECTRODE, 3-YOKE, 4-INTERNAL PROBE, 5-DEE PROBE

*Fig.*2. Median-plane of the RCNP AVF cyclotron and the position of the source.

2.4 Detectors

For measurement of the extracted alpha particles, we used surface barrier solid state detector with 500 μm thick and 300mm^2 (ORTEC), while for the energy distribution measurement over a finite space, we used 20 mm $\times$ 20 mm two dimensional solid state position sensitive nuclear detector (Hamamatsu, S-2291). These are set just in front of the object slit of the extracted beam from the AVF cyclotron. Output signals of each detectector are amplified and delivered to the cyclotron operating room, and are analyzed by pulse height analyzers.

2.5 Source Position

The position of the source should satisfy the following condition: (1) The radial position in the cyclotron corresponds to the energy of the emitted alpha's. There are two branches of alpha decays, and their energies and branches are 5.485 MeV (85.2%) and 5.443 MeV (12.8%), so we set that position to the former branch; (2) It should be kept behind the dummy dee electrode to avoid the discharge between the dee electrode and the alpha source; (3) At its radius, the orbit separation should be more than 10 mm to clear the source backing by the next turn. Thus, we set the main magnetic field strength to the value corresponding to the extraction energy of the alpha particles of 30 MeV. Furthermore, we raise the acceleration voltage higher than the usual values by factor about two, because the orbit separation becomes 5 $\sim$ 6 mm within a routine parameter of the cyclotron and this value is not sufficient to the above requirement. To obtain this voltage we modified puller and ion source geometry.

The other important point is the source setting angle to the probe, since in the azimuthally varying field machine, the impinging angle of the beam to the probe changes with the radius as shown in Fig. 3. Around the radius of 300 mm, the impinging angle is estimated to be less than 1° from $\tan^{-1}$ (pr/p), where Pr means radial component of total kinematical momentum (p). Thus, we could neglect such a small angle and we set the surface of the source parallel to the beam probe.

2.6 Yield Estimation

Taking into account the acceleration efficiency and source intensity, we estimate the detection yield with a detector on the transfer line stated already. If we assume the values such as angular acceptance (ϵ_{solid}), r.f. phase acceptance ($\epsilon_{r.f.}$), extraction efficiency (ϵ_{ext}), detector efficiency (ϵ_{det}) and effective source area (ϵ_{source}), the total counts per second (n) is described as follows,

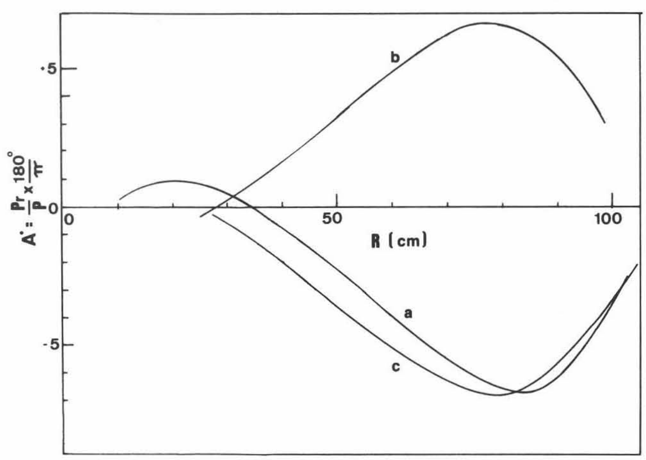


*Fig.*3. The impinging angle of the beam to the source-probe (c) as a function of its probe position. (a) and (b) are for the other beam probes. function of its probe position.

$$n = N_{source} \cdot \epsilon_{source} \cdot \epsilon_{solid} \cdot \epsilon_{r.f.} \cdot \epsilon_{ext} \cdot \epsilon_{det}$$

$$= 3.33 \times 10^6 \cdot \frac{1}{5} \cdot 10^{-3} \cdot 10^{-1} \cdot 10^{-1} \cdot 1$$

$$= 6.7 \times 10^0 counts/sec$$

where N_{source} is the source intensity measured with 2π-counter. Here, effective source area is estimated from the orbit separation; by $V_{acc} = 50$ kV, that value is 7 ~ 8 mm, then only about one fifth of the total emitted particles from the source can clear the source backing for the next turn of the accelerated particles.

3. EXPERIMENTAL RESULTS

Before the acceleration using the alpha source, the all parameters of the cyclotron were checked with the beam from the usual internal ion source; by raising the acceleration voltage, parameters both for the initial accerelation region and for beam extraction should be readjusted to get good extraction efficiency. By optimizing the position of ion source, puller and extraction electrodes and by adjusting the deflector voltage and valley coil current, the extraction efficiency is 10 ~ 15 % at the dee voltage twice as high as the usual value. There, however, remain structural problems to be optimized in the central region of the accelerator. By using the extracted faint beam the detector was calibrated in energy at the focal point of the transport line. It is noted that there remains the ability to produce alpha particles in 5 or 6 minutes just after turning off the arc and filament powers of the usual internal source. Thus, at more than 15 minutes after the power-off of the source, we successfully detected the accelerated and extracted alpha particles of 30 MeV with ^{241}Am source. The experimental summaries are as follows;

i) The detected alpha particles in two minutes at several values of the source-probe position is shown in Fig. 4, by adjoining two independent runs.

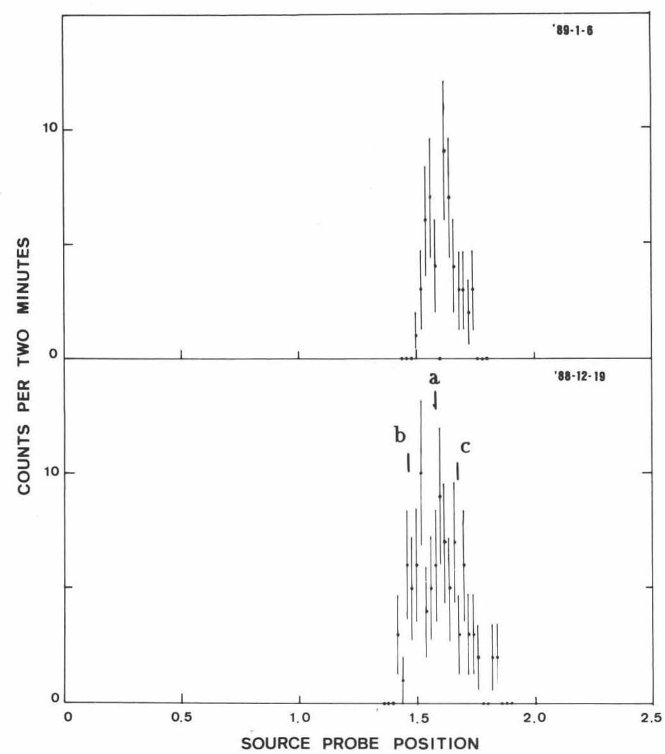


Fig.4. Yields in two minutes at several source- probe positions. The energy resolution of alphas's is measured at three different radial positions a), b) and c).

ii) The observed counting rate, however, is about 1/20 of the estimated counting rate in the previous section. This extremely lower value may come from the large ambiguity for ϵ_{solid}.

iii) The energy spectra of the detected alpha particles at three different radial source position with the same acceleration voltage are shown in Fig. 5. They show no large difference among them.

iv) About 25 % lower dee voltage than that used at the present detection measurement causes the larger decrease of the energy of the extracted particles; the difference between two peaks in the energy spectra is about 1.6 % as shown in Fig. 6. These are compared by varying only dee voltage without any change of other parameters. This comparison was made by using ^{241}Am source and usual ion source.

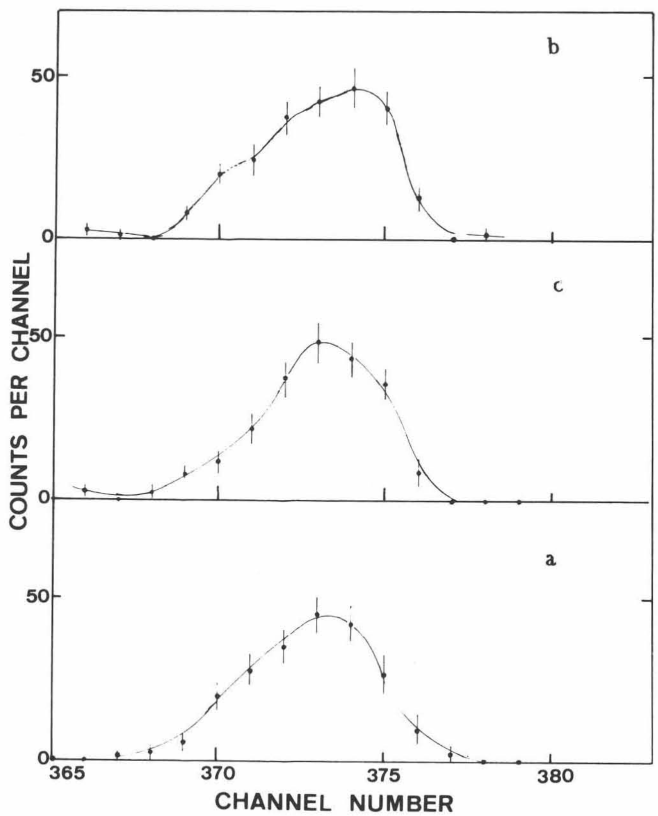


*Fig.*5. The energy spectra of detected alpha's at three radial source positions; a, b and c are shown in Fig. 4.

4. DISCUSSION AND SCOPE

To increase the acceleration efficiency, matching for the transverse phase space is crucial problem. The narrower source geometry would increase the effective source area. Total efficiency of the acceleration for alpha particles would be much improved by optimization of the source geometry and acceleration voltage.

Setting the source not only on the median-plane but also on the off-median-plane will be helpful to determine the transverse phase space matching. Finally, as additional resources, focusing device just in front of the exit slit would improve the capture efficiency of the accelerator so much.

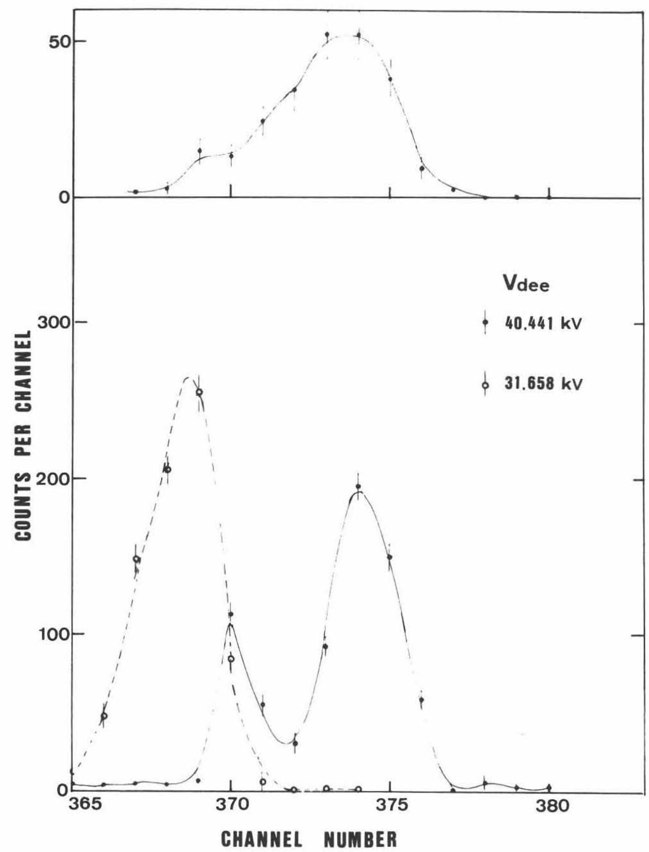


*Fig.*6. The comparison of the energy spectra by using ^{241}Am-α source and usual ion source.

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