Risk Assessment of the SPES On-Line Front End: HAZOP and LOPA Analysis

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INTRODUCTION

The On-Line Front End represents the heart of the SPES facility. The system is currently in advanced installation phase in the ISOL Hall (S018): a shielded underground bunker enclosed by up to 4 meters thick concrete walls and ceiling. On this station the collision between the high intensity (up to 250 μA) primary proton beam (Ep ~ 30-70 MeV) and a multi-foil uranium carbide target within the SPES Target Ion Source (TIS) unit takes place. The Coupling Table, visible in Fig. 1, is responsible of the coupling and decoupling of the TIS unit with the protonic and radioactive beam lines, which needs to be periodically replaced for efficiency reasons. The robustness of this component is critical due to the limited possibility to perform maintenance interventions in such highly radioactive environment. For this reason, an extensive risk assessment has been developed to improve the system in terms of operational safety, hardware design, robustness and reliability. The quantitative analysis takes into account the most critical failure scenario during operation, their consequences and the proposed safety measures. A detailed description of the SPES On-Line Front End is reported in [1].

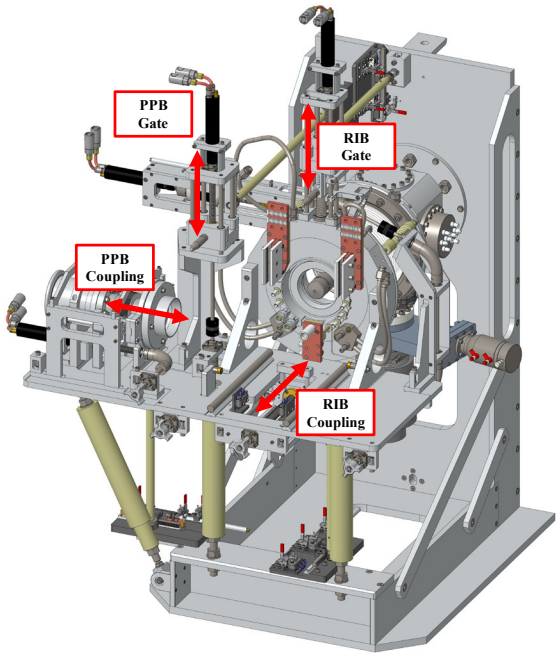

Fig. 1. SPES On-Line Front End Coupling Table (ST_FRE_02).

HAZARD AND OPERABILITY STUDY

The Hazard and Operability (HAZOP) Study [2] represents the first semi-quantitative risk assessment tool applied during the Probabilistic Hazard Assessment (PHA). A general study was developed in the past for the whole SPES facility [3,4]. Despite the correctness of the approach, the analysis was led by general safety perspective and was not focused on the Front-End Remote Handling operation. As a result, a specific study has been developed through a systematic approach aimed at identifying safety and environmental risks as well as major operational problems. The analysis focuses on the most critical components of the Front End Coupling Table and the Horizontal Handling Machine, in Fig. 2. The process starts with the systematical identification of dangerous situations, operability problems that may originate from deviations in the operating specifications and which could give undesirable (anomalous) consequences. In the subsequent phase, severity (S) and likelihood (L) levels are applied to the identified scenarios according to the SPES safety objectives harmonized directives, while safeguard measures and recommendations are provided. The resulting scenario is then evaluated according to the SPES safety objectives [5]. The reduced risk after the application of safeguard measures is then compared to the unmitigated risk for each scenario. The most critical events are the ones originated by deviations that cannot be automatically restored through the remote handling systems. In this case an operator must access the radioactive area and fix the problem. The proposed safeguard measures are intended to reduce the probability of human interventions thanks to the implementation of backup actuation systems, diagnostic devices, preventive maintenance program and periodic checks. On the other hand, severity is lowered reducing the exposure time through optimized intervention procedures, remote inspections, and operator training. The complete HAZOP analysis, applied to the SPES On-Line Front End is available in [6].

LAYER OF PROTECTION ANALYSIS

The Layer Of Protection Analysis (LOPA) [7] is a method used to evaluate high-risk scenarios and allows to determine the effectiveness of the proposed Independent Protection Layers (IPL) through a risk tolerability criterion.

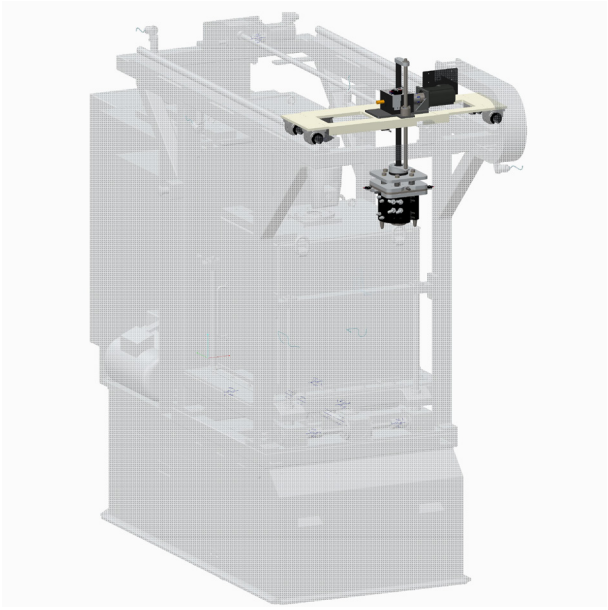

Fig. 2. Horizontal Handling Machine Gripper (ST_HHM_02_08).

The combination of two approaches represents the preliminary phase for the identification of the Top Events in the Fault Tree Analysis. As for the previous step, a general study on the global SPES facility is available [8], nevertheless it is not focused on the Remote Handling operation of the SPES On-Line Front End. For this reason, a specific LOPA analysis has been performed, narrowing the hazard scenarios emerging from the HAZOP analysis considering only the ones with human intervention required in the production bunker S018. In addition, for the study the facility is considered in maintenance mode, this case is critical because the effectiveness of the Access Control System (ACS), as IPL, is limited. The analysis allows to verify if the proposed IPLs are sufficient to meet the identified target frequency of occurrence for the specific hazard scenarios. In addition to IPLs, two conditional modifiers have been considered: the bypass of the Machine Protection System (MPS) and the implementation of backup actuation system, both measures can reduce the probability of human interventions. The LOPA analysis showed that final frequencies satisfy the target frequency for every hazard scenario except for the Extraction Electrode, where the existing IPLs are anyway sufficient to meet the order of magnitude. However, some IPLs are currently not fully implemented. In particular, there is a lack of maintenance procedures, a preventive maintenance program with periodic inspections and an operator training program. The details of the SPES On-Line Front End LOPA analysis are reported in [9].

RESULTS AND CONCLUSIONS

The HAZOP and LOPA analysis applied to the SPES On-Line Front End are extremely useful to identify critical hazard scenarios and the most effective independent protection layers. The start of operation of the system requires the completion of all the discussed safeguard measures to minimize the risks associated with the identified events. In particular, it is critical to develop a backup actuation system for the Extraction Electrode to face possible failures on the main actuator. The possibility to equip the Horizontal Handling Machine (HHM) with a dedicated backup actuation system is currently under discussion. With this configuration it would be possible to compensate the defective motion with an external device during a remote handling task. The goal is to allow the remote TIS unit removal, thus minimizing the major sources of radiations. The subsequent maintenance intervention will be therefore executed under minimized environmental dose. An experimental test campaign is currently under development [10] for the optimization of the maintenance interventions in the SPES ISOL Hall (S018) according to the ALARA (As Low As Reasonably Achievable) approach for the minimization of personnel exposure to ionizing radiations.

[1] F. D'Agostini, "DOC_00000122, I sistemi di movimentazione automatica della coupling table del front end del progetto SPES," Internal report, SPES Document Repository.

[2] IEC 61882:2016 - Hazard and operability studies (HAZOP studies) – Application guide

[3] Pilz Italia Srl, “Functional Design Specification (FDS) – SPES Project," INFN, v2, 2019.

[4] Pilz Italia Srl, “Hazard and Operability (HAZOP) Study – SPES Project," INFN, v3, 2019.

[5] M.L. Allegrini et al., HAZOP and LOPA analysis applied to SPES project, LNL Annual Report 2018.

[6] G. Lilli, M. Sanavia, "DOC_00000127, Hazard and Operability Study (HAZOP) of the SPES Front End during remote handling operation," Internal report, SPES Document Repository.

[7] IEC 61511-3:2016 - Functional safety - Safety instrumented systems for the process industry sector

[8] Pilz Italia Srl, “Layer of Protection Analysis (LOPA) – SPES Project," INFN, v8, 2021.

[9] G. Lilli, M. Sanavia, "DOC_00000128, Layer Of Protection Analysis (LOPA) of the SPES Front End during remote handling operation," Internal report, SPES Document Repository.

[10] M. Sanavia et al., "Maintenance assessment of the SPES Front-End," this Annual Report.