Benefits from developments in the field of Decommissioning for Fukushima Daiichi fuel debris retrieval: Remote-Controlled Laser Cutting Process – 17110

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ABSTRACT

Among the numerous challenges towards the decommissioning of Fukushima Dai-ichi reactors, removing fuel debris is certainly one of the tougher ones, requiring several technical developments. One of them, related to laser cutting of fuel debris is being developed by a French consortium “ONET Technologies, CEA and IRSN”. Remote controlled laser cutting was implemented for the first time in a real decommissioning workshop in 2015, in UP1 reprocessing plant. In addition to laser cutting development in air and underwater, key aspects of fuel debris cutting of representative of corium debris simulants was performed to test the quantities of aerosols, gas and dusts released during the debris laser cutting.

INTRODUCTION

CEA (French Alternative Energies and Atomic Energy Commission) is both the operator of important nuclear facilities throughout the nuclear cycle, in charge of major new built or D&D projects, and a R&D group with dynamic policy of technology transfer. The position of CEA in D&D is unique because of the number and the diversity of facilities under decommissioning, some with high levels of contamination. Innovative solutions are thus being developed in 6 main axis to protect the operators, minimize the overall costs and reduce the volume of waste:

- Investigations in the facilities
- Radiological measurement of waste
- Robotics, laser cutting devices and virtual reality
- Decontamination of soils and structures
- Waste treatment and conditioning
- Methods and Information Technology (IT)Tools for project and waste management

CEA developed tools for its own D&D projects when they didn’t exist yet on the market: robots, tele-operated equipment, cutting process and software for validation and optimization of intervention scenarios.
In order to improve cutting yields while limiting aerosols and waste generated, CEA developed powerful Lasers with robust and mature technologies, which are easily automatized with a manipulator. Specific laser heads were conceived: heads for cutting in air with air-cooling to prevent water leaking and heads for cutting under water (Fig.1).

Figure 1: Torches in air and underwater

Onet Technologies is a leader in the French nuclear industry. The company specializes in engineering and technological maintenance solutions for nuclear reactors, with a focus on the primary circuit, along with dismantling operations and treatment of radioactive waste. With a current workforce of more than 2,700 engineers, technicians and other employees, it operates sites and maintains long-term partnerships around the globe. Onet Technologies has been actively involved in providing remote-controlled dismantling solutions for the Fukushima plant since 2013 through studies and development of innovative processes.

UP1 DISSOLVER DISMANTLING

The suitability of laser cutting process for stainless steel components up to 10cm thickness in air and under water has already been shown and is coupled with remote manipulators for dismantling operations in high radiation doses.

These advanced techniques were implemented in an active decommissioning trial, for the dismantling of two highly active dissolvers with thick Uranus (which kind) stainless steel in UP1 reprocessing plant (Fig.2).

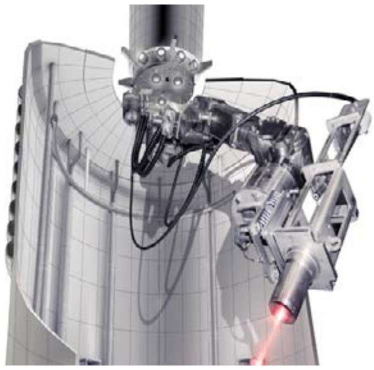

Figure 2 : Laser cutting applied to dissolver dismantling

The first tests of these coupled technologies, developed by CEA R&D (laser cutting and “Maestro” manipulator and simulation in immersive room), started in 2014 in Marcoule CEA site, with the first laser cutting in December 2015. It is subcontracted by CEA to ONET, “Maestro” being commercialized by Cybernetix, a subsidiary of Technip. ONET Technologies was chosen by CEA to design, build and operate the overall dismantling and waste treatment system for this project (2011 – 2018 period, 15000 hours of engineering studies, 11 metric tons of primary waste, 60 metric tons of secondary wastes).

CEA developed laser cutting technique applied to nuclear decommissioning, with compressed air used as head cooling, and demonstrated Laser cutting capability of 100 mm for stainless steel 316L with a 8 kW laser, in air [1].

In the UP1 dissolvers trial, elementary inactive tests based on a 6 kW Nd-Yag laser source were made in 2015 to qualify the cutting performance with Uranus material, which is much harder than stainless steel, allowing it to meet the safety criteria and to check the physical characteristics of waste resulting from the laser cutting operations. Mass and grain dimensions of particles in aerosols were measured and laser power was optimized to minimize aerosols production.

BENEFITS FOR FUKUSHIMA

Based on R&D developments led by CEA in the fields of Dismantling and severe accident simulation, on IRSN skills in airborne measurement and on the experience of ONET and Cybernetix, a project was selected for Fukushima Dai-ichi, in order to help fuel debris retrieval, including:

- Laser cutting performance test campaigns: in-air, under a few centimeters of water, under a few meters of water (representative conditions of the decommissioning scenarios)
- Simulants development, production and characterization
- Dust and fumes measurement and characterization campaign, in air and underwater

Test material for laser cutting Simulants

The choice of the simulant composition was driven by the representativeness for:
- Cutting performance: Material behavior to be as close as possible to the actual fuel debris (melting temperature, metallography structure, thermal conductivity and heterogeneity)
- Dust generation: Aerosols generated by simulant cutting to be used to estimate the aerosols source term released by the future fuel debris.

Two representative corium compositions were selected:
- An in-vessel debris having the average of Fukushima Daiichi Unit 2, lower head debris composition best estimates from the OECD Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station (BSAF) [2].
- An ex-vessel debris composition chosen from DOE calculations on Fukushima Daiichi Unit 1 molten core concrete interaction in order to maximize the concrete content and bound the possible composition space [3].

Fission Products expected 10 years after plant shutdown have also been taken into account.
As it was not possible within the current project timeframe to perform debris cutting tests with depleted uranium oxide, it has been necessary to simulate uranium oxide and hafnium oxide has been considered as the best option.

Based on its 20 year experience in corium experimental R&D, PLINIUS platform at CEA Cadarache was chosen to fabricate these simulants. Two blocks of 8-10 kg were induction melted. After melting and cooling, samples were analyzed (microstructure and chemical composition) and laser cutting of these simulant blocks was successfully carried out. Both corium simulant materials contained non-radioactive fission products with the aim to be representative for the study of aerosols released during laser cutting.

Figure 1 Manufactoring of In and Ex vessel simulants in Plinius facility [4]

Laser cutting performance test campaigns:

The performance of laser cutting on fuel debris has been addressed in 2015 with more than 130 laser cuts confirmed very good results, better than stainless steel, for emerging cuts: up to 100 mm cuts could be made with acceptable fragmentation and a good flexibility of the cutting parameters (standoff, angle, gas pressure). Emerging cutting process is adapted for structures cutting with a minimum power of 1kW by centimeter depth to be cut. Performance for non-emerging kerfs is more challenging though, with reduced depth and possible instability of the cut. Under the same conditions used for crossing through cuts, depths reached for non-emerging cuts are smaller because of the greater difficulty in evacuating the melted material.

However, the use of auxiliary supply gas during the cut showed the achievement of stable cuts and confirmed the feasibility to remove a piece from a massive fuel debris.

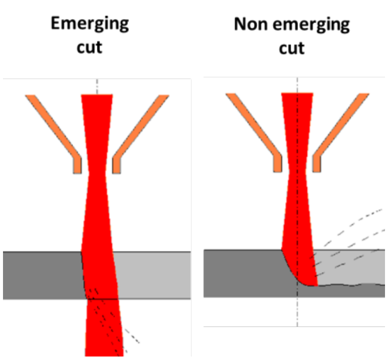

Figure 2: Emerging and non emerging cuts

Laser cutting tests were pursued in the DELIA 2 facility, under 5m of water in non-emerging configuration.
These tests allowed following outcomes:

- Cutting performance under several meters of water with efficiency of water curtain technology
- Cutting performance underwater in non-emerging cut configuration-
- Analysis of the fuel debris simulants before and after cut: drosses and water sediments
- Estimation, confirmed by tests of gas production and extrapolation to fuel debris with analyze and study of the laser cutting secondary outlets in order to extrapolate the results to fuel debris

A Compilation of all results and final performance assessment of the technology in air / underwater in emerging and non-emerging configuration will be produced by the end of March 2017 for final assessment of the overall cutting performance and associated operating constraints.

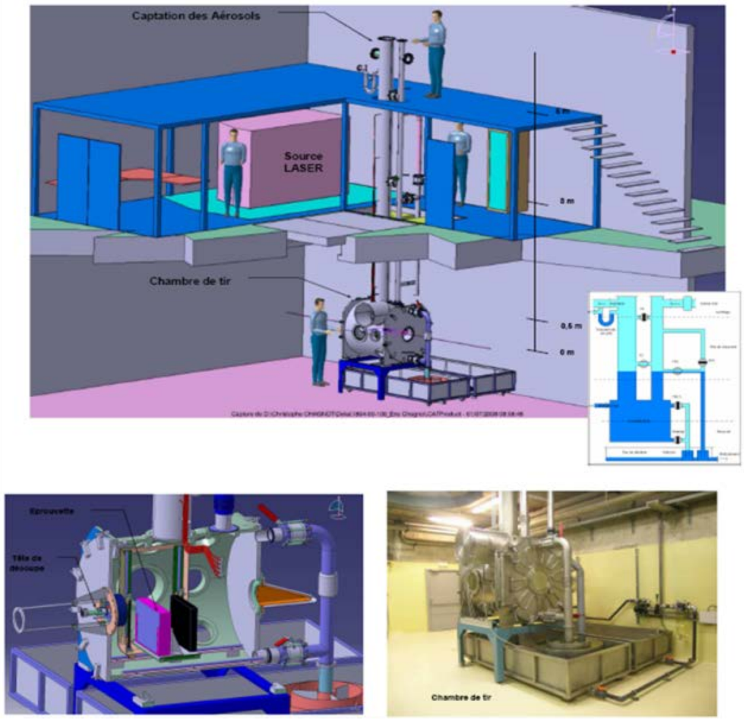

Figure 3: View of Saclay DELIA facility for laser cutting under water and airborne characterization

Figure 4: Cutting tests on simulants

Dust and fumes measurement and characterization campaign

Figure 5: General view of the sampling line for aerosols characterization

Laser cutting is known to generate less secondary effluents than other thermal techniques, and this fact has been demonstrated for fuel debris cutting. A specific loop for gas, dust and fumes was commissioned and implemented, focused on aerosol and gas measurements. On-line characterization of gas composition and aerosols characteristics is achieved during laser cutting tests of ex-vessel and in-vessel inactive simulants, for in air and under water configurations. The aerosol source term (particle under 10 µm) was evaluated based on physical magnitudes such as size distribution, airborne mass concentration, aerosol composition. An estimation of particles deposition (for particles over than 10 µm around the cut were made in a Fukushima typical configuration. Based on analysis of these results and estimation of aerosols particles and gas production during laser cutting of simulant generation, in air and underwater, a collection system was designed with first assessment of dust and fumes collection efficiency.

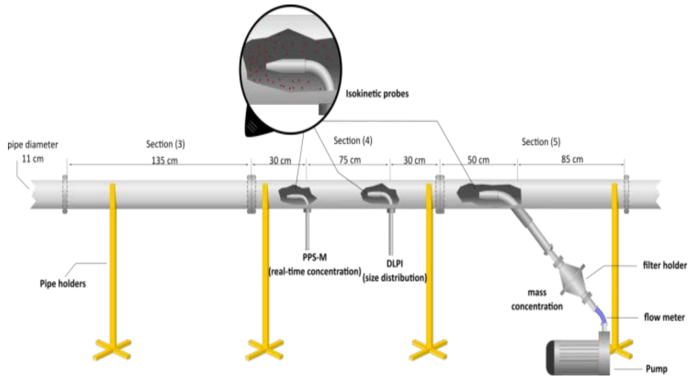

Figure 6: Principle of the sampling line with instruments for aerosols characterization

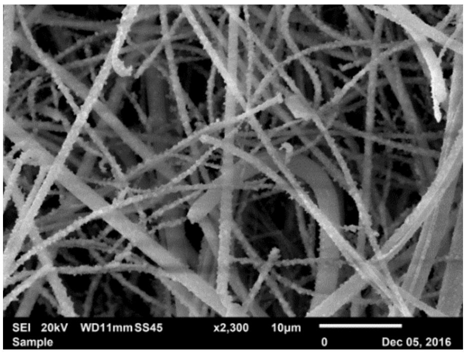

Figure 7: Visualization of aerosols by SEM (Scanning Electron Microscopy)

CONCLUSIONS

Laser cutting technologies have a great potential for corium cutting in PCV and RPV of Fukushima damaged reactors, and presents numerous advantages over most of the traditional mechanical and other thermal techniques:

- The cutting performance of laser and the very limited implementation constraints are among the best advantages of this process. With the ability to cut >100mm, it outpaces traditional mechanical cutting techniques. In addition, this technology offers high cutting speed (> 10mm/min); it has no crucial need for cooling and it allows removing blocks of material (of reasonable size) which is another great advantage compared to mechanical techniques.
- The implementation of laser cutting is fairly easy; it has the ability to cut complex shapes with flexibility of the stand-off and is not too impacted by geometrical parameters (angle, stand-off). Laser cutting also has the advantage to apply no force on the fuel debris, which induces less constraints for the manipulator mechanics and allows size reduction of the larger pieces without having to hold the cut elements in position. This flexibility in implementation is a major advantage of the technology compared to all techniques that need to follow the shape of the element to be cut, or produce vibration with risk to block any cutting tool.
- Laser cutting is a robust technique, with no moving parts and limited cables, which can be implemented by remote means. In addition, the same tool is able to cut a various range of material, with change which is again a real advantage compared to mechanical techniques.
- Finally, compared with other thermal cutting techniques, the aerosols production is the lowest achievable, and there is no problem of visibility. It has no need for abrasive, which therefore does not increase the

generated waste during the implementation and does not need water feeding. Compared to mechanical cutting, the scrubs and chips remains mainly attached to the cut piece which limits the scrubs retrieval activities.

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