SURVEY CONTROL NETWORK MAINTENANCE AND COORDINATE UPDATE STRATEGY AT THE RAON HEAVY-ION ACCELERATOR*

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Abstract

RAON needs a stable geodetic reference network to support the precision alignment of its accelerator beamlines and experimental devices. This paper describes how that network is maintained. It is re-observed periodically to check the stability of the floor monuments and to update the alignment reference coordinates, and because the measurements have to fit into short shutdown periods, the aim has been to shorten the workflow and simplify the instrument setup without giving up accuracy, combining digital leveling for the vertical coordinate with laser tracker measurements for the horizontal ones. Four in-house digital leveling campaigns have since been completed in an area with unrestricted access. They reproduce the spatial pattern of the earlier measurements, but the loop closure errors are still too large for a coordinate update, and the candidate causes identified so far are to be examined in dedicated tests before the vertical data are released as a new reference.

INTRODUCTION

RAON is Korea's rare-isotope accelerator facility, operated by the Institute for Rare Isotope Science (IRIS) of the Institute for Basic Science (IBS) in Daejeon [1]. The total beamline length is approximately 1.3 km, and the survey control network that supports its precision alignment consists of approximately 700 floor monuments and 500 wall monuments [2].

The low-energy superconducting linac (SCL3) was commissioned and has been used for beam operation since 2023. For the high-energy superconducting linac (SCL2), the tunnel and the cryogenic distribution system exist, but the cryomodules are still under development and are not yet installed [3].

The survey control network was established in 2019 and was subsequently remeasured and updated on an annual basis by a specialized external metrology contractor through 2023. As the facility has moved into routine user operation, two constraints have become dominant. First, the areas under beam operation are accessible only during scheduled shutdown periods, so any network maintenance must be completed within a short and fixed time window. Second, network maintenance is progressively being transferred from the external contractor to the in-house alignment team, which requires the procedure, the achievable uncertainty and the repeatability to be quantified before a coordinate update can be released.

This paper looks back at how the RAON survey control network has been monitored since 2019 and at two attempts to update part of it under realistic access constraints. The maintenance strategy now in use follows from what those attempts showed.

THE RAON SURVEY CONTROL NETWORK

The RAON accelerator complex and the section addressed in this work are shown in Fig. 1. The control network consists of floor monuments, installed along the beamline in the tunnels and in the experimental halls, and wall monuments, which provide additional geometric constraints and elevated targets. Floor monuments are stainless steel and epoxy-anchored in drilled holes, while wall monuments are fixed with anchors; both carry 1.5-inch reflector mounts [2]. The areas of the building are separated by thick concrete structures, so the network is carried between them through alignment holes of 200 mm diameter [2]. All monument coordinates are expressed in the RAON global coordinate frame, whose final origin is defined at the first SCL2 cryomodule [2].

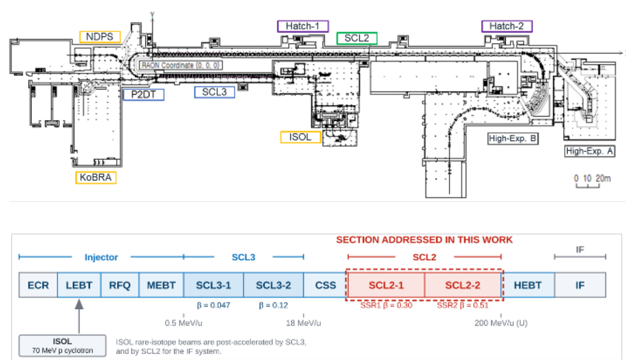

Figure 1: Layout of the RAON accelerator (top) and the accelerator lattice (bottom).

The network is realized in a conventional way: vertical coordinates (Z) are determined by precise digital leveling, horizontal coordinates (X, Y) are determined by laser tracker measurements, and the two data sets are combined in a global bundle adjustment [2]. In the following, this combination of a laser tracker (LT) and a digital level (DL) is referred to as the conventional method, and it is used as the reference against which simplified schemes are evaluated.

Every component alignment at RAON is referred to this network, so its internal consistency and its long-term stability set the limit on the tolerance that can be guaranteed: ±150 μm for most devices and ±1 mm for the superconducting cavities [2].

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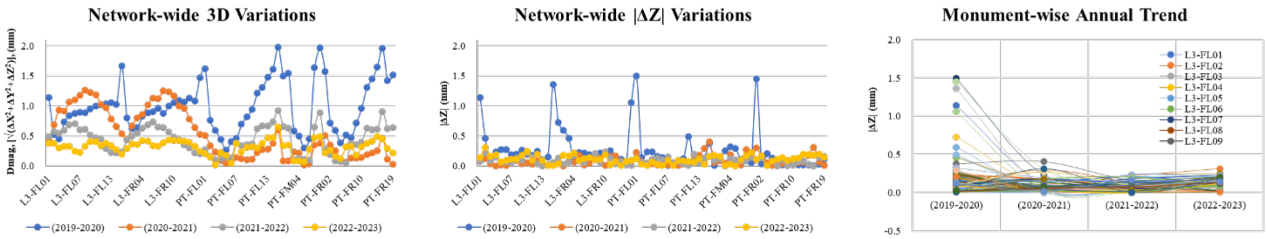

Figure 2: Epoch-to-epoch coordinate differences of the SCL3 control network. Left: network-wide 3D difference magnitude. Centre: network-wide absolute vertical difference. Right: monument-wise annual trend of the absolute vertical difference.

PERIODIC MONITORING, 2019–2023

Monument installation started in the SCL3 area in 2019, and the survey control network was established in the same year. From 2020 to 2023 the network was remeasured annually so that coordinate changes and long-term structural movement could be tracked [2]. The epoch-to-epoch coordinate differences obtained from these campaigns are summarized in Fig. 2.

The network-wide 3D difference magnitude and the absolute vertical difference are largest for the first interval, 2019–2020, where individual monuments reach up to about 2 mm, and decrease monotonically over the following intervals. For the last interval, 2022–2023, the majority of monuments remain well below 0.5 mm. The monument-wise trend shows the same behaviour: the initially scattered values converge after 2020–2021 and remain grouped thereafter.

This behaviour is consistent with structural settlement following the completion of civil construction. More than three years after construction was completed the movement has largely died away, yet epoch-to-epoch changes of 0.2–0.3 mm still remain in parts of the network.

The network coordinates are therefore valid only for a limited period and have to be re-observed periodically. Without that, movement of the building and of the monuments cannot be told apart from apparent changes of the accelerator components.

LOCAL NETWORK UPDATE UNDER SHORT-SHUTDOWN CONSTRAINTS

Background

During the summer 2025 shutdown a beamline alignment check and the installation of reference markers for target positioning were carried out in the low-energy experimental area. In the course of that work, coordinate changes were detected in part of the control network, which could indicate local structural movement. A local three-dimensional coordinate update of the affected part of the network was therefore required.

The area is under beam operation, so the update had to fit into a short shutdown between user beam experiments. The conventional method, which requires a digital leveling campaign in addition to the laser tracker measurement, does not fit into such a time frame when it is executed by the in-house team. Two simplified schemes were therefore tested against the conventional method.

Measurement Schemes

Scheme (A) used a laser tracker only, with the vertical coordinate also taken from the tracker. Scheme (B) added a total station (TS). In scheme (A) each tracker station observed only the monuments in its immediate vicinity, which leaves the network weakly constrained globally and allows a smooth drift to build up along it, and the total station was meant to tie the stations together and suppress that drift. Both were evaluated against the conventional LT + DL result in terms of the required time, the instrumentation effort and the resulting coordinate uncertainty, as summarized in Table 1.

Table 1: Simplified Schemes Compared with the Conventional Method

Scheme	Time	Instrument	Uncert.
Conventional	–	–	reference
(A) LT only	shorter	simplified	higher
(B) LT + TS	no gain	no gain	≈ (A)

Findings

Scheme (A) was faster and simpler, but its coordinate uncertainty sat well above that of the conventional method, above all in the vertical component. Scheme (B) did not recover the accuracy, and the extra instrument setup ate up the time advantage, so it gained nothing on either count. Only one campaign fitted into the available shutdown, so the reproducibility of either scheme remained untested.

Neither simplified scheme can therefore replace the conventional method for an update that is to be released as a new reference. A fast method is still needed, one that keeps the accuracy of the conventional method and carries enough redundancy to show that the result repeats. It was decided to reproduce the conventional method in-house first, in an area where access is not restricted, to quantify what the team can achieve before any update is issued.

TRIAL OF A LOCAL UPDATE BY THE CONVENTIONAL METHOD IN SCL2

SCL2 as a Controlled Testbed

SCL2 was chosen as a controlled testbed. Wall and floor monuments are already installed there, and the area was measured in several campaigns by the external metrology contractor, so a reference data set exists, and the coordinates in it proved comparatively stable from one campaign to the next. With no beam operation and no installed cryomodule, access is free enough for trials to be repeated as often as needed.

The target workflow runs from precise digital leveling with a Leica LS15 for the vertical coordinate, through laser tracker measurement with a Leica AT960LR for the horizontal coordinates and a global fit of all observations in the Unified Spatial Metrology Network (USMN) bundle adjustment of SpatialAnalyzer (SA), to the release of a validated coordinate set. Before the fit, the leveled heights are reduced to a single plane: the height difference introduced by the curvature of the Earth is computed for each floor monument from its distance to a virtual apex and removed. This geodetic line correction is already standard practice at RAON. Digital leveling is the step currently under investigation.

Digital Leveling Campaigns in 2026

Four in-house digital leveling campaigns were carried out in 2026, with a factory calibration of the instrument in between (Table 2). Coverage, duration and environmental conditions were varied on purpose, so that their influence on the result could be assessed.

Table 2: In-House Digital Leveling Campaigns in SCL2.

No.	Date	Coverage	Closure
1st	May 2026	Full SCL2, multi-day	723 µm
calib.	Jun. 2026	LS15 factory calibration	–
2nd	Jul. 2026	Partial, multi-day	n/a
3rd	Aug. 2026	Full SCL2, 2 days, FWD and RTN on separate days	512 µm
4th	Aug. 2026	Half of SCL2, 1 day, ventilation off	n/a

The leveling route is shown in Fig. 3. Each campaign consists of a forward (FWD) run along the tunnel and a return (RTN) run over the same monuments, so that the loop closure can be evaluated and a closure correction can be applied before the data enter the network adjustment.

Forward–Return Consistency

Figure 4 shows, for each monument, the elevation from the RTN run minus that from the FWD run, plotted in survey-route order, for the three 2023 contractor campaigns and the 2026 in-house campaigns. All three 2023 campaigns stay close to zero, within roughly ±100 µm over the whole route. The 2026 campaigns do not. Their difference keeps one sign throughout: every monument comes out higher on the way back than on the way out.

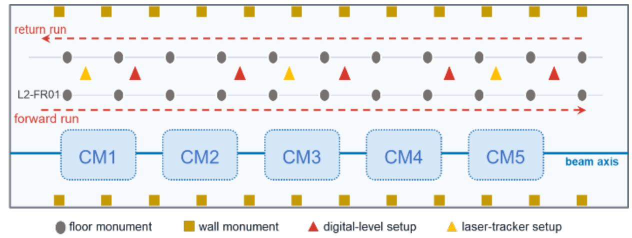

Figure 3: Schematic of the SCL2 leveling route.

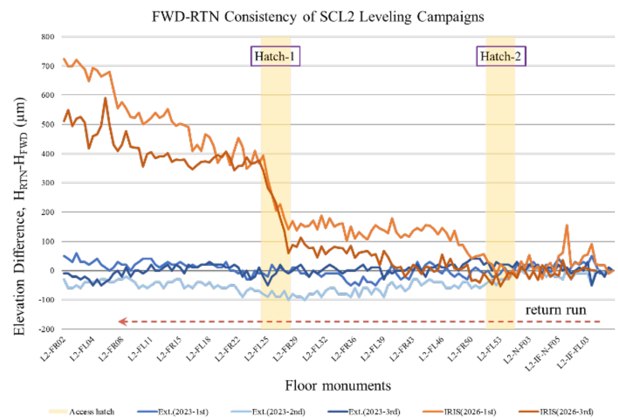

Figure 4: Difference between the forward and return runs of the SCL2 leveling campaigns.

The FWD run starts at the left of the plot and the RTN run returns from the right, so the difference is near zero at the turning point and builds up towards the start, reaching the measured closure errors of 723 µm and 512 µm in the first and third campaigns. It is a misclosure of the leveling loop, not a height change of the floor. Superimposed on it, a step-like change of about 250 µm occurs near the Hatch-1 access region. It appears at the same place in the first and the third campaign, and in the incomplete second campaign as well, so it is reproducible and tied to the location.

These closure values are large for a control survey of this type and lie outside the range normally accepted as input to a weighted bundle adjustment. The vertical data therefore cannot be released as an updated reference until the cause is identified. One check on the instrument itself lies between the two full campaigns: the LS15 was returned to the manufacturer for calibration in June 2026, and the closure error of the next full campaign fell from 723 µm to 512 µm. Part of the discrepancy may therefore have been instrumental, but the step at the hatch survived the calibration unchanged.

Monument Elevation Profiles

To separate a measurement effect from real floor movement, the relative elevation profiles of the SCL2 floor monuments were compared with the average of the 2023 campaigns. The result is shown in Fig. 5.

The 2026 profiles reproduce the 2023 spatial pattern down to the local features, and differ only by a small overall positive offset. The SCL2 floor has therefore not changed appreciably between 2023 and 2026, which is what makes the area usable as a controlled testbed and leaves the measurement itself as the source of the discrepancies in Fig. 4.

Several causes were considered: the local response of the floor and of the structure at the instrument setup positions, in particular on and near the hatch covers; forced airflow from the ventilation system; vibration in the tunnel; and operator technique. The fourth campaign was run with the ventilation switched off to remove the strong airflow. The overall offset dropped slightly; the step in the hatch area did not move. Airflow is therefore not what drives the step, and a mechanical or setup-related effect at the hatch is the more likely explanation.

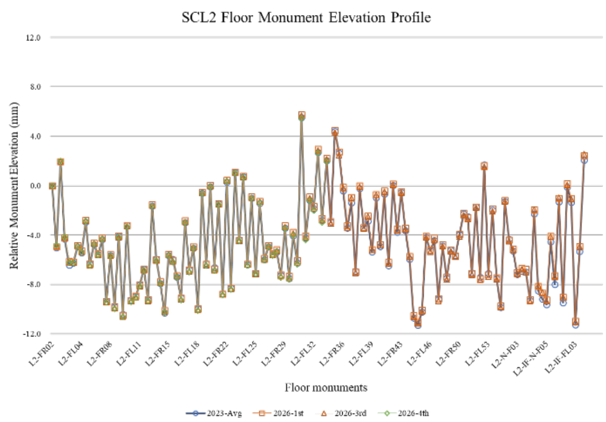

Figure 5: Relative elevation profile of the SCL2 floor monuments.

NEXT STEPS

Vertical Component

The digital-level setup locations will be optimized first, so that instrument stations and turning points sit away from the access-hatch region. A vibration study in the SCL2 tunnel will then show how much ambient vibration affects the measurement and whether particular equipment is responsible.

Horizontal Component and Station Planning

Once the vertical component has been validated, a laser tracker campaign with the AT960LR will follow for the horizontal coordinates, then a USMN global fit and the release of the updated coordinates. The station layout will be optimized in advance using the measurement planning (MP) functionality of SA.

The scheme under consideration is an extended overlapping stationing. In the local update described above the tracker was moved in short steps and each station observed only the monuments nearest to it. Here the stations are spaced further apart and each covers a longer section of the tunnel, so that adjacent stations share as many monuments as possible. More redundant observations then enter the USMN bundle adjustment, which should stiffen the network globally and keep errors from accumulating along the chain of stations. What the simulation has to settle is the balance between the number of stations, which sets the measurement time, and the amount of overlap, that is, the number of monuments that adjacent stations have in common, which sets the redundancy. Since it returns a predicted coordinate uncertainty for each candidate layout, the number of stations can be fixed against a target uncertainty instead of against a fixed spacing. That the layout matters in practice is visible elsewhere: at the KEK injector linac, adding a single station changed the shape of the horizontal coordinate uncertainty along the beamline [4]. The simulation should predict such effects before a campaign rather than after.

CONCLUSION

The RAON survey control network, established in 2019, was monitored and updated annually by an external metrology contractor through 2023. The movement fell off over that period, but epoch-to-epoch changes of about 0.2–0.3 mm remain, so the coordinates cannot be treated as a permanent as-built set. When a local update was later needed in an area under beam operation, a simplified laser-tracker approach fell short of the conventional method in both accuracy and repeatability within the access time available.

In SCL2, digital leveling was reproduced by the in-house team, but large forward–return discrepancies, closure errors of 512–723 µm and a recurring step near the access hatch are still unresolved. The 2026 elevation profiles reproduce the 2023 spatial pattern down to its local features, which places the cause in the instrument or the procedure rather than in the floor itself.

A tunnel vibration study and better digital-level setup locations away from the access hatch come next, followed by laser tracker measurements for the horizontal coordinates with a simulation-based station layout. What all of this is aimed at is a documented in-house procedure, with a stated uncertainty budget and a repeatability that has been demonstrated rather than assumed, that fits inside a short shutdown and that says when a coordinate update is released and when the existing reference is kept.

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