Executive summary

This document describes the science motivation and technical plans for upgrading the rare isotope research capability at the National Superconducting Cyclotron Laboratory (NSCL) by replacing its Coupled Cyclotron Facility (CCF) with a more powerful facility – the Isotope Science Facility (ISF). The ISF will provide the nuclear science research community with significantly increased intensities and varieties of world-class beams of rare isotopes. It will take full advantage of the in-flight production technique's short beam development and fast isotope separation times and provide maximum flexibility to experimenters to choose the most appropriate approach to each problem.

ISF construction will build upon the strength and expertise of NSCL faculty and staff and utilize NSCL equipment (extant and under construction) to achieve major cost savings. The proposed site is a new location on the MSU south campus, which offers an unconstrained and fully optimized facility layout with ample space for future science-driven upgrades. Transition from CCF operation to ISF operation can be accomplished with about six months disruption of the ongoing experimental program. The construction cost in FY06 dollars is slightly less than $500 million. A less favored alternative of building the ISF on the current NSCL site would reduce the cost by roughly 20%, but would require significant sacrifices.

The heart of the proposed ISF is a high-power superconducting heavy-ion linear accelerator capable of delivering beams of all stable elements with variable energies up to at least 200 MeV/nucleon and beam power up to 400 kW. This accelerator will make it possible to produce rare isotope beams with even the shortest half-lives at unprecedented intensities, using in-flight production and separation techniques.

The ISF reaccelerated beam facility will incorporate an advanced cyclotron stopper, an EBIT (Electron Beam Ion Trap) charge-breeder, and, for reacceleration, a superconducting linac that will be built at the NSCL over the next few years. The ISF reacceleration linac will be capable of reaccelerating thermalized beams of rare isotopes to energies of at least 12 MeV/nucleon over the entire mass range. Together with the fast beams from in-flight production, the ISF will provide a broad spectrum of rare isotope beams with energies between 0 and 200 MeV/nucleon. ISF beam intensities will be competitive with and often exceed those at the facilities worldwide that will be completed during the next 10 to 15 years. Such intensities are higher by several orders of magnitude than those currently possible at the CCF or anywhere else today.

The ISF relies on modular, expandable, and optimized concepts to fulfill the evolving needs of the rare isotope research community. The modular approach allows upgrades to proceed with minimal impact on the existing research program. For example, if needed, higher energy (primary or secondary) beams are possible by a straightforward addition of accelerator cryo-modules. The civil infrastructure for a high-power ISOL target for rare isotope production is part of the current baseline ISF plan. This will allow for full implementation of a high-power ISOL target and the associated isobar separator with a modest upgrade and minimal facility downtime. The future scientific needs of the community will dictate the priority for these or any other upgrades.

The ISF will build on the tradition within MSU, the NSCL, and the user community of excellent undergraduate, graduate, and post-doctoral education. Its location on the MSU campus will greatly facilitate educating the next generation of nuclear scientists by continuing the NSCL's hands-on approach to scientific education in experimental and theoretical nuclear physics, nuclear chemistry, accelerator physics and engineering, nuclear astrophysics, and related instrumentation and societal applications. The university setting also facilitates public awareness and understanding of nuclear science as well as the development of cross-disciplinary teams.

The ISF will allow major advances in nuclear science and nuclear astrophysics by providing intense beams of nuclei far from stability at energies from a few keV to up to 200 MeV/nucleon. The main experimental program will be exploring the limits of nuclear stability and determining nuclear properties in the uncharted regions of nuclei with very unusual proton-to-neutron ratios. ISF-produced data will guide the development of reliable theoretical models with predictive power for key nuclear properties. The broader impact of the ISF experimental program and the new predictive models will provide insight into the nature of many-body quantum systems and mesoscopic science. ISF research will explore the unique features of nuclei and facilitate intellectual links to studies of mesoscopic systems in chemistry, biology, and nanoscience.

Intense beams of neutron-rich isotopes will add to our knowledge of the very heavy elements by allowing the synthesis of transactinide nuclei that are more neutron rich than those possible with stable beams. These nuclei are predicted to be more strongly bound and longer-lived and thus could be accessible to chemical study.

Nuclear data generated by the ISF will help to develop reliable models of astrophysical environments that describe nucleosynthesis and stellar evolution in the cosmos, especially models of explosive events, such as X-ray bursts, core-collapse supernovae, thermonuclear (Type Ia) supernovae, and novae. Sound astrophysical models are needed to extract reliable information on astrophysical objects from the high-quality observational data produced by ground and space-based observatories.

Energetic nucleus-nucleus collision experiments at the ISF will allow exploration of the equation of state of neutron-rich nuclear matter near normal and subnormal nuclear densities. This knowledge plays an important role in determining the properties of neutron stars.

Rare isotopes produced by the ISF can be used in testing fundamental symmetries that describe the strong and weak forces in nature and searching for new physics beyond the Standard Model. The availability of a broad range of isotopes makes it possible to select the best, specific nuclear system that can isolate or amplify specific physics of interest.

The ISF also will produce many new isotopes in research quantities offering opportunities for cross-disciplinary work, such as research linked to national security, biomedicine, or nuclear energy. Often such work can proceed concurrently, provided that the required infrastructure is put in place by appropriate modular additions.