## *Review of the experimental Research project using Radioactive Nuclear beams*

The committee wants to thank the director of IPNS and the spokespersons of the proposal for the good preparation of the meeting, the material sent before hand and the very detailed presentations made during the meeting. In the following we would like to focus our conclusions mostly on the 5 year proposal and after some general considerations make only some comments on the long term implication called "next-TRIAC".

### 1) INTRODUCTION

The final goal of the presented proposal is to understand the rapid neutron capture process nucleosynthesis, specifically, to study *N*=126 waiting point isotones and nearby nuclei and provide their basic information such as half-lives. As the first step toward the goal, the proposal aims to measure half-lives of several nuclei at *N*=126 and nearby nuclei by using a $^{136}$Xe beam and a Pt target at Riken RIBF with a new detection system. The group (TRIAC group) at KEK is going to stop their activity with TRIAC in Tokai because of the limited intensity and limited future of the Tandem accelerator at JAEA. The committee understands the situation and appreciates a new initiative of the group. The TRIAC group has developed the ISOL facility with fission fragments. The committee is concerned that the R&D efforts on the ISOL facility may stop during the 5 year proposed program. We heard a possible future program which will use fission fragments for further extensive study of nuclei around *N*=126 based on the results of proposed experiment. The proposal shows somewhat of a new direction of the group. The committee likes to encourage the new initiative of the group. Since the KEK is an inter-university laboratory open to the world, the committee wants to encourage the group to enlarge the collaboration to include university groups world-wide.

### **2)The scientific merit of the 5 year proposal** :

Heavy elements in the universe have been synthesized in explosive steller processes, among which the most important process is believed to be rapid neutron-capture process (r-process). The r-process have been known to occur in supernovae explosions, neutron-star mergers, etc., but still presents us a number of open questions. One of them is the peaks in the element abundance pattern. The first and second peaks appear in lighter mass region, and have been explained to a certain extent. On the other hand, the third peak located around *A*=195 seems to contain different aspects. The third peak is rather prominent, and its presence affects the amount of actinide nuclei and heavier ones created by explosive astrophyical processes.
The present proposal has capability to clarify this question by measuring β-decay lifetimes of some key nuclei. These key nuclei mean the so-called waiting-point nuclei with *N*=126 lying in the r-process path.

There is strong physics interest in the data to be obtained. The lifetimes of the nuclei to be reached determine the height of the 3rd peak of the abundance pattern, and also the amount of actinide nuclei (and beyond) created by explosive astrophyical processes. From the viewpoint of nuclear structure, the lifetimes attract much interests, because the Gamow-Teller and First-Forbidden β transitions compete in these nuclei, depending on how the shell structure changes with higher neutron excess.

This competition has never been seen in nuclei studied so far, and can open an entirely new domain of nuclear physics in the sense that the "forbidden" transitions are comparable with the "allowed" transitions. In addition, the nuclei with $Z<80$ and $N\geq 82$ have never been reached experimentally, and the proposed experiments can be the first attempt to this untouched frontier of the nuclear chart, giving us some glance to this frontier most likely.

The proposed method to create exotic nuclei appear to have high and unique potential to explore other exotic nuclei. Namely, the method is a general one, and one can generate many other exotic nuclei by using stable and RI beams. This gives an additional justification to the proposal with an intriguing prospect for the wide future.

## 3) Evaluation of the 5 year proposal : Experiment and Techniques

The proposed five year program to measure half-lives of nuclei in the region around $A\sim 195$ has high scientific interest. Half-lives of nuclei in this region will be very important for understanding the details of r-process nucleosynthesis. A peak in the production yields occurs around $A\sim 195$, which indicates that the nuclear structure of neutron-rich nuclei around the $N$=126 shell is quite important. The β-decay lifetimes in this mass region are particularly difficult to calculate since the normal Gamow-Teller transitions are blocked. Thus 1st forbidden decays may be important, which are more difficult to predict. For this reason, many groups around the world are interested in this problem.

The difficulty that all of the groups are facing who want to measure half-lives relevant to the $A\sim 195$ r-process production peak is to determine the best way to produce a sufficient yield of nuclei to carry out the experiments. The TRIAC group has proposed a novel way to approach this problem. They propose to use multi-nucleon transfer reactions (MNT), ultimately with radioactive neutron-rich heavy projectiles at energies around 10 A-MeV, and heavy targets to produce proton-deficient nuclei around the neutron number $N$ = 126. The nuclei produced in the MNT reactions would be stopped in a gas catcher. Following this, the isotopes would need to be separated so that pure samples could be obtained for carrying out the life-time measurements.

Two different gas catcher options are now being used around the world. One of these options uses He gas to produce very slow $1^+$ ions. The ions are extracted by an rf system that drives the ions to the exit nozzle. After the gas catcher, a traditional high-resolution bending magnet can be used to produce isobaric separation. The other alternative that is now proposed to be used is to stop nuclei in a heavy gas such as argon. In this case, the incoming ions are neutralized as they are slowed down. They are transported through the gas flow to an exit region where laser ionization is used to pick out a specific element. The ions are then pulled from the argon gas using ion-collector electrodes. Once a relative pure sample of nuclei is produced, they can be transported to a collection station after isotopic separation with a mass analyzer magnet. Measuring both β- and γ-rays will provide the information that

can be used to determine the half-life and other spectroscopic properties. This method would have high collection efficiency with good *A*- and *Z*-separation. This could be the advantage over other methods of production, *e.g.* fragmentation of intermediate-energy projectiles such as uranium, which may encounter difficulty of isotope separation.
In order to understand if the approach outlined in the proposal will work, several technical issues must be studied. First, systematic measurements of MNT cross sections are needed in order to assess the feasibility of producing sufficient nuclei to carry out the proposed measurements. The method of estimate in the proposal is based on some experimental data but it is not sufficient to determine the full range of yields especially for nuclei of interest in this study. The group proposes carrying out measurements to determine cross sections using stable beams, such as $^{136}$Xe, from the injector cyclotron at RIBF on heavy targets like $^{198}$Pt. Ultimately the goal is to harvest very neutron-rich nuclei by using RIBs like $^{144}$Xe on $^{198}$Pt produced with an ISOL-based accelerator complex. A setup to measure the reaction cross sections with stable beams could be put together relatively quickly. Determining cross sections with their energy dependence will then provide a way to normalize the calculations that have been carried out. It is a crucial step to verify that the proposed technique will indeed work.

While these measurements are proceeding, further design work should proceed on the gas cell concept. The group proposes to use the argon gas catcher with laser ionization. The efficiency of this type of gas catcher as a function of the primary beam intensity must be understood. Using the heavy gas to neutralize the atoms should help reduce the effects that have been found in helium-based gas catchers at high incident particle rates. But this must be verified. The design being developed by the group has the beam penetrating through the region of the gas cell that would be used to stop the ions of interest. This may set a practical limit on the amount of beam that can be used that is far below the beam that can be supplied. Methods to test this prior to constructing the full gas cell system would be desirable.

The final stage of the experiment is the counting station where half-lives will be determined. The detection scheme proposed for the counting station would work but it should be optimized for efficiency and cost. One option that the group should consider is the use of gas ionization chambers for counting β-decays instead of plastic scintillator. The gas chambers are somewhat less sensitive to γ-rays than plastic scintillator and thus might be better to help reduce background. Given the costs associated with beam time to produce the nuclei, it may be cost effective to use multiple counting stations versus a single station and a moving tape.

As noted above, it is crucial to determine if the estimates for the MNT cross sections are reasonable with a series of experiments. Once the measurements validate that the yields are sufficient and the gas cell stopping versus beam intensity is understood, then construction could proceed on the gas cell, laser ionization system and detector stations.

In order to carry out the project, the group would need to obtain about 250 M Yen of funding. If the project works as expected, this would be a rather small investment for the potential return. Continuous support from KEK for this project is recommended. A well constructed proposal with appropriate milestones would seem to have a good chance for outside funding.

**4) Next- TRIAC preliminary plan and International context**

As advocated by the promoters' of the proposal, the most interesting isotopes in the third peak in the r-process may need very intense secondary Xe isotope beams far beyond the intensities which have been achieved at TRIAC with the Tandem as a proton driver to produce fission fragments. The committee understands that such a proposal (Next-TRIAC) will benefit from the years of R&D on target-ion source development, ECR charge booster realisation and secondary RIB injection and acceleration in the existing RFQ and Linac accelerator.

The next–TRIAC plan includes planned physics post–acceleration beyond 1.1 MeV, namely up to 10 MeV/n for fission fragments in the mass range between 80 and 140. However, building a high power Linac (>200KW), a production target zone which can handle up to 10*14 fiss/s and a post accelerator up to 10 MeV/n is a rather large size project, with a time line of about 6 to 8 years (2010-2018), an investment budget of the order of a few hundred M$, and a team of about 50 qualified physicists, engineers and technicians, not mentioning safety issues. Therefore such proposal can be considered from the physics point of view if it encompasses a much larger physics program and a much larger physics community.

The idea to complement the existing and competitive fragmentation facility at RIKEN, RIBF, by a high power ISOL facility is quite attractive. A new joint KEK-RIKEN venture is an interesting long term project. So, this option is connected with the long term future choices of RIKEN and KEK. On this long time scale, it may be considered that J-PARC also has the high power driver needed in a project like Next-TRIAC. However one may also consider developing a similar or even broader physics program by suggesting that IPNS/KEK enter as a new partner in one of the ongoing very competitive and similar ISOL projects abroad. In fact such a facility is being built at Ganil(FRANCE), called Spiral 2 and will start operation in 2012-2013. A similar but rather downscaled project is also being considered at SPES, Legnaro, Italy, but it is not yet fully funded.

In conclusion at this stage, the Next–TRIAC proposal needs to assess its needs and feasibility in a broader Japanese and International context.

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