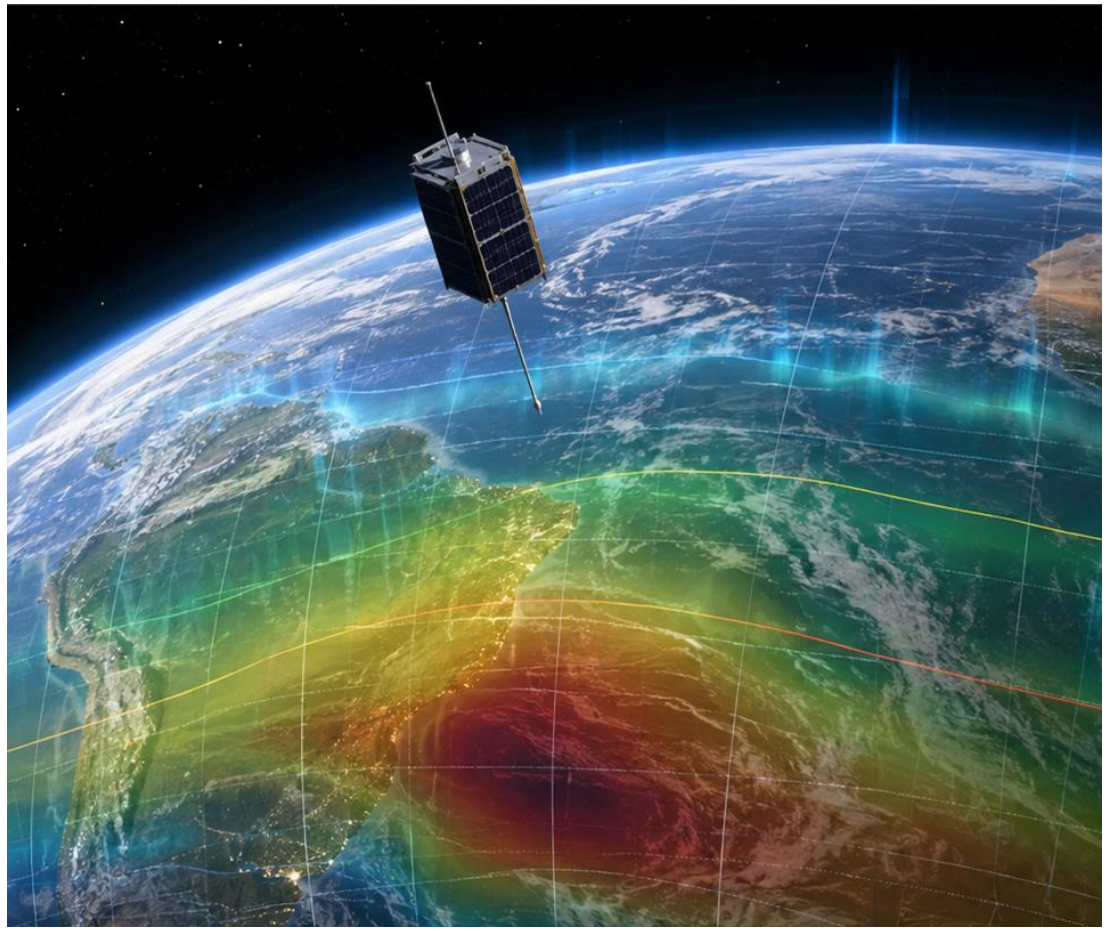
Albedo Neutron Monitoring in Polar Low Earth Orbit Using a Compact Dual-Mode Radiation Detector on REXIS

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29th WRMISS • Prague, Czech Republic • 1–3 September 2026

Stellar Nuclear

Powering the future of space exploration.

- Founded in 2024 in the Czech Republic; focused on space nuclear technologies.
- Activity areas: radioisotope power concepts, compact fission power.
- ESA BIC Czech Republic participant; locations in Brno, Prague and Hrušovany, with a U.S. presence in San Luis Obispo.

RHU/RTG development

modular RHU/RTG concepts for satellites, lunar night and long-duration missions.

RAVEN microreactor

compact fission power for sustained lunar/Mars surface operations and deep-space exploration.

REXIS inspection satellite

Remote inspection of legacy spacecraft, ejected reactor cores and demonstration targets.

Space nuclear sources and radiation signatures relevant to REXIS

REXIS distinguishes between two physically different target classes and optimises for their most useful stand-off observables.

- More than 30 nuclear objects in orbit (reactor cores, RHU sources)
- State and integrity mostly unknown
- REXIS mission to fill this knowledge gap

RTG / RHU objects

- Pu-238 decay heat source; no criticality and generally weak external gamma signatures.
- Most relevant remote observable: neutrons from spontaneous fission and (alpha,n) reactions.
- Alpha particles are only useful if the fuel is exposed and the approach distance is very small.
- Representative case: TRIAD-01/TIP-1 class RTG.

Typical stand-off emphasis: neutron excess

Operated reactor objects

- Fission systems leave long-lived fission-product and activation signatures after operation.
- Most relevant stand-off observable: gamma lines, especially the 661.7 keV line from ^{137}Cs.
- Neutrons are usually less diagnostic than for RTG targets; geometry and shielding matter strongly.
- Representative cases: SNAP-10A, BES-5 / Buk, TOPAZ heritage objects.

Typical stand-off emphasis: gamma spectroscopy

Representative signatures at ~100 m standoff distance

TRIAD-01 RTG

n ≈ 0.016 cm^{-2} s^{-1} (nominal)

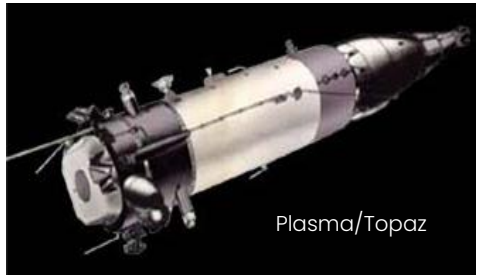
SNAP-10A reactor

661.7 keV gamma: ~1.5 cm^{-2} s^{-1}
core-only escape basis

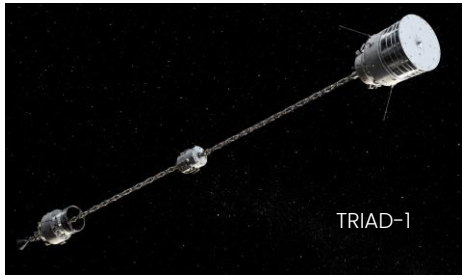
Exposed fuel only

alpha may be detectable only at close range

Message for WRMISS: the same gamma–neutron detector that supports REXIS target inspection can also acquire useful background radiation data in free flight.











REXIS (REACTOR EXAMINATION AND INSPECTION SATELLITE) mission

Phase 0 ongoing.

PRIMARY OBJECTIVES — PO-1 / PO-2

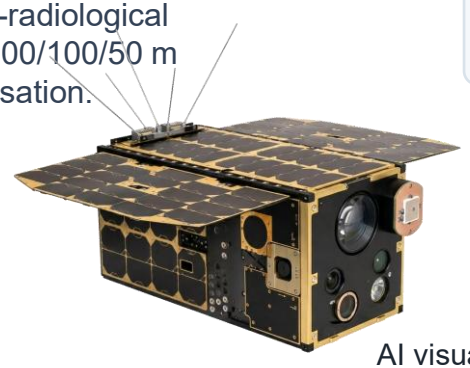
- PO-1 Visual inspection: ≥80% surface reconstruction, tumble state and ADR-feasibility evidence using visible and thermal-IR imaging.
- PO-2 Radiological characterisation: identify radionuclides—or set upper limits—and estimate source term and dose rate at 100 m.
- Operating geometry: gamma ≥100 m; neutron 50 m and ≥100 m; alpha <50 m (requirements TBC).

SECONDARY OBJECTIVES — SO-1 / SO-2

- SO-1 Gamma transient monitoring: opportunistic GRB/event detection in the 100 keV–1 MeV band.
- SO-2 Neutron-environment monitoring: continuous, geolocated background data outside proximity operations.

REXIS-DEMO

- Use the same sensor suite at an ESA-owned, non-radiological defunct target to validate autonomous approach, 200/100/50 m inspection, safe retreat and background characterisation.



AI visualisation

Mission profile

- High-inclination / near-polar LEO. Current DEMO design regime is approximately 690–1290 km and 90–100° inclination; the wider nuclear-target family extends to roughly 700–1500 km.
- Target-inspection geometry: background / far-field arcs → 5 km → 500 m → 100 m → 50 m range-stepped observations.
- Outside proximity operations, the payload can monitor ambient neutron and gamma fields continuously.

What REXIS measures

Gamma radiation

Alpha particles

Visible / thermal imaging

Neutrons

Range + attitude context

Background...

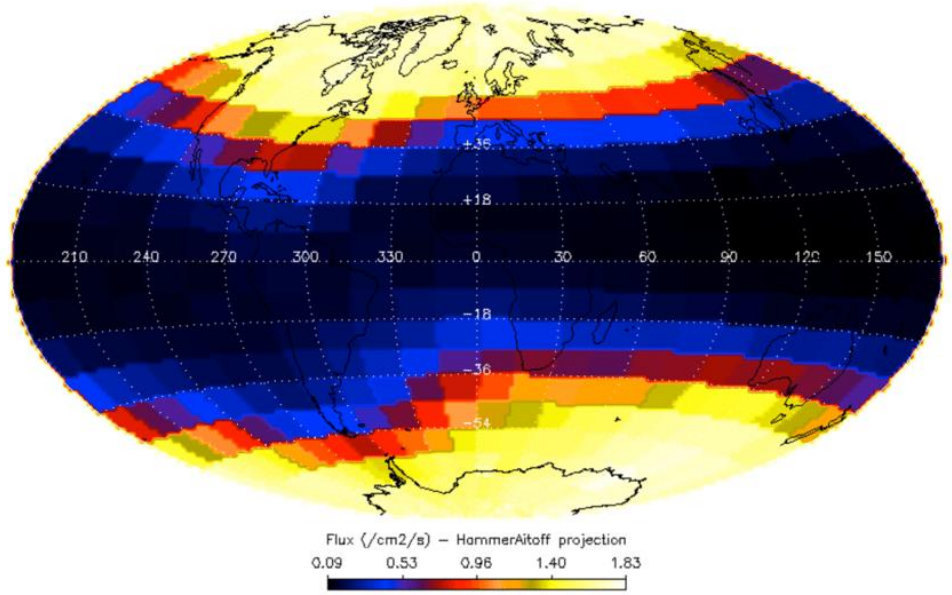
A. Target-associated excess

- Weak stand-off signals must be separated from orbital background.
- Range-stepped observations and line-of-sight changes test whether counts scale with proximity to the target.
- Gamma lines and neutron excess are interpreted together with optical/thermal geometry.

Primary mission use case

Albedo neutron simulation

Improvements of FLUKA Calculation of the Neutron Albedo
DOI:10.1109/TNS.2016.2611019



B. Ambient orbital field

- Earth albedo, trapped-particle secondaries and spacecraft-generated background vary with orbit and geometry.
- Continuous free-flight data are needed to interpret target observations and support spacecraft dosimetry.
- This background dataset has stand-alone value.

Secondary science use case

What about to map albedo neutrons?

What has actually been measured in LEO?

ISS-rich, free-flight sparse — and often difficult to compare because altitude, shielding, geometry and energy response differ.

Dataset	Environment	What it provides
ISS-RAD FND	ISS internal (~400 km)	0.2–8 MeV neutron spectra and dose; long-duration crew-environment record.
BTN-M1 / BTN-M2	ISS internal + external	Thermal-to-fast monitoring, SAA structure, long solar-cycle context.
Radi-N / Radi-N2	ISS internal	Week-long surveys and dose-equivalent synthesis; strong shielding dependence.
NEXTSat-2 / LEO-DOS	Free flight (~550 km, 97.8°)	Closest modern analogue for external mapping; stilbene response in ~1.6–8.5 MeV band.
OSO-6 / COMPTEL / FIB	Historical free-flight or external	Earth-albedo and solar-neutron measurements at MeV to high energies.

Altitude / geometry snapshot



Closest modern external analogue is LEO-DOS, but it operates well below the REXIS target-family altitude regime.

What is still missing in polar free-flight LEO

Altitude regime

Sparse external measurements above the ISS and especially across the ~700–1500 km target range.

Free flight vs structure-coupled

ISS datasets are invaluable, but station geometry and local shielding strongly affect the field seen by the detector.

Co-registered context

Attitude, geomagnetic coordinates, altitude, live time and detector state are often not packaged together in reusable public products.

Instrument response transparency

Response matrices and spacecraft mass models are rarely distributed together with derived environmental quantities.

This is why REXIS should claim a new geolocated dataset in a poorly covered regime.

REXIS contribution to albedo neutrons measurement

The main gap is the lack of a well-characterised external dataset in the altitude and geometry regime relevant to REXIS.

REXIS CONTRIBUTION

- Extend free-flight neutron measurements from ~550 km to 700–1500 km in a near-polar orbit.
- Separate Earth-albedo and spacecraft-secondary background from target-correlated excess using baseline arcs, range and attitude changes.
- Co-register native counts with UTC, position, altitude, geomagnetic coordinates, attitude, range, live time and quality flags.
- Publish response matrices and the spacecraft mass model; keep measured counts distinct from model-derived flux.

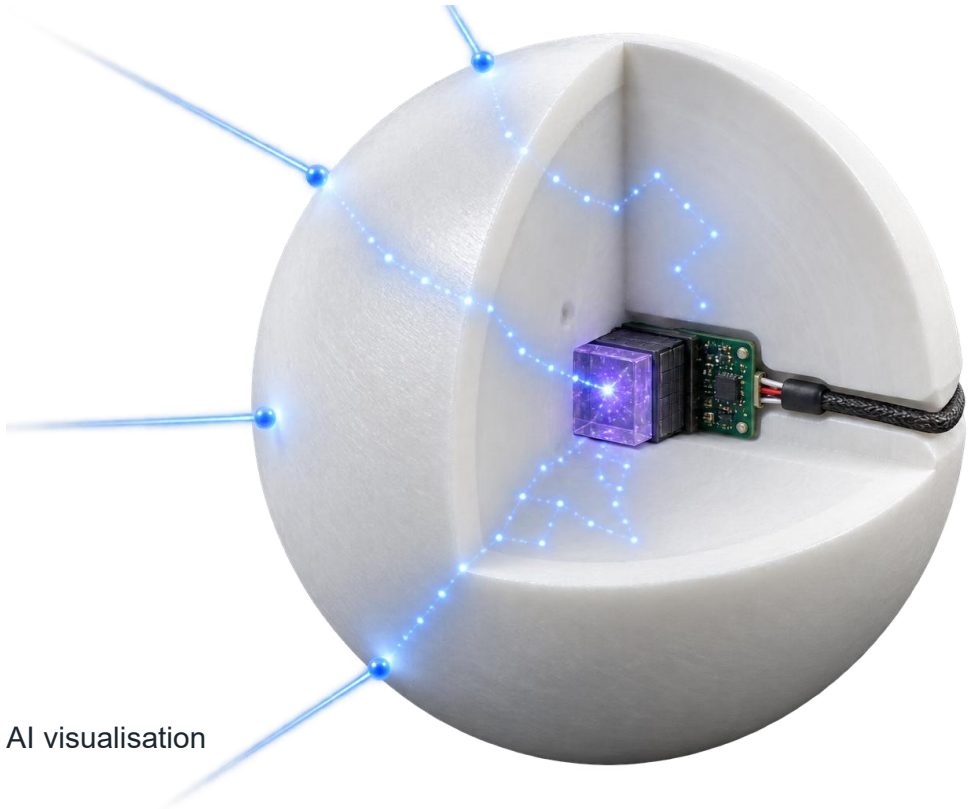
SCOPE AND LIMITS

- The preliminary GN head is strongest for 1–4 MeV target/background discrimination; it is not a multi-sphere dose-equivalent spectrometer.
- Radi-N/Radi-N2 (2026) found ~50% of ISS neutron dose equivalent above 15 MeV; REXIS results must not be generalized to total crew dose.

Community use

transport-model validation, dosimetry support, interpretation of mixed fields and target observations

The REXIS gamma–neutron detector: architecture



AI visualisation

12 cm HDPE moderator	hydrogen-rich sphere used to moderate fast neutrons into a detectable capture signal
Central ^{6}Li-CLLBC crystal	38 × 38 mm baseline scintillator; CLYC retained as the fallback material
4 × 4 SiPM + SIPHRA readout	compact photodetector/readout chain compatible with a microsatellite resource envelope
Dual observable instrument	^{6}Li-CLLBC scintillator measures 100 keV–1 MeV photons; ^{6}Li-capture region near 3.1–3.2 MeV (pulse shape discrimination)

To be developed at CTU...

Preliminary GN accommodation: 1.2–1.5 kg, 1.1–1.3 L, ≤3 W

Why this architecture?

The baseline is a compact “scintillator-in-sphere” compromise: not perfect at everything, but strong for the specific REXIS problem.

One compact head

Shared housing, interfaces and electronics for both gamma and neutron science.

High neutron acceptance

Moderation in HDPE improves sensitivity to weak 1–5 MeV neutron fields.

Useful gamma capability

The same crystal supports reactor-oriented gamma spectroscopy.

Clear neutron signature

^{6}Li capture provides a distinctive analysis window.

Microsatellite compatible

Mass, volume and power fit a low-resource mission better than many multi-head alternatives.

Fallback retained

CLYC can be substituted if CLLBC procurement or qualification becomes problematic.

Pros and Cons of gamma-neutron detector

Strengths

- **Large neutron collection geometry**
- **Optimised for the weak RTG neutron signal**
- **Good charged-particle shielding,** the HDPE Bonner sphere provides substantial shielding of the central detector from the orbital charged-particle environment.
- **Simultaneous gamma and neutron measurements**
- **One common detector configuration for both reactor and RTG targets**
- **Clean ^{6}Li neutron-capture signature**, allowing neutron selection primarily by pulse height and reducing dependence on PSD for nominal neutron detection.

Weaknesses

- **Nearly omnidirectional neutron response**
- **No stand-alone neutron spectrum from a single sphere diameter**; it is not a full Bonner-sphere spectrometer.
- **Gamma performance is degraded by the HDPE moderator** through attenuation and additional Compton scattering.
- **Detector response is strongly coupled to the moderator, mechanical support and spacecraft geometry (incl. spacecraft-induced background)**
- **CLLBC is hygroscopic and requires hermetic packaging**
- **Single-head architecture reduces redundancy**
- **Technology maturity is still relatively low,** the integrated configuration has not yet been demonstrated in the relevant space environment.

In-orbit measurement strategy and data products

Polar background arcs
free-flight counts

Belt / high-rate intervals
reduced-bias or safe mode

Target approach
range-stepped observations

Retreat / follow-up
background re-check

What is co-registered

- UTC and live time
- Position, altitude and geomagnetic coordinates
- Attitude and detector state
- Temperature and quality flags
- Target range / geometry during proximity operations

Interpretation workflow

Measured counts → what the detector directly observed

Detector-folded model → what the instrument should see for a given field

Environmental inference → derived field estimate with uncertainties

What can REXIS actually validate?

The useful comparison is detector-folded prediction versus geolocated measurement — not a claim that one compact head reconstructs the full neutron spectrum.

Model inputs that vary along the orbit

- Altitude and Earth geometry
- Geomagnetic cutoff / latitude
- Neutron energy and arrival angle
- Solar modulation / time dependence
- Spacecraft material surrounding the detector

Modern albedo models already include several of these dependencies; the problem is sparse validation in the REXIS orbital regime.

REXIS comparison quantity

Environmental model
predicted neutron field at spacecraft location

↓

Detector + spacecraft response
Monte Carlo folding through moderator and mass model

↓

Measured counts
time-, position- and attitude-tagged observables

Compare in count space first; infer environmental flux only after response and uncertainty propagation.

What REXIS can test well

- Spatial gradients along a high-inclination / near-polar orbit.
- Altitude dependence across the mission target regime.
- Repeatability and temporal changes within the mission lifetime.
- Agreement between multiple transport models after folding through the same response.

Scope limit

The baseline GN head is most informative for its own response band; it must not be generalized into a complete crew-dose neutron spectrum.

What REXIS needs from the WRMISS community

The science value can be increased before launch if the response, calibration and data products are designed for reuse from the start.

Data products

Agree on a compact geolocated schema: native counts, live time, detector state, ephemeris / attitude, geomagnetic coordinates, response version and quality flags.

Calibration & intercomparison

Identify useful reference neutron fields and an intercomparison strategy with LEO-DOS, ISS-RAD / BTN and ground facilities.

Model comparison

Define a common benchmark in count space for Geant4 / CRAND and other transport-environment tools before converting to environmental quantities.

Release & reuse

Keep response matrices, uncertainty metadata and spacecraft mass-model information versioned with the measurement products.

Desired outcome from WRMISS: feedback on the calibration / response plan and on a data format that is genuinely useful for later model validation and dosimetry studies.

Conclusions

REXIS adds a new measurement regime	Free-flight high-inclination / near-polar measurements at substantially higher altitude than the ISS and the ~550 km LEO-DOS reference case.
The albedo dataset is mission-critical	It is both a science product and the background model needed to identify weak target-associated neutron excess.
The detector is deliberately non-directional	The moderated CLLBC / CLYC concept trades directional reconstruction and full spectroscopy for neutron acceptance, compactness and a shared gamma–neutron head.
Useful data require transparent response information	Native counts, live time, calibration, response matrices, spacecraft mass model, attitude / ephemeris and uncertainties must travel with every derived result.

Thank you • Discussion welcome

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ANTS 2026 | Advanced Nuclear Technologies in Space

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