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THE SPES TARGET ION SOURCE AUTOMATED STORAGE SYSTEM

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Abstract

At the SPES (Selective Production of Exotic Species) facility, intense Radioactive Ion Beams (RIBs) are produced by the interaction of a 40 MeV proton beam with a multi-foil uranium carbide target employing the Isotope Separation On-Line (ISOL) technique. The Target Ion Source (TIS) unit constitutes the core of the isotope production process. TIS units are replaced on a periodic basis during operation to maintain high performance. An automated storage system has been designed to accept highly radioactive TIS units and house them during a cooling period prior to decommissioning. The system is conceived to meet strict functional and safety requirements. Its peculiar design allows for improved reliability and availability during critical operations, as well as minimization of staff exposure to ionizing radiation during maintenance tasks. This contribution describes the design and control architecture of the Temporary Storage System (TSS). The equipment is part of a structured framework of remote manipulation, consisting of various machines interlocked with the Access Control System (ACS) and the Machine Protection System (MPS).

INTRODUCTION

The SPES (Selective Production of Exotic Species) project of INFN-LNL (Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro) is building a facility for interdisciplinary research on Radioactive Ion Beams (RIBs) [1, 2]. The fission reaction triggered by the impact of the 40 MeV 200 μA Primary Proton Beam (PPB) with 7 UCx disks enables the production of the isotopes [3, 4]. The interaction point lies within the so-called Target Ion Source (TIS) unit, a vacuum chamber installed on the SPES Front-End [5].

The progressive target efficiency reduction demands the replacement of the TIS unit on a constant schedule. Due of the extremely radioactive environment [6], a network of remote handling devices is used to take care of this need in an automated manner. Following the irradiation on the SPES Front-End, exhausted TIS units must be stored in a secure area for radioactive decay before being disassembled. In the context of the SPES remote handling framework [7], a novel storage system has been built based on the knowledge gathered in existing ISOL (Isotope Separation On-Line) facilities [8–10]. In this work, the SPES Temporary Storage System (TSS) is presented. Figure 1 depicts an illustration of how an irradiated TIS unit is transferred from the leading SPES remote handling vehicle, known as the Horizontal Handling Machine (HHM), to the TSS. The system, which is

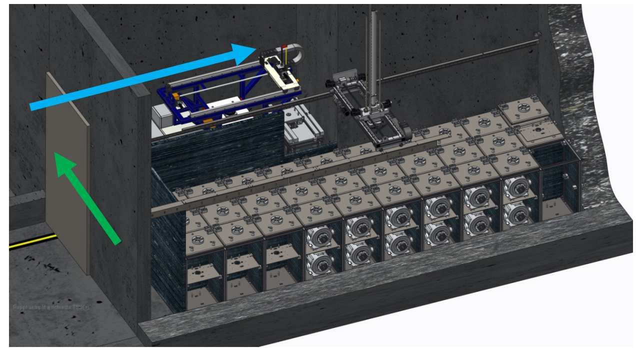

Figure 1: 3D view of the SPES Temporary Storage System. In this example, an irradiated TIS unit removed from the SPES Front-End is installed on the TSS slider by the HHM.

conceived to meet strict functional and safety requirements, may accommodate up to 54 irradiated TIS units for a cooling time of 2 to 5 years

SHIELDING AND VENTILATION

The admission of authorized operators to specific classified working zones is controlled by an Access Control System (ACS), which is continuously monitoring the SPES target area. Personal Protective Equipment (PPE) is required for workers to reduce the risk of contamination [11]. The TSS storage architecture was designed to maximize shielding between the personnel-accessible area and radioactive sources introducing multiple lead sheets between the storage modules. In this configuration, highly radioactive TIS units are stored in the inner positions, whereas less activated ones are retained in the outer modules. The use of radiation-tolerant materials ensures the system's robustness [12, 13]. The TSS environmental dose contribution has been assessed in thorough simulations taking into account the TSS filling

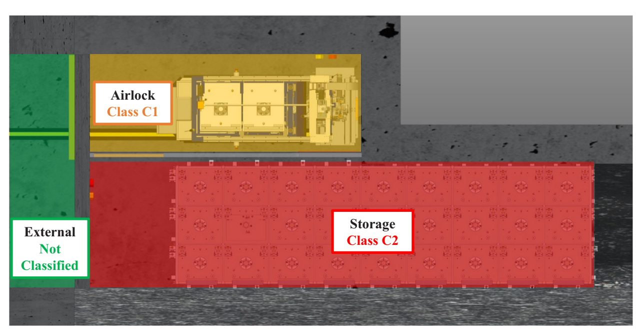

Figure 2: Map of the TSS containment areas classification based on the expected permanent level of surface contamination, according to ISO 17873.

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rate based on the SPES operational schedule and considering full irradiation cycles at nominal power [14]. Exhausted TIS units are removed after a five-year cooling time to be disassembled and properly disposed of in a dedicated Hot Cell.

The different TSS zones are maintained at specific air pressures according to the International Standard ISO 17873 [15] to ensure a controlled air flow from various locations according to their expected contamination level. While the external corridor is a non-classified zone, the storage area is designated as a C2 zone. The introduction of an airlock sector (C1) prevents air from mixing through an access door and a ventilation gate. The first is utilized by the HHM to enter the area and offload irradiated TIS units onto the TSS slider, while the second allows the chamber to enter the TSS cartesian manipulator working zone. Figure 2 reports the described zone classification. The room pressure is constantly monitored by the ventilation control system, which permits brief transients during handling operations while preventing the simultaneous opening of the two access doors.

HARDWARE DESCRIPTION

This section will describe the three primary TSS functional units: the storage rack, the cartesian manipulator and the sliding table. The basic module, shown in Fig. 3, offers six storage places, distributed across three columns and two levels. Combining 9 modules, the TSS storage rack features a total capacity of 54 TIS units. To ensure an acceptable dose rate, vertical lead sheets surround each column, a removable shelf divides the two storage levels, and a shielding cover encloses the cell. During operation, shielding lids or shelves can be stacked on top of adjacent lids to free the trajectory towards a specified storage spot. Each rack element features a standardized coupling interface intended for use with the cartesian manipulator. Redundant mechanical switches are

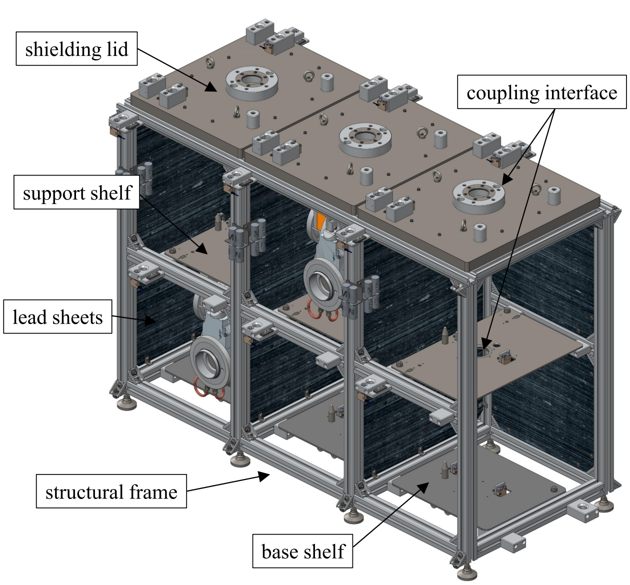

Figure 3: Basic functional unit of the TSS rack. Each storage module is designed to host 6 TIS units.

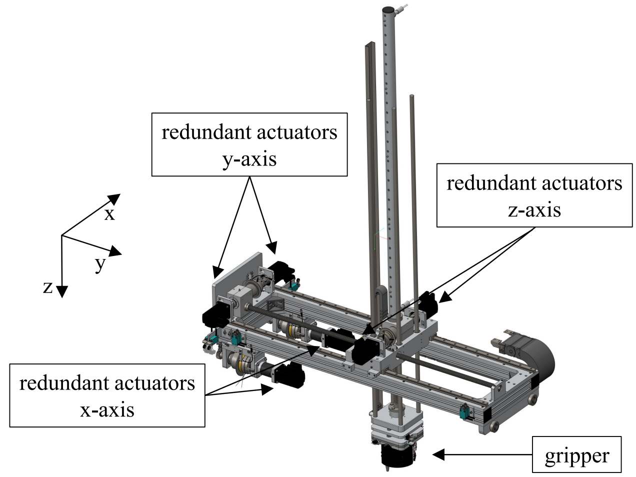

Figure 4: View of the TSS cartesian manipulator.

used in each location to determine the proper placement of TIS units, shelves, and lids within the frame. The TIS units removed from the SPES Front-End by the HHM are placed on a sliding table inside the TSS airlock. This device enables the object to be moved over the storage rack, where it can be picked up by the TSS cartesian manipulator. A ventilation gate in the normally closed position maintains the differential pressure between the TSS airlock and the storage area. During the loading and unloading phases, the gate opens, allowing the TIS unit to be transferred between the two workspaces. The radioactive TIS units are moved and positioned inside the storage rack by the TSS cartesian manipulator, visible in Fig. 4. This system includes three linear axes, each of which comes with backup actuators. This feature, in the event of a failure, enables the completion of the crucial task and securing the machine prior to inspections or maintenance, preventing staff exposure to excessive dose rates. The manipulator is equipped with a redundant pneumatic end effector: a quick tool changer used as the main gripper. This device can manipulate TIS units, shielding lids, and supports thanks to a standardized mechanical interface. A compensation module enables compliance with $\pm$ 5 mm misalignment in all directions, while a series of mechanical end switches stops the motion in the event of unexpected collisions. The main gripper is connected and powered by a backup unit. If a problem arises during the manipulation of a radioactive TIS, the backup gripper may be released to complete the task and restore the storage rack under safe conditions.

CONTROL AND SAFETY

Each storage cell can be modeled by identifying six distinct cartesian positions (or levels) on the standard coupling interface of the various motion payloads within the storage rack. Each location, such as the shielding lids, support shelves, or TIS units, is described by a set of coordinates encoded by a unique identifier and stored in a dedicated database. The operator selects a pickup location and an

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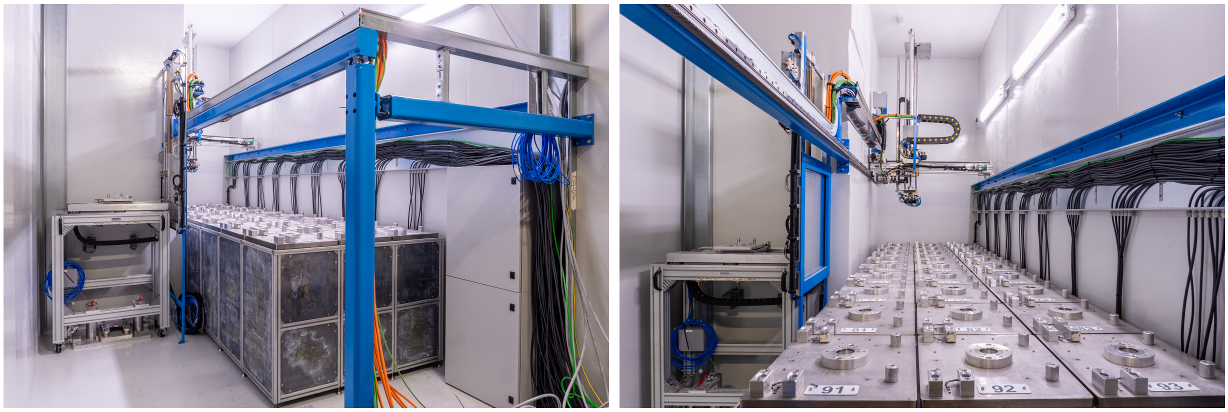

(a) (b)

Figure 5: The TSS during installation at the SPES facility. The slider, gate door, and storage rack appear in the side view (a), whereas the cartesian manipulator and storage rack are displayed in the top view (b).

available space within the rack to deposit a radioactive TIS unit for storage in the TSS. An automatic routine plans the required motion tasks to accomplish the storage sequence. The algorithm lists all the steps to free the trajectory from the TIS pickup location to the final storage destination. Thanks to a modular structure, the entire sequence can be divided into smaller tasks. Each sub-task includes a start (pick) and a destination (drop) location. Every position that the TSS cartesian manipulator can access vertically is equipped with redundant presence switches. Once grasped, the gripper's sensing devices acknowledge the proper TIS unit engagement before moving it to the drop point. At this stage, the presence switches at the destination site detect the positioned item and authorize the TIS unit release. The process is completed by lifting the manipulator to the top position while waiting for the next sub-task. The motion planning software is based on two nested state machines: the inner loop controls the execution of sub-tasks, while the external layer manages trajectories and executes the complete sequence. The TSS control system acts as the supervisor for the other remote handling devices, gathering control, safety, and interlock signals. This setup provides a single interface for connecting to both the SPES Access Control System (ACS) and the Machine Protection System (MPS). Two different Programmable Logic Controllers (PLCs) govern the control and safety logic. The first device manages standard physical or fieldbus (MODBUS TCP/IP) signals for system operation, whereas the second PLC exchanges double-channel signals with designated safety partners up to IEC 62061 Safety Integrity Level (SIL) 3.

TESTS AND VALIDATION

A TSS prototype has been created as a preliminary stage to validate the mechanical design and the control architecture. Comprehensive tests on this system confirmed the design choices on mechanical couplings, tolerances, fixings, etc. Furthermore, most critical components, such as switches, clutches, motors, and sensors, have been stressed to reveal potential system weaknesses. In a subsequent stage, an extensive test campaign has been conducted on the whole system with a specific focus on motion trajectories and control algorithms. Different TIS units have been shifted across all the storage locations within the rack, while the available support shelves and shielding lids have been manipulated to test the possible system configurations. Repetitive trials have confirmed the excellent quality of the system in terms of robustness, safety, and reliability. The full-scale TSS has been manufactured, assembled, and it is currently being installed in the SPES facility, as shown in Fig. 5. Once finalized, the commissioning plan will involve reliability, functional, and dysfunctional testing on the entire plant under actual operating conditions before it is put into service.

CONCLUSIONS

In this contribution, the SPES Temporary Storage System has been described in terms of its physical layout and control logic. An in-depth feasibility study has been developed with a specific focus on mechanical design, risk analysis, radiation-tolerant materials, control system architecture, and operational safety. The proposed solution complies with the facility's functional and safety requirements and will be soon integrated with the complementary machines of the remote handling framework. The experimental tests on the TSS prototype allowed for the validation of the system's conceptual layout as well as the hardware components. In addition, thanks to a robust and modular architecture, the control software developed for the TSS prototype can be conveniently scaled and deployed in the final system. Following the completion of the TSS installation, a comprehensive commissioning plan will be used to test the reliability of the system, the maintenance procedures, and the recovery scenarios in case of failure.

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