FRIB Decay Station

1. **What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?**

Decay spectroscopy will be one of the primary methods to study exotic nuclei at FRIB and it will require an efficient, state-of-the-art detection station(s) equipped with instruments capable of characterizing various forms of radiation such as gamma rays, conversion electrons, beta particles, protons, alpha particles and neutrons. This decay station will unveil nuclear properties at the "frontiers" of the chart of nuclides where dramatic changes in nuclear structure, such as shell gap quenching, appearance of new magic numbers or a rapidly changing deformation, are expected to occur. These phenomena will serve as a stringent test for universal effective nucleon-nucleon interactions. They are also important for quantitative understanding of the nucleosynthesis. For example, the beta decay Q values, half lives and beta-delayed neutron branches are required to reproduce the r-process abundances. Similar arguments apply to the rp-process on the proton-rich side of the valley of stability. The limits of nuclear existence will be explored through novel decay modes such as detailed studies of spontaneous two-proton decay and possibly through discovery of direct neutron emission. Precise studies of super-allowed beta emitters will further constrain the unitarity of the CKM matrix and thus place tighter limits on physics beyond the standard model. Similarly, studies of beta-neutrino correlation measurements using ion traps will be performed.

2. **What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?**

The decay station will consist of various detector subsystems. The existing and planned setups were described in detail in separate questionnaires. Various components of the decay station will be used in conjunction with the fragmentation separator, the low-energy radioactive beams extracted from the gas cell or from the ISOL facility, the ion and atomic traps, and the separator for reactions with reaccelerated radioactive beams.

The system will be modular and portable so it can be deployed at different beam lines with customized configuration. It is envisioned that individual components of the decay station will surpass existing systems in terms of efficiency, resolution, granularity and speed. They can be tested and used for research at other laboratories and at NSCL until the FRIB is operational.

3. **Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?**

The decay station will consist of several detector subsystems. So far we identified the following major components:

a) implantation-decay arrays – arrays of high granularity Double-sided strip detectors for detecting fragments and correlating them with their subsequent decays
b) high-resolution gamma-ray array - a compact and efficient array of Ge detectors augmented by scintillators
c) total absorption spectrometer – an efficient array of scintillators for calorimetric measurements
d) neutron detector array – an array for detection of beta delayed neutrons and direct neutron decay; both ^{3}He gas detectors and neutron time of flight detectors for neutron energy measurements are considered
e) detector array for measuring short life times – an array of fast scintillators for measuring electronically lifetimes in the ps-ns range

These detectors will be complemented by smaller specialty arrays such as Si(Li) or PiN diode detectors for conversion electrons, plastic detectors for high energy beta particles etc. The decay station can also be used in connection with a moving tape collector or an isobar separator for background reduction.

4. **What is the current stage of development of your project ?**

Individual decay station components are at different development stages.

a) The NSCL Beta Counting Station has been used for decay experiments following fragmentation since many years. A high granularity DSSD has been developed and used at ANL for experiments with fusion evaporation reactions. A digital DSSD system is operational at HRIBF for almost a decade and underwent recently a significant firmware upgrade. A new digital high-granularity DSSD was recently funded by DOE at ANL.
b) These systems will serve as a starting point for designing a next generation Si implantation-decay station for FRIB. Complete proposals for both a dedicated high-efficiency, high resolution compact gamma-ray array (CERDA) and a Ge implantation decay array (IDEA) already exist. Other options, such as using existing Ge clover detectors or GRETINA modules in combination with scintillators, are being considered.
c) A total absorption spectrometer MTAS is under construction at ORNL. Liquid Xe and Ar large volume scintillators are in the development stage at Yale.

d) The neutron ^{3}He detector NERO is already available at NSCL. A digital ^{3}He neutron detector has been constructed recently at HRIBF. The construction of the neutron time of flight array of plastic scintillators VANDLE is funded and has already started.

e) A fast, high efficiency and granularity scintillator array for picosecond timing measurements is at the conceptual design stage. A small timing BAF2 array is available at HRIBF.

f) Large implantation area, fast tape transport systems constructed at LSU can be replicated for experiments with FRIB. High resolution conversion electron detection can be performed using an existing segmented large area conversion Si(Li) detector BESCA or its larger successor. Various high efficiency beta scintillator detectors also exist.

5. **What is the approximate cost of the project: discuss possible sources of funding.**

It is anticipated that a proposal to build a dedicated Ge array for decay studies at FRIB will be submitted to DOE. The estimated cost of the CERDA array without electronics is ~$10M. However, this project can be staged and existing gamma-ray detectors can be used initially. Other options such as use of GRETINA modules are also considered.

The Ge DSSD implantation detector IDEA has an estimated cost of $1M.

A digital high-granularity DSSD for use with the S3 separator at GANIL and the EMMA separator at TRIUMF was funded by DOE at ANL at the cost of $900k. Its digital electronics, which dominates the total cost of the project, can be used to instrument the FRIB implantation-decay station. Other digital electronics systems are already available at NSCL and HRIBF, and could also be used. It is however likely that by the time FRIB is build, all these digital systems will need to be upgraded.

A cost estimate for a large ~250 crystal $LaBr_3$ based array, based on similar plans in Europe, is on the order of ~$5-10M. Such array could be used for in-beam spectroscopy or total absorption spectrometry. The cost is highly scalable by the choice of and number of crystals. A small 1 inch crystal currently costs about $10k. An array with small crystals for fast timing measurements after decay would cost about $1M. Since the operation of FRIB is still years away, other emerging materials need to be monitored. The cost of adopting the Modular Total Absorption Spectrometer to fragmentation studies will be about $50-100k. The currently developed neutron detector arrays may require significant overhaul by the time the FRIB gets build which will cost on the order of $1M in adding and replacing scintillator modules (with possible new materials) and electronics. New tape system and associated high efficiency beta detectors may cost of the order of $50-100 k.

A replica of the conversion electron detector will cost about $50k, the full array could cost $200k not including electronics. CERDA, if implemented will be capable of detecting conversion electrons ad well.

6. **Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.**

Members of collaborations for individual components of the decay station are listed on separate questionnaires. They are also members of the FRIB Radioactive Decay Station Working Group.

7. **Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (Meetings? Participants?, Circular mailings? Have you a web-site?)**

The FRIB Radioactive Decay Station Working Group was formed to promote and facilitate the design and construction of experimental apparatus for decay studies, which will take full advantage of the new and exciting opportunities provided by FRIB. So far, more than 30 scientists from 12 US and foreign institutions, have registered. Detailed information about the group and its activities can be found on the website: http://groups.nscl.msu.edu/fribdecaystation/index.html A follow-up workshop is planned this year to discuss technical issues and ways to transition from several small collaborations into a coherent effort aimed to build the world's best decay station.

8. **What alternative designs were considered? How did you arrive at a final design?**

Extensive simulations were carried out to optimize the performance of the CERDA array. The use of existing detectors from the SEGA array or from other available clover arrays in alternative configurations was considered. They could be used as part of the array in the initial phase. The simulations of possible implementation of the GRETINA modules are ongoing. This workshop will identify existing options and the planned collaboration meetings will be devoted to developing optimal designs.

9. **What equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.**

There exist a multitude of smaller detection systems in the U.S. laboratories, which are used for decay studies both at Coulomb barrier energies (ANL, LBNL, ORNL, WSNL) and after fragmentation (NSCL). Similar setups exist in major facilities abroad. New generation implantation-decay arrays are under construction for radioactive beam facilities at TRIUMF (GRIFFIN), RIKEN and FAIR(DESPEC).