

CINP Nuclear Structure Working Group for the SAP Long Range Plan

Summary of briefs received, future plans

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Total: 21 Briefs

Experiment: 18

- Adam Garnsworthy, TRIUMF
- Jens Lassen, TRIUMF
- Ania Kwiatkowski et al., TRIUMF
- Chris Ruiz, TRIUMF
- Carl Svensson et al., Guelph
- Barry Davids et al., TRIUMF
- Ritu Kanungo et al., TRIUMF x 3
- Iris Dillmann, TRIUMF x 2
- Kris Starosta, Simon Fraser University
- Paul Garrett, Corina Andreoiu, Guelph/SFU
- Stephan Ettenauer-Malbrunot, TRIUMF x 2
- Thomas Planche, TRIUMF
- Frederic Sirois, Polytechnique Montreal

Theory: 3

- Alex Gezelis, Guelph
- Jason Holt, TRIUMF
- Petr Navratil, TRIUMF

Of which

- 1 (Garnsworthy) is the flagship experiment at TRIUMF
- 5 are new facilities/programs (Dillmann, Ettenauer-Malbrunot, Kanungo, Planche, Sirois)
- 3 are off-shore programs (Dillmann and Kanungo at GSI, RIKEN Garret/Andreoiu at various labs)

The Advanced Rare Isotope Facility (ARIEL)

Adam Garnsworthy, TRIUMF

2027 – 2034

ARIEL is TRIUMF's flagship project conceived to ensure Canada's leadership role in rare isotope science. During the period covered by the forthcoming Long Range Plan ARIEL will move from construction to delivering science.

ARIEL significantly expands TRIUMF's Rare Isotope Beam (RIB) program for Nuclear Physics and Astrophysics, Nuclear Medicine and Materials Science

Resources:

Capability	Will deliver isotopes. . .	First experiments
CANREB	...to elucidate our fundamental understanding of atomic nuclei by enabling studies of the evolution of structure and dynamics of neutron-rich nuclei.	~2027
Two simultaneous RIBs	...as probes of magnetism at interfaces and surfaces of new functional materials using β -NMR.	~2028
Photo-fission	...to elucidate our fundamental understanding of atomic nuclei by enabling studies of the evolution of structure and dynamics of very neutron-rich nuclei approaching the r-process path.	~2028
Proton target station	...for molecular imaging of diseases and treatment of cancer in the ARIEL collection station and isotopes for developing a standard model for nuclear physics.	~2028
Three simultaneous RIBs	...to search for new forces in nature by searching for violations of Fundamental Symmetries. It will also mark the milestone of three simultaneous rare isotope beams delivered to users.	~2029
Routine 5000 RIB hours per year	...to deliver new capabilities of ARIEL for scientific discoveries.	~2029
Full driver beam intensities	...to determine how the heavy elements from iron to uranium were produced in the universe.	~2030
Routine 9000 RIB hours per year	...to fully exploit the new capabilities of ARIEL for all scientific programs.	~2032

TITAN: precision measurements for nuclear structure, nuclear astrophysics, and fundamental interactions

Ania Kwiatkowski, TRIUMF

2027 – 2034

- High-precision atomic-physics techniques for RIB with ion traps
- Nuclear structure, nuclear astrophysics, fundamental symmetries, theory

2034 – 2041

- TITAN will exploit the soon-to-be-commissioned ARIEL facility and the next-generation of radioactive-ion-beam (RIB) production at TRIUMF towards the neutron dripline, to examine structural evolution for increasingly extreme ratios of neutrons to protons as well as to make breakthrough contributions to the study of explosive end-of-life scenarios in stars.

Resources: \$375,000

Evolution of nuclear shapes, moments and charge radii – collinear fast beam laser & resonance ionization spectroscopy

Jens Lassen

2027 – 2034

- collinear fast beam laser spectroscopy & collinear RIS user facility
- new polarized species for β NMR & nuclear science
- investigate nuclear moments & shapes (rad-mol)
- investigate nuclear moments & shape evolution in the actinide region
- push sensitivity towards octupole deformation sensitivity
- deliver spin-isomer beams

2034 – 2041

Gamma-Ray Spectroscopy at TRIUMF-ISAC/ARIEL

C.E. Svensson, Guelph

Centered around GRIFFIN and TIGRESS, TIGRESS + EMMA

Nuclear Structure, Astrophysics, Fundamental Symmetries, Detector Development

1. How does the structure of nuclei emerge from nuclear forces?
2. How are the elements formed in the Universe?
3. What is the new physics beyond the electroweak Standard Model?

Shape coexistence

Rocchini et al., Phys. Rev. Lett. 130, 122502 (2023), Mashtakov et al., Acta Phys. Pol. B 18, 2-A21 (2025); Kalaydjieva et al., Acta Phys. Pol. B 16, 4-A15 (2023); Garrett et al., Phys. Rev. Lett. 123, 142502 (2019); Ortnner et al., Phys. Rev. C 102, 024323 (2020); Gillespie et al., Phys. Rev. C 105, 044313 (2021); Smallcombe et al., Phys. Rev. C 110 024318 (2024)

2034 – 2041

Exploitation of ARIEL beams

*“Ultimately, the parallel operation of the current ISAC 500 MeV proton beamline, the ARIEL e-linac, and a second 500 MeV proton beam driving the ARIEL production targets will provide **three simultaneous radioactive beams, tripling the beamtime** available to the suite of state-of-the-art research infrastructure at ISAC and ensuring Canada’s continued leadership role in ISOL-based rare isotope science for the foreseeable future.”*

Resources: \$3,200,000

EMMA

Barry Davids, TRIUMF

TIGRESS + EMMA experiment required directly measuring the cross section of the $^{83}\text{Rb}(p,\gamma)^{84}\text{Sr}$ radiative capture reaction at energies relevant to p-process nucleosynthesis in supernovae using an accelerated radioactive beam,

Phys. Rev. Lett. 127, 112701 (2021); Phys. Rev. C 107, 035803 (2023)

2027 – 2034: direct cross section measurements of importance for the astrophysical p and r processes including Si-He thin films produced in Sevilla, Spain; building and commissioning new focal plane decay station; working in conjunction with TIGRESS

2034 – 2041: studies of new radioactive beams around Sn-100; (α,n) measurements; experiments with ARIEL beams

Resources: \$150,000

Nuclear Astrophysics at ARIEL:

Direct measurements, scattering and reaction spectroscopy for astrophysics and low-energy benchmarking of *ab initio* nuclear theory

C. Ruiz, TRIUMF

Radiative Capture with the DRAGON Recoil Separator

Direct and indirect measurements for astrophysics using TUDA, SONIK and TACTIC

➤ Scattering with radioactive beams for *ab initio theory benchmarking*

(α , n) reactions

11 PRLs, PRC, NIMs

2027 – 2034

- taking advantage of unprecedented ARIEL radioactive beams with the opportunity for more types of beam at high intensities and more beam-hours

2034 – 2041

- develop new detection techniques and ancillary detection systems to expand the reach of the facilities to hitherto inaccessible types of reaction, as well as upgrading the DAQ systems to enable seamless integration with other detector arrays and facilities at TRIUMF and from abroad.
- replacement of the existing BGO array with a Lanthanum Bromide (LaBr₃) array, in order to leverage the recently developed resonance timing method
- integration with other detectors such as GRIFFIN, or the DEMAND neutron array

Resources: \$270,000

Reaction spectroscopy of exotic nuclei with IRIS and Active Target TPC

Ritu Kanungo

- IRIS will take advantage offered by the solid H₂/D₂ target and the combined merit of the ARIEL/ISAC beams available at TRIUMF. Development of an Active Target TPC will bring complementary advantages to further expand the scientific program, especially enabling reactions with ^{3,4}He and detecting rare particle emitting decay modes.

”Nuclear Force Imprints Revealed on the Elastic Scattering of Protons with ¹⁰C” A. Kumar et al., Phys. Rev. Lett. 118 (2017) 262502; selected as Editors Suggestions and featured in Viewpoint in Physics.

2027 – 2034

- studies of light nuclei around the proton and neutron drip-lines to investigate nuclear shell structure, new excitations, exotic halos and skins, and nucleosynthesis. New experiments with medium heavy nuclei using beams from CANREB will be undertaken.

2034 – 2041

- reactions to study neutron-rich isotopes of specifically Sn and Kr provided by ARIEL
- nucleon transfer reactions with these most neutron rich isotopes, expected to have the best feasibility condition for running at ARIEL based on beam intensity, energy and the advantage of solid H₂/D₂ target.

Resources: \$400,000

Nuclear Structure Laboratory at SFU

Kris Starosta, SFU

2027 – 2034

- structure characterization of double- β decay candidates through $\beta - \gamma$ decay spectroscopy
- structure characterization of neutron-rich isotopes accessible through nuclear fission and other modes of nuclear decay
- identification and implementation of novel methods of production and separation of radioisotopes from fast-neutron induced nuclear reactions for fundamental research and applications in medicine and industry.

2034 – 2041

- continue to be in the Canadian and the world-wide effort investigating nuclear interactions with the aim of describing nuclear structure and reactions from first principles
- development of collimated tagged Am/Be neutron sources,
- acquisition of a high-yield neutron generator, developments of schemes for neutron flux amplification through secondary nuclear reactions,
- development of schemes for moderation of fast neutrons, and
- development of a neutron-generator driven subcritical nuclear reactor.

Resources: \$205,000

Exploring the exotic nuclear landscape with reactions using in-flight radioactive beams

Ritu Kanungo, TRIUMF; off-shore

2027 – 2034

- Ongoing programs at RIBF, GSI/FAIR and at FRIB. One target of the program will be around the traditional shell closures $N = 28, 50$ and 82 with two-fold aim of constraining the symmetry energy from neutron skin thickness measurements and find signatures of shell structure changes. The most neutron-rich light nuclei will be explored at FRIB, and the heavy isotopes will be measured at GSI. The intermediate mass nuclei, as well as nuclei around the proton drip-line will be measured at RIKEN-RIBF.

2034 – 2041

- The measurements will continue for long-term specifically with added new capacity as both FRIB and FAIR ramps up to full power. As the highest energy beams become available at FAIR the program will extend to the heaviest region of closed shell around $N = 126$ in the r-process path.

Resources: \$220,000

Two-step rare isotope production facility at TRIUMF

Ritu Kanungo, TRIUMF

development of two-step rare isotope beam production

2027 – 2034

- Design around 2030 after ARIEL is fully functional

2034 – 2041

- consultations, planning, etc

Resources: TBD

Detailed nuclear structure studies of nuclei on or near the valley of stability

Paul Garrett, Guelph; Corina Andreoiu, SFU

2027 – 2034

- Coulomb excitation, neutron capture, and β -decay experiments that cannot be performed at the TRIUMF-ISAC/ARIEL facilities

2034 – 2041

- odd-mass nuclei to provide a deeper understanding of the impact of the single-particle effects on the underlying collective properties.
- γ -ray spectroscopy following neutron capture reactions.
- odd-odd nuclei relevant for $0\nu\beta\beta$ initially targeting ^{136}Cs .
- activities are carried out at ANL, LNL, ILL, HIL, University of Jyvaskyla, and the University of Cologne.

Resources: \$750,000

TRISR - A dedicated storage ring for neutron captures on radioactive nuclei

Iris Dillmann, TRIUMF

A low-energy heavy-ion storage ring coupled to an ISOL-type radioactive beam

2027 – 2034

- A demonstrator facility is proposed at the presently only low-energy storage ring connected to a RIB facility, the CRYRING at GSI Darmstadt/ Germany. A funding proposal is presently under review (decision: October 2025). As part of this proposal, a design study for a "ideal storage ring" will be carried out. The TRIUMF-ISAC facility is one option to host such a new, dedicated storage ring (TRISR).

2034 – 2041

- For Canada: Successful funding application via CFI and hopefully construction of the TRISR at TRIUMF.

Radioactive Molecules (RadMol)

Stephan Malbrunot-Ettenauer, TRIUMF

- to establish a dedicated TRIUMF laboratory for the investigation of radioactive molecules.

2027 – 2034

- (assuming CFI funding) creation of the RadMol laboratory at TRIUMF; molecular EDM studies with unprecedented sensitivity to time-reversal-violating nuclear Schiff moments

2034 – 2041

- radioactive molecules represent an opportunity to access nuclear anapole moments of short-lived radionuclides. As nuclear anapole moments violate parity, they provide a unique view on the interplay between nuclear structure and fundamental symmetries at play inside the atomic nucleus. Molecules are unique environments where the nuclear anapole moments can interact with the surrounding electron cloud, leading to amplified and thus detectable parity-violating effects at the molecular level. Molecular spectroscopy of cold radioactive molecules. Nuclear Medicine.

Resources: \$1.2M/year NSERC; \$41.5M other sources; \$5M international

antiProton Unstable Matter Annihilation (PUMA)

Stephan Malbrunot-Ettenauer, TRIUMF

- investigates the neutron-to-proton density ratios at the surfaces of exotic, short-lived atomic nuclei.

2027 – 2034

- online PUMA measurements of halo nuclei and nuclei with neutron skin; development of HYPER - production of hypernuclei from low-energy antiprotons

2034 – 2041

- formation and study of exotic hypernuclei from the interaction with radioactive ions either at ISOLDE at CERN

Decay spectroscopy of exotic nuclei at GSI-FAIR

Iris Dillmann, TRIUMF, GSI

Storage rings and BELEN Decay Spectroscopy; n-rich nuclei

“High-temperature ^{205}Tl decay clarifies ^{205}Pb dating in early Solar System”, G. Leckenby et al., Nature 635, 321 (2024)

“Bound-state beta decay of $^{205}\text{Tl}^{81+}$ ions and the LOREX project”, R. S. Sidhu et al., Phys. Rev. Lett. 133, 232701 (2024):

2027 – 2034

ILIMA@ESR: This program will continue with minor detector and facility upgrades in the existing storage ring (ESR) until the new storage ring CR at FAIR is funded and constructed (no timeline yet).

BELEN@DESPEC: This program will ramp up as soon as the SuperFRS is fully commissioned (est. 2029/30).

2034 – 2041

FAIR

Resources:

Development of Enabling Accelerator Technologies

T. Planche, O. Kester, R. Laxdal, A. Gottberg, T. Junginger, J. Lassen, C. Charles, Y.-N. Rao, R. Leewe, P. Kunz, V. Verzilov

2027 – 2034

- the completion and full operational ramp-up of the ARIEL facility, modernization and enhanced capabilities of ISAC accelerators, and initial upgrades to the TRIUMF cyclotron for higher beam intensities. THz radiation technologies and the realization of a compact accelerator-based neutron source (CANS). Critical infrastructure like upgraded high-power beamlines, enhanced SRF support infrastructure, new ion sources, and material testing facilities will be developed. High-temperature superconducting accelerator magnets, SRF materials and processes, machine learning and robotic assembly.

2034 – 2041

- 0.5 MW operation of the TRIUMF e-linac and ramping up ARIEL laser ion source capabilities. Storage ring, a facility dedicated to electron scattering on trapped radioactive ions and a conceptual design towards the realization of a major new facility based on a two-step radioactive ion beam production.
- International: 5 cryomodules to HL-LHC, contributions to EIC and the Future Circular Collider

Resources: \$700,000

High-temperature superconducting magnet technology for supporting research in subatomic physics

Frederic Sirois, Polytechnique Montreal

2027 – 2034

- design solenoid or dipole magnets

2034 – 2041

- High Temperature Solenoid magnet network with a clear vision should be well in place by 2034, well connected to the major players worldwide. Canada should also have put in place facilities and modeling capabilities to lead projects involving large-scale accelerator/detector magnets.

Resources: \$500,000 NSERC, other sources CFI \$10M

Theory

- Nuclear many-body theory: Input to CINF Brief, Alex Gezelis, Guelph
- *Ab initio* atomic and nuclear theory for nuclear structure/astrophysics, fundamental symmetries, and new physics searches, Jason Holt, TRIUMF
- *Ab initio* nuclear theory for applications in astrophysics and tests of fundamental symmetries, Petr Navratil, TRIUMF

Nuclear many-body theory

Alex Gezerlis, Guelph

2027 – 2034:

- explore the connections between nuclear forces, and the physics of light nuclei and neutron stars
- producing highly optimized next-generation nucleon-nucleon and three-nucleon interactions, their use in Quantum Monte Carlo studies of neutron-star crusts, nuclei, and model systems
- mean-field studies of heavy nuclei

2034 – 2041

- connections between lattice Quantum Chromodynamics (QCD) computations and low-energy nuclear theory
- nonperturbative approaches using Quantum Monte Carlo methods to medium-mass and heavy nuclei, using state-of-the-art artificial intelligence techniques

Resources: \$600,000

Ab initio atomic and nuclear theory for nuclear structure, astrophysics, fundamental symmetries, and new physics searches

Jason Holt, TRIUMF

novel many-body approach, the valence-space formulation of the in-medium similarity renormalization group (VS-IMSRG), which extends the scope of *ab initio* theory to that of the nuclear shell model and beyond.

2027 – 2034:

- expansion of the VS-IMSRG beyond ^{208}Pb
- calculations of the nuclear matrix element for neutrinoless double beta decay and WIMP-nucleus structure functions for dark matter direct detection searches and neutrino-nucleus scattering for all experimentally relevant nuclei, with quantified uncertainties.
- anapole moments, Schiff moments, and EDM, as well as calculating the atomic theory inputs for measurements of isotope shifts, which will give absolute nuclear charge radii and can be connected to other interesting searches for BSM physics.

2034 – 2041:

- global calculations of all atoms and essentially all nuclei, using consistent nuclear forces and electroweak currents with quantified uncertainties.
- masses, β decay, and neutron capture rates for use in *r*-process nucleosynthesis simulations.

Resources: \$150,000 NSERC and \$500,000 CFI

Ab initio nuclear theory for applications in astrophysics and tests of fundamental symmetries

Petr Navratil, TRIUMF

predictive *ab initio* theory of nuclear structure and nuclear reactions for light- and medium mass nuclei

2027 – 2034:

- applications of *ab initio* nuclear theory for interpretation of precision experiments testing fundamental symmetries and physics beyond the Standard Model

2034 – 2041:

- computation of the nuclear many-body Green's function that will include continuum effects
- *ab initio* theory for nuclear deformation
- generalization of the present nuclear wave function expansion scheme for
- description of bound and unbound states by a component describing high-energy excitations such as giant resonances.

Resources: \$140,000 NSERC

Common requests/recommendations

Maintain and increase the SAP envelope

Increase the grant amount proportional to the research excellence

Increase HQP support

Thank you
Merci