Laser Dismantling Environmental and Safety Assessment

PRESS RELEASE

Pierrelatte, 13th June 2023

European H2020 Research & Innovation Project

LD-SAFE

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INTRODUCTION

To meet the challenge of proposing a new innovative technology to the European nuclear decommissioning market (to improve safety, radioactive waste, time and cost aspects), LD-SAFE demonstrated, over the last three years, numerous outcomes and evidence for the preparation of future implementation of laser for RPV/RVI segmentation (PWR and BWR components).

PROGRESS

Please find below a presentation of the LD-SAFE Consortium contribution on all key technical activities carried out so far, and by topic.

- Laboratory trials and calculation (accomplishment of a first cutting campaign to feed the safety assessment):
  - Laser beam residual power: laser cutting process absorbs only a part of the laser power delivered to the work piece to melt and cut through. The unabsorbed laser power, called residual power, propagates in the form of optical radiation beyond the work piece and is likely to reach mechanical structures located behind it, so called background structures. Heat provided by the residual power can weaken or damage these structures by affecting their mechanical resistance or tightness.

    Therefore, CEA assessed, in laboratory conditions, the impact of laser beam residual power and the risk of damage on background structures in the context of dismantling of nuclear power reactors. Specific instrumentation was designed and tested to characterize the spatial intensity profile of residual laser beam and its thermal impact on background structures. Since the thermal impact depends on various parameters, such as cutting speed, distances between background structures and work pieces, material type to be cut and its thickness, laser cutting tests are carried out to gather data and plot graphs (build abacus charts) from which it is possible to estimate potential damages for specific workshop configurations.

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On the basis of the definition of the most representative material and most restrictive configurations of RVI cutting (including analysis of background structure), in air experimentations have been carry out, showing that the initiation phase of laser cutting process is a critical phase when the cut initiate at the edges of the work piece and the extent of damages depends on laser beam to work piece edge distance, secondly that residual power beam may generate blind kerfs of a few millimeters when the background structure is very close to a very thick work piece which has to be cut. Moreover, tests performed underwater showed the absence of residual power risk, due to absorption of water at the laser wavelength and the scattering of light by air bubbles.

Additional experimentations are on-going to identify the spatial intensity profile of residual laser beam on graphite plate and 304L stainless steel plate as background, at various distances (thermal impact of residual laser beam measured with thermal cameras).

- Secondary emissions (aerosols): the knowledge of the size distribution and the morphology of particles released during cutting operations undertaken for nuclear power plant dismantling activities is important for safety and radioprotection issues. This information allows predicting particle transport and deposition and particle behavior against confinement equipment implemented to avoid radioactive particles dispersion in the facilities and environment. Furthermore, quantitative characterization of the contaminated aerosols is essential to develop and optimize technologies to capture and contain particulate pollutants, mitigating against environmental contamination and human exposure.

  Airborne particles emitted during laser cutting of various grades of stainless-steel are submicronic particles with mainly fractal morphology. Results have been acquired by IRSN on aerosol characterization in terms of particle size distribution and morphology, mass and number concentrations, particle mass flow rate generation and agglomerates composition. Laser cutting trials were performed in air, nitrogen atmosphere and for underwater conditions. The repeatability of the airborne particle generation characteristics during laser cutting has been checked extensively during the trials, demonstrating the well-controlled conditions for the laser cutting process, for the aerosols sampling, and for the aerosols analyses both in terms of aerodynamics and physico-chemical measurements (by CEA). Main results show that the particle generation characteristics are not very dependent of the stainless-steel grade. Nitrogen atmosphere leads to a strong reduction of the airborne particle generation associated to a decrease of the particle size.

- Hydrogen gas generation: underwater cutting generates dangerous gases (H_2) and this risk has to be assessed.

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A first experimental study to evaluate hydrogen gas generation during laser cutting of 304L stainless steel of various thicknesses was performed in DELIA Facility (Saclay) by CEA. Specific sampling line and instrumentation were implemented to measure H2 during laser cutting as a function of the cutting speed and thickness. Preliminary measurements performed showed very low values of hydrogen concentration in air, in the range of few hundreds of ppm for the case of DELIA facility. However, as H2 concentration in air depends on the assist gas flowrate and airflow ventilate rate of the facility, these preliminary results must be adjusted with a scaling factor determined for each facility. An analytical study to understand physico-chemical mechanism of hydrogen gas generation during underwater laser cutting of 304L stainless steels is on-going, as well as a numerical simulation of thermal fields of the heat affected zone. SEM (Scanning Electron Microscope) and EDS (energy dispersive spectroscopy) analysis mapping the chemical composition of generated oxides are expected.

A second experimental campaign to measure H2 during cutting by laser underwater in various conditions and configurations is on-going. The objective is to compare experimental results to numerical results, and therefore refine the numerical model to be able to calculate H2 for other configurations.

- Protection of the Workers and environment:
  - Technology Appraisal: an assessment of the laser system maturity has been performed at the start of the project by Vysus Group. This consisted of defining project goals related to the performance of the laser system and to the protection of the workers and the environment. Once the goals were defined and agreed upon by the consortium, the laser system was broken down into individual components, their individual and integrated function within the laser system. Each component was then given a technology maturity rating based on the technology readiness level of the component and its maturity for use in a nuclear decommissioning environment. At this stage, each component risk has been assessed against the defined goals and safety requirements. The final output of the Technology Appraisal is a risk matrix that highlights components where uncertainty and/or risk that was at a level that required mitigation.

  - Technology Qualification: the technology appraisal report and the risk matrix were used as a foundation to create a set of activities and actions assigned to each of the partners and their associated Work Packages. The objective of the activities is to produce evidence to the effect that the identified risk has been mitigated or reduced to as low as reasonably possible. The basis of evidence has been assessed and scrutinized in a Technology Qualification (TQ) process. Upon completion of all activities to a satisfactory level, the TQ process will be end with the provision of a Technology Qualification certificate. This certificate will confirm that the identified risks regarding maturity of laser cutting

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technology for decommissioning in a nuclear environment have been mitigated, as demonstrated by the activities and actions throughout the TQ process.

  - Guidelines for the use of laser cutting technology in reactor dismantling environment: towards the end of the project, a set of guidance notes will be issued, incorporating lessons learnt in LD-SAFE (including laboratory trials both related to aerosol and gas generation, as well as the generic safety assessment). The guidance notes will be designed to aid end users in how to use lasers correctly, safely and efficiently in decommissioning activities of PWR and BWR components. The guidance provided will include activities to be performed before, during and after using the laser system both in-air and for underwater cutting.

- Safety assessment:
  - Risk analysis: a risk analysis was established by TECNATOM following a structured process (IAEA SRS No. 77). The preliminary identification and evaluation of radiological and non-radiological risks for normal and accidental conditions was performed in a complementary and iterative manner, considering IAEA checklists, a HAZOP study, and a benchmarking of risks identified for other RPV/RVI dismantling projects. Potential deviations from normal conditions were screened, identifying three initiating events that were further analyzed: fire/explosions, loss of filtration/local confinement, and drop of loads. The consequences were evaluated in a deterministic manner, qualitatively and quantitatively (predefined radiological inventory), and based on that, a recommendation of design options (for normal conditions) and safety measures (for abnormal/accidental conditions) was done. All the information was summarized in two risk matrixes: one for normal conditions and other for abnormal or accident situations.

  - Summary of risks identified (from laboratory tests and qualification activities): then, a compilation of all risks identified during laboratory tests and qualification activities have been performed, evaluating its impact on the Generic Safety Assessment.

  - Generic Safety Assessment: a Generic Safety Assessment has been developed, considering the outputs from the summary of risks, as well as many other information that became available within other project activities. Major assumptions and uncertainties identified in the risk analysis were solved or reduced. Due to the generic nature of the assessment, End Users would have to adjust the information to their specific conditions (i.e., radiological inventory and segmentation plan). It is expected that the Generic Safety Assessment will provide an added value to facilitate the safety demonstration of the laser use by the end-user in the frame of the licensing process.

  - Independent review: A review performed by IRSN of the Generic Safety Assessment has been done to ensure the appropriateness of the identified safety measures. The scope and level of detail of the independent review is commensurate with the safety stakes

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associated with the maturity of the laser technique and challenges of RPV/PPI dismantling tasks. Recommendations are provided to the End User to ensure the interfaces between LD-SAFE and target facility are covered, as well as recommendations to be considered within the safety assessment (including hypotheses to be verified within the industrial demonstrator operated by ONET).

- Demonstrators:

  Case study for the demonstrators: the development of the main requirements of the in-air and underwater demonstrators have been identified. The case study for the demonstrators gathers all the project outcomes, inputs, and expectations (from the members of the End User Group following questionnaires). It highlights the main challenges to address with the laser cutting technology and the main answers to provide to the future end users, including nuclear safety management. This set of goals to achieve is the baseline for the development of the demonstrator. To enhance this baseline, an overview of the reference environment and cutting scenarios are made. These items showcase typical constraints to be encountered in actual NPP dismantling worksite. Due to the non-radioactive nature of the mock-ups to be cut, some constraints cannot be considered in the case study. Nevertheless, an analysis has been made to include as much item as possible to ensure the best level of representativeness. With all these elements put together, the goals of the case study are implemented into quantified specifications, and the latter into requirements to perform the laser demonstrations (one for in-air cutting environment and the other one for underwater).

  This step allowed ONET to design, procure, install and commission the complete laser system. This representative and industrial system, which could be deployed in a real dismantling project, will be implemented at first at CEA Marcoule for in-air cutting tests, and then at ONET Technocenter for underwater cutting tests.

  - Mock-ups: designed to challenge the technology by anticipating difficulties expected to arise at the stage of operation. Those difficulties were identified, listed and grouped based on the information of the Case study and on the inspection and analysis of detailed PWR and BWR drawings. A design file has been written and included a representativeness note (i.e. a list of similarities and differences between the mock-ups and real internals). Representative, complex parts are expected to be attached and detached from a crudely designed support system; the complex parts and their arrangement will simulate geometric and congestion-related constraints. The mock-ups will then be transported towards the demonstrators in order to be tested in various conditions.

  - Preparation of the demonstrators: the procurement of the complete laser system is now finalized. Its implementation, installation and commissioning at CEA Marcoule is on-going whereas underwater demonstration is under construction. In regards with both

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demonstrators, accurate cutting scenarios for NPP have been developed to be included in the test programs (which will be elaborated with specific attention drawn to feedback collection). In-air cutting tests are planned for September 2023 and underwater demonstration is planned for December 2023.

CONCLUSION

Three years have been spent on the ambitious LD-SAFE project which aims to demonstrate that both the in-air and underwater laser cutting technologies are effectively operational for the dismantling of the most challenging components of Nuclear Power Reactors (Reactor Pressure Vessel and Internals).

One year is remaining to reach the finalization of the Generic Safety Assessment, the achievements of in-air and underwater demonstrators (to highlight the performance, the ease-of-use, the relevancy of the safety systems of laser cutting technology without forgetting the demonstration of its economic advantage), the delivery of the Technology Qualification Certificate (when all remaining qualification actions are achieved) and guidelines for the use of laser cutting technology in reactor environment. This next step of the project will provide more confidence to operators to use laser as an alternative to the conventional cutting techniques and could enhance the safety, economic and technical aspects of one of the most challenging tasks of Nuclear Power Reactor dismantling.

This project has the opportunity to support European nuclear field in remaining a step ahead in the development of this technology by achieving a world first laser dismantling of a Nuclear Power Reactor.

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