SECAR Service Level Description

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Table of Contents

Revision History

Revision	Issued	Changes
R001	2 March 2026	Original Issue

Authorizing Document

None.

Authorized Documents

None.

Authorized Committees and Boards

None.

Named Program Roles

None.

Awareness Training

None.

Enabling Training

None.

1 Objective

This document describes the level of service FRIB will be able to provide for the operation of SECAR and for user support for experiments with SECAR.

2 Abbreviations

BGO	Bismuth germanium oxide
D	Dipole
DAQ	Data Acquisition system
Data-U	Data-analysis user area
FP	Focal Plane
GFR	Good-Field Region
GUI	Graphical User Interface
Hex	Sextupole / Hexapole
HO	Higher order
HV	High Voltage
IC	Ionization chamber
JENSA	Jet Experiments in Nuclear Structure and Astrophysics (windowless gas-jet target)
MCP	Multi-channel plates
PID	Particle Identification
Q	Quadrupole
ReA3	Rare Isotope Reaccelerator stage 3
SECAR	SEparator for CApture Reaction
SLD	Service Level Description
TOF	Time-of-Flight
WF	Wien Filter

3 SECAR Overview

SECAR is a recoil mass separator designed[1] to measure low-energy **(p,γ)** and **(α,γ)** and other radiative capture and transfer reactions like **(p,n)** and **(α,n)** in inverse kinematics with radioactive beams. It provides high primary-beam suppression using two **Wien filters** combined with magnetic optics, enabling direct recoil detection at stellar energies relevant to novae, X-ray bursts and other astrophysical sites. SECAR is optimized for complete transmission of the recoil cone with high mass separation and strong beam rejection depending on beam and reaction properties.

4 Standard Configuration

Location / Layout: SECAR is installed in the ReA3 experimental hall. The beam from the ReA3 accelerator is sent to the target chamber to interact with the target material (gas or solid). The reaction recoils and the beam proceed through different ion-optical sections for charge-state selection and mass-separation to separate recoils from beam and detect the recoils in the final focal plane detectors. See Figure 1.

Angular and dE/E acceptance limits as well as transmission function depend on ion optics chosen (see below for demonstrated cases).

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[1] G.P.A. Berg *et al.*, Nuclear Inst. and Methods in Physics Research, A 877 (2018) 87–103

4.1 Operational Features

4.1.1 Target

SECAR supports three different types of targets that provide different properties and advantages for a wide variety for reaction measurements:

- The windowless gas target (JENSA) provides continuously recycled Helium gas of up to 1×10^{19} atoms/cm² areal density in a highly focused 4–5 mm thick jet for well-defined reaction location.
- The extended windowless gas-cell option is recommended for uncertain resonance energies providing areal densities up to 7×10^{18} atoms/cm² for helium and 3×10^{18} atoms/cm² for hydrogen over a 12.4 cm long gas cell.
- Alternatively, user supplied solid target foils can be mounted inside the extended gas cell chamber or the jet chamber to provide higher target densities and other target materials.

4.1.2 Charge-State Selection

Recoils will exit the target carrying different charge states, depending on interaction point in the target and gas pressure, but for effective mass separation one specific charge state needs to be isolated. Dipoles B1&B2 in Section 1 in combination with horizontal slits at the first focus FP1 achieve separation even for adjacent charge states. Typically, the most abundant recoil charge state is selected.

To determine which charge state should be selected, the first dipoles can be used to measure charge state distributions via relative beam intensities after the first bend. For this measurement, a dedicated beam with the same isotope or element (i.e. same Z) as the recoil beam must be requested as part of the proposal.

In cases where no charge state equilibrium is reached in the target, a carbon stripper foil can be inserted downstream of the target, to act as a charge state booster.

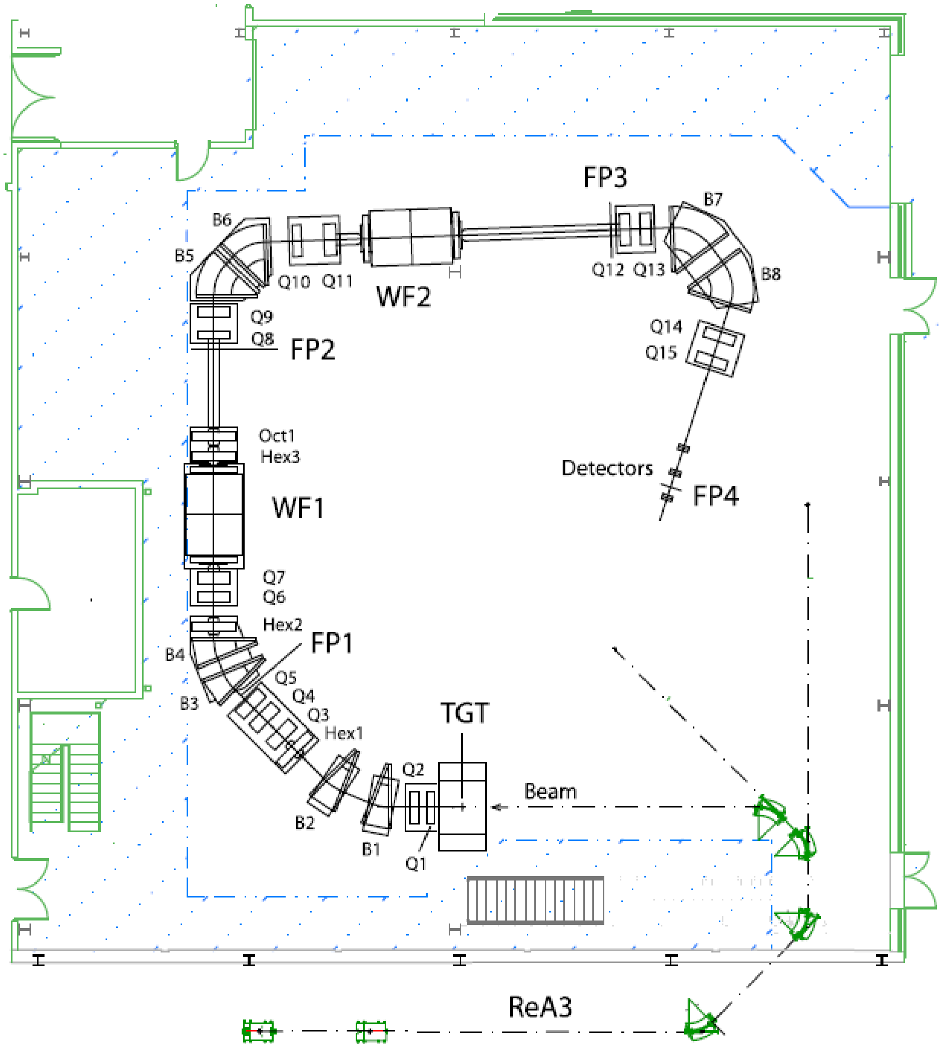

Figure 1: SECAR floor plan with four ion-optical focal planes (FP1 - FP4) suitable to study nuclear reactions in inverse kinematics.

4.1.3 Ion Optics

The SECAR system employs Wien filters for separation by velocity. A major advantage of this is that the electric and magnetic bending radii can be chosen as free parameters depending on experiment requirements for rejection, and maximum available field strengths. However, for each choice of bending radius **R** a modified ion optics must be developed that compensates the resulting transport differences of the off-center ion trajectories. Generally, rejection performance of the Wien filter section will be worse for larger **R**. Rejection is expected to depend strongly on experimental details such as beam energy, beam mass, beam charge, target beam spot properties, target properties, vacuum, and is expected to vary from experiment to experiment.

The currently developed and supported ion optics are:

- **R**(WF1) = 7 m, **R**(WF2) = 7 m. This optics has been demonstrated to provide >90% transmission for angles up to +-12.5 mrad, and energy variations of +-2.5%. It has been developed for p,γ and α,γ measurements with more stringent rejection requirements.

Rejection for $^{16}O(\alpha,\gamma)$ has been demonstrated to be better than 10^{-13}. Rejection for examples of (p,γ) measurements remains to be demonstrated.

- **R**(WF1) = 10 m, **R**(WF2) = infinity (WF2 off). This optics has been used for (α,n) measurements and total beam rejection was demonstrated to be of the order of 10^{-11}.
- **R**(WF1) = 9.85 m. **R**(WF2) = 23.4 m. This optics has been developed for measurements without stringent rejection requirements such as (d,p) measurements.
- **R**(WF1) = infinity, **R**(WF2) = infinity (both Wien filters off). This optics has been developed for (p,n) reaction measurements and the measured properties are published for a $^{58}Fe(p,n)^{58}Co$ measurement[2].

Ion optics for other bending radii can be developed in collaboration with the user upon request, depending on availability of resources and under consideration of the magnet parameters listed below:

- **Dipoles**: 8 H-type dipoles with a maximum B field of 0.64 T; GFR tolerance $\Delta B/B \leq \pm 0.02\%$; HO corrections via shaped effective-field boundaries.
- **Quadrupoles**: One combined-function (Q+Hex) and 14 quadrupoles; gradients up to ~±5.4 T/m; wide horizontal GFR to accommodate large envelopes.
- **Multipoles**: 3 Hexapoles and an octupole for HO correction and flexibility.
- **Wien Filters**: Two identical compact WF modules (magnetic + electrostatic dipoles with a common vacuum vessel) with WF1 electrodes conditioned to ±250 kV, WF2 electrodes conditioned to ±100 kV (anticipated to match WF1 voltage in the future); horizontal GFR ±110 mm; vertical GFR ±35 mm; effective field length ≈2365 mm; fields matched to keep $E/B \approx v$ in fringe regions.

4.2 Detectors

4.2.1 Target Region

Depending on the selected target chamber, detector setups are as follows:

- JENSA gas jet target chamber has two silicon PIPS detectors that can be positioned independently between 30° and 55° with respect to the beam axis, to monitor the beam intensity via ion scattering. The same chamber is large enough to accommodate other detectors provided by users, if coordinated with and approved by the SECAR instrumentation scientist.
- For extended-target operation, two silicon PIPS detectors are inside the chamber for beam monitoring (at 30° & 45°). An array of 26 BGO detectors surround the extended target providing ~50% γ-ray detection efficiency at 1.3 MeV for resonance beam energy optimization and for additional rejection (gamma-recoil coincidences; see 4.3.1).

4.2.2 Focal-plane Detector System

The final section of SECAR has several detectors to further increase the rejection of beam particles and detect the absolute number of recoils from reactions at the target.

4.2.2.1 MCP Time of Flight System

A dedicated system of two MCP detectors registers electrons emitted by ions interacting with thin foils in the beamline 140 cm apart. This time-of-flight path allows ion separation by velocity

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[2] P. Tsintari *et al*. Phys. Rev. Research 7, 013074 (2025)

with ~1 nanosecond resolution to reject the faster unreacted beam in the data analysis. The ions interaction point with the foil, which is recorded by the MCP detectors as well, can be used to further improve the timing resolution and rejection.

4.2.2.2 Stopping Detector System

Ions are stopped in the position sensitive 34 cm long IC (max 50 Torr). This energy loss measurement can provide an alternative/additional way to separate recoils from any beam ions that made it to the end via PID. Alternatively, the IC can be replaced by a hybrid of a 5 cm IC ΔE energy loss section and a ~300 μm thick, 64x64 mm DSSSD to stop ions for total energy measurement and high position resolution (2mm in X & Y).

4.3 Electronics and Data Acquisition

4.3.1 Detector Electronics

The standard SECAR detector electronics and data acquisition are based on VME electronics and utilizes XIA Pixie-16 modules. With 250 MHz sampling rate these modules allow real-time triggering, filtering and pulse height extraction from the data stream with the option to acquire traces for offline analysis.

4.3.2 DAQ Framework

The NSCLDAQ-based SECAR DAQ framework is consistent with other FRIB systems and handles data acquisition and event building by recording detector hits in time-stamped event lists for online and offline analysis. The synchronized clock cycles allow filtering events for coincidences between the target area detectors and the focal plane detectors and a TOF analysis of these selected events to suppress random coincidences in the event window. Ancillary detector DAQs can be merged upon request.

Typical operation leverages target and focal plane detector scalers and online spectra of signals in SpecTcl for monitoring (see 4.4.1). The exact throughput and dead-time depend on selected detectors and trigger logic.

4.4 Analysis Software and Tools

4.4.1 Online/Offline

SpecTcl is the standard software used for online monitoring during an experiment. It allows to display various accumulated spectra from the live data stream. Spectra include BGO γ-ray energy spectra, separator and MCP TOF distributions and IC PID plots for mass-separation diagnostics and monitoring; The software is also available to users for offline analysis upon request to the SECAR instrumentation scientists.

4.4.2 Dedicated Computers and Software for SECAR Operation

SECAR operation is handled by the Phoebus CSStudio control software, run from dedicated computers on the controls network in Data-U5. SECAR DAQ and scalers, High Voltage control software for detectors and SpecTcl are run on dedicated computers on the DAQ network in Data-U5. The use of these computers is restricted to instrumentation and beam scientists, as well as trained users.

4.4.3 Ion Optics Transport Code

COSY-based ion optics transport code and tools, including advanced optimization methods used internally for optics verification and settings management can be provided to users to develop non-standard ion-optics.

4.5 Ancillary Systems

Integration of new ancillary systems requires coordination with the SECAR instrumentation scientist and the vault coordinator.

5 Instrument Support Level

5.1 Support by Instrumentation Scientist

FRIB provides support for SECAR. Setup of the instrument will be coordinated by the SECAR instrumentation scientist. On-site support is normally available 9 a.m.–5 p.m. (working days). On-call support for critical technical assistance outside normal hours can be requested via the Operator-in-Charge (OIC), who will contact the instrumentation scientist on call.

Scope across experiment phases (standard configuration):

- **Preparation**: Answer technical questions for proposals; advise on achievable mass separation/acceptance and expected backgrounds; provide guidance on resolution trade-offs for extended targets and mass-slit settings; review ancillary integration and DAQ merging plans.
- **Setup & Tuning**: Provide standard ion-optics settings, charge-state selection procedures, and WF scaling; coordinate target (JENSA) conditions and vacuum; operate/verify separator performance to design limits (e.g., acceptances, rigidity).
- **Running**: Perform setting changes; monitor gas target performance and optics/beam rejection; assist with online PID/TOF checks; manage cleanup slits and focal-plane conditions consistent with rate limits.
- **Analysis**: Assist with interpretation of online data and offline analysis.
- **Note**: Support covers operation **in the standard configuration** described in this SLD. Modifications or additions (e.g., non-standard detectors, custom HV in WFs, alternate optics) are the responsibility of the users and require coordination well before the experiment.

5.2 Additional Support

Instrumentation scientists can train users to operate selected equipment and perform certain procedures. Training is offered once per experiment at pre-arranged times. Typical segments and indicative durations (subject to update):

- JENSA target adjustments: 1 hour.
- Charge-state selection and mass-slit use: 1 hour.
- Diagnostics & camera use: 1/2 hour.
- Online SECAR DAQ monitoring using SpecTcl (TOF/PID etc.): 2 hours.
- Basic troubleshooting (vacuum/gate valves/DAQ): 1 hour.
- Basic operation of drives (e.g. viewers, Faraday cups, attenuators, etc.): 1/2 hour.
- Recording/loading of magnet settings and optics scaling: 1/2 hour.

Special requirements beyond the standard configuration like non-standard ion-optics, must be communicated to the instrumentation scientist and stated in the SECAR worksheet part of the proposal. Changes outside the approved scope are subject to schedule and resource availability.

6 Additional Instrument Support not covered in this Service Level Description

Any request for support not covered in this SLD (i.e integration of new ancillary systems and merging ancillary DAQs with the SECAR DAQ) should be submitted to the **FRIB Manager of User Relations** prior to the submission of an experiment proposal for pre-approval.