

PROCESS SIMULATION FRAMEWORK FOR NUCLEAR DISMANTLEMENT INTEGRATED WITH LASER CUTTING

Kim, I.; Lee, J. & Ha, J.

Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu,
Daejeon, 34057, Republic of Korea

E-Mail: ikjunekim@kaeri.re.kr, jhl@kaeri.re.kr, jhha78@kaeri.re.kr

Abstract

Process simulation is essential in nuclear facility dismantlement operations because high-radiation environments prevent human operators from making real-time interventions. Since all operations must be conducted remotely, rigorous planning of cutting paths, speeds, and sequences is required to ensure complete separation while minimising secondary waste. Furthermore, accurately pre-estimating the size and weight of cut pieces is crucial for the safe handling and disposal of radioactive materials. Process simulation serves to validate cutting plans and identify potential hazards prior to actual operations. In this study, we propose a process simulation methodology that accurately generates the geometric shapes of waste materials produced during cutting. Current simulation methods often fail to account for the variation in cutting depth as a function of the cutter's traverse speed. This limitation hinders the accurate prediction of outcomes for non-contact methods such as laser cutting. To address this, we developed a framework to simulate laser cutting operations and implemented a prototype module based on a commercial process simulation system.

(Received in January 2026, accepted in April 2026. This paper was with the authors 1 week for 1 revision.)

Key Words: Dismantlement Process Simulation, Nuclear Facility Dismantlement, Laser Cutting

1. INTRODUCTION

Laser cutting has emerged as a particularly advantageous technique for the decommissioning of nuclear facilities. The process generates an exceptionally thin cut width, which directly translates to a reduction in the volume of secondary waste produced during dismantlement operations. As a non-contact thermal process, the mechanical forces exerted on the workpiece remain negligibly small, affording precise and flexible manipulation of the cutting trajectory. The compact profile of the laser cutting head further enables the system to navigate components featuring intricate or confined geometries that would otherwise be inaccessible to bulkier tools. With its continuously expanding machinable thickness range and concurrent decline in system costs, the technology has demonstrated considerable practical progress – including successful experiments in which stainless steel plates of up to 100 mm thickness were severed in underwater conditions [1, 2].

Laser cutting process simulation prior to actual cutting is essential for planning trajectories in nuclear facility dismantlement operations. The process simulation verifies that cutting paths can effectively cut the target product while enabling prediction of secondary waste quantities and determination of cut piece dimensions and weights. In nuclear dismantlement scenarios, accurate process planning is critical due to the high-radiation environment where operators cannot make real-time adjustments, making pre-planned cutting trajectories and waste management strategies indispensable for safe and efficient operations.

Laser cutting is a thermal cutting method that melts and separates the target object by concentrating high-energy laser beams on a specific point (Fig. 1). The amount of thermal energy transferred to the material is directly proportional to the exposure time – the longer the laser beam remains on a spot, the more energy is absorbed and the deeper the cut. The laser cutter's transverse speed is a key parameter in the cutting process, as it directly controls the exposure time at each point along the cutting path. At slower speeds, more energy is

transferred to each point, resulting in deeper cuts. Conversely, faster speeds reduce exposure time, leading to shallower cuts.

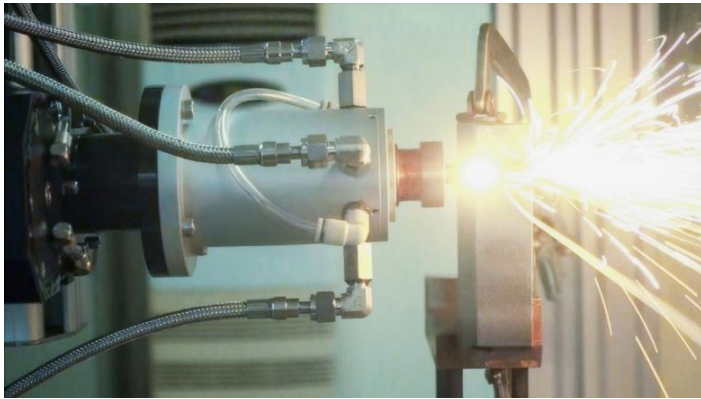


Figure 1: Laser cutting of SUS304 plate in the air.

For effective nuclear dismantlement planning, optimising the laser cutting path requires a clear understanding of the relationship between the laser cutter's transverse speed and the resulting cutting depth. While extensive research [3-5] has explored laser cutting from thermal and fluid dynamics perspectives – focusing on heat transfer, melt pool dynamics, and material removal mechanisms – these fundamental physics-based approaches do not directly translate to practical path planning for industrial decommissioning.

Currently, determining the appropriate cutting speed and path in practical dismantlement operations heavily relies on empirical data and operator experience rather than systematic process simulation. This reliance on experience limits the efficiency and predictability of the decommissioning process.

Establishing a definitive relationship between cutting speed and depth would enable highly precise cutting path planning. Such precision would significantly reduce cutting time, simplify the overall planning process, and allow for reliable predictions of decommissioning costs based on time, cut shape, and the mechanical properties of the cut product. To address this critical gap, we developed a speed calculation algorithm based on a process simulation system and proposed a laser cutting process simulation framework.

2. RELATED WORKS

Dismantlement process simulation can be approached from various perspectives, such as evaluating the vibration response of cutting robots based on multi-body dynamics to ensure operational stability [6], utilising multi-criteria simulation models to optimise machining parameters for improved efficiency and cost-effectiveness [7], and performing micro-scale optimisations of tool geometries to reduce cutting forces and thermal loads during precision machining [8]. However, our approach focuses on discrete process simulation for creating a cut result model specifically tailored for nuclear facility dismantlement planning and execution. This process-oriented simulation perspective differs from analytical approaches in that it prioritises operational feasibility, real-time decision-making, and practical implementation over detailed physical phenomena modelling.

We compared our study with existing studies in two groups: the first one is about nuclear facility dismantlement simulations, and the other is about discrete event simulation for the machining process. Hyun et al. designed a seamless dismantling system for a Korean nuclear facility and implemented a simulation system for it. They proposed a CAD model-based cutting algorithm and simulation methodology as they used the CAD model as a digital mock-

up [9-11]. Kim et al. designed a cutting simulation framework for nuclear facilities. They created the framework to easily modify the scenario in the process modelling procedures [12].

The key distinction of our approach lies in its time-based, dynamic cutting simulation. As illustrated in Fig. 2, conventional methods pre-generate cutting volumes prior to simulation execution, relying solely on the positional path and assuming a constant cut thickness. Consequently, they fail to account for variations in the cutter's transverse speed and cannot provide information on intermediate cutting progress or progressive waste generation.

In contrast, our framework dynamically generates cutting volumes at each time step by calculating variable cut thickness based on real-time speed data. By progressively updating the cutting geometry during the simulation, our methodology enables the accurate assessment of intermediate cutting states, cut product geometry, and cumulative secondary waste at any given time. This dynamic prediction capability is essential for operational planning, cost estimation, and safety assessment in nuclear facility dismantlement.

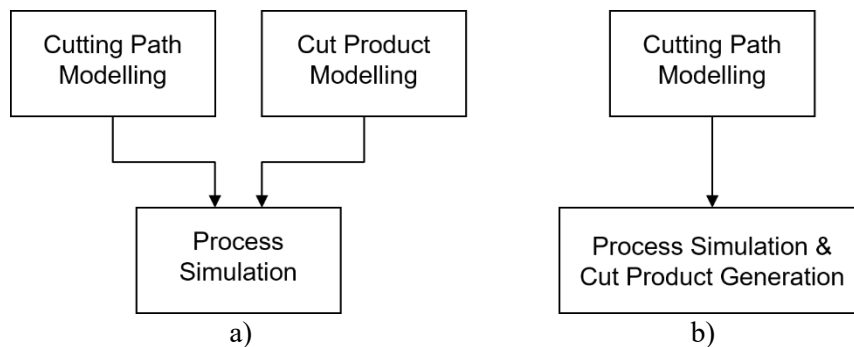


Figure 2: Comparison with existing methods; a) existing cut simulation method, b) proposed method.

Many studies have been conducted to generate the cut shape using simulation in various fields. Rojek et al. present a numerical modelling approach for rock cutting processes using the discrete element model of rock [13]. Similarly, Eberhard and Gaugele present a discrete element model to accurately describe metal cutting processes [14]. Madić et al. developed a mathematical model using genetic programming to accurately predict the relationship between laser cutting parameters and kerf taper angle in CO₂ laser cutting [15].

While existing numerical studies yield highly accurate cutting results, their heavy computational demands make them impractical for process simulations that require rapid updates within very short time steps. To address these efficiency challenges, recent research has increasingly explored the integration of GPU-accelerated parallel computing and AI-driven surrogate models to achieve real-time performance in laser cutting simulations [16-18]. Although these hardware-accelerated and data-driven methods significantly reduce inference time, they often involve complex pre-training phases or specialised hardware requirements.

To overcome these remaining bottlenecks while maintaining geometric flexibility, our approach abstracts the laser cutting geometry – specifically the kerf and cut thickness – using a Boundary Representation (B-rep) solid model. As a mathematically-defined model, B-rep enables rapid and precise cutting simulations through efficient Boolean operations, bypassing the need for heavy iterative computations. Unlike computationally intensive numerical or purely data-driven methods, utilising a B-rep model ensures fast and efficient process simulation without the need for extensive training datasets. Furthermore, this solid modelling approach allows the resulting cut geometries to be seamlessly integrated into downstream analysis. This is essential for evaluating the mechanical properties of dismantled components, assessing the feasibility of dismantling scenarios, and accurately predicting overall decommissioning costs.

3. PROPOSED METHODOLOGY

We designed a framework for dismantlement process simulation as shown in Fig. 3. We defined the cut scenario with the object model, device model, and cutting path. The object model represents the target of the cutting, while the device model represents the laser cutter and carriers. The cutting path contains the laser cutting trajectory, which is composed of the position and speed of the cutter model. Once the cut scenario is simulated in the process simulation, the model observer detects the movement of all the models in the cut scenario and obtains the position of the laser cutter to calculate the transverse speed of the cutter relative to the object model.

The observed information is processed in the cutting module to create the cutter profile, which is used to cut the object model. The object model is cut by the created cutter profile using a Boolean remove operation at every simulation time-step.

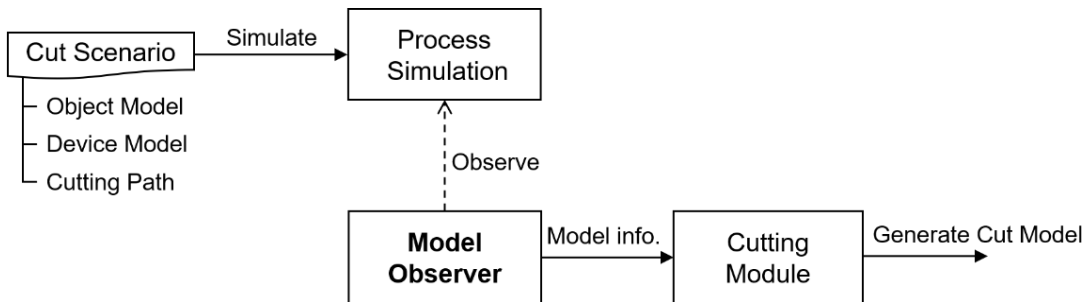


Figure 3: Laser cutting simulation framework.

The model observer plays the main role in the framework. Based on the observed information, the model observer calculates the relative speed of the cutter model in relation to the object model. First, a coordinate system is created on the target model based on the TCP (Tool Centre Point) position of the laser cutter. This is achieved by calculating the transformation from the TCP of the laser cutter to the coordinate system of the object model. This position represents the specific point at which the object model is cut by the cutter profile. At each position, the traverse distance between the current and previous position is determined and divided by the simulation time step. Using this method, the traverse speed of the laser cutter relative to the object model can be accurately calculated within the process simulation.

An example of the calculation of the traverse speed is shown in Fig. 4 which is the cut position where the laser cutter is fixed and the object model is rotated through 360 degrees. At each position the traverse speed is $v = \|\mathbf{p}_i - \mathbf{p}_{i-1}\|/time_step$ where v is the transverse speed, \mathbf{p}_i and \mathbf{p}_{i-1} are the current and previous positions respectively, and $time_step$ is the simulation time interval.

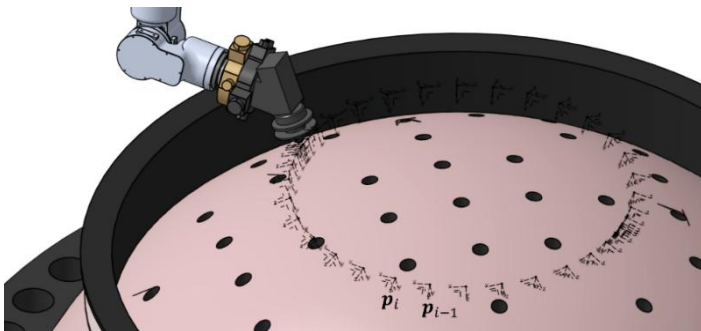


Figure 4: Cut position of the object model.

To enable the framework, we additionally need to define the cutter profile that cuts the object model. The cutter profile is determined by the kerf and the cut thickness of the laser cutter. The observer applies the required value, which is collected during the simulation, to the parameters of the cutter profile to cut the object model at the specific time.

Fig. 5 illustrates an example of cutter profile of a laser cutter. The cutter profile is defined by the parametric model and has the user-accessible parameters to update the shape of the cutter profile. The cutting module can access the simulation system and gathers the motion and speed of the laser cutter model. Based on the collected information and the device properties, the cut thickness and the kerf width are calculated. Using the values, the cutting module creates different shapes of the cutter profile at each time step.

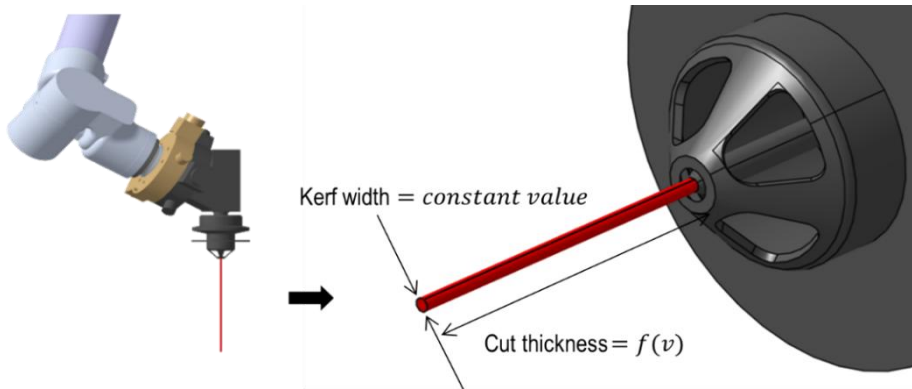


Figure 5: Definition of a cutter profile.

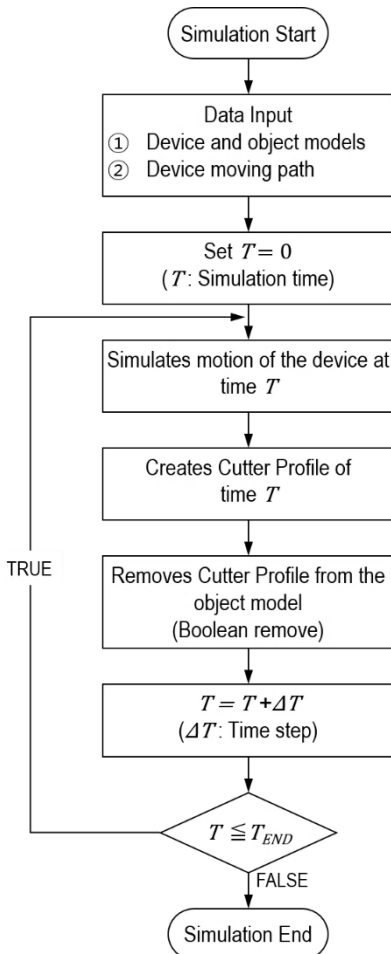


Figure 6: Cutting simulation flow chart.

Fig. 6 illustrates the detailed procedural flowchart of the time-based cutting simulation. The process begins with data initialisation, where the 3D models of the cutting device and the target object, along with the predefined moving path, are imported into the simulation system. The simulation time (T) is then initialised to zero.

During each iteration, the system first simulates the mechanical motion and spatial position of the device at the current time T . Based on this localised kinematic data, the system dynamically creates a cutter profile corresponding to that exact moment. This profile is then mapped to the object model's coordinate system, where the cutting module performs a Boolean remove (subtraction) operation to eliminate the intersecting volume from the target object.

Following this material removal, the simulation time is incremented by a predefined time step (ΔT). This sequential procedure – motion simulation, profile generation, and Boolean subtraction – is iteratively repeated until the current time T exceeds the designated simulation end time (T_{END}). Ultimately, the progressively generated simulation results are utilised to evaluate the overall feasibility, required time, and cost of the planned dismantlement scenario.

4. IMPLEMENTATION AND APPLICATION

4.1 Implementation

To demonstrate the proposed methodology, we developed a simplified process simulation utilising virtual laser cutting properties. The test scenario involves a straight linear cutting path along the edge of a block (Fig. 7 a). As the cut thickness of the laser is dependent on the transverse speed of the device, we modelled the cutting characteristics using the inverse relationship $y = 10/x$ for this test. This formulation was chosen to effectively illustrate the dynamically generated cut shape (Fig. 7 b).

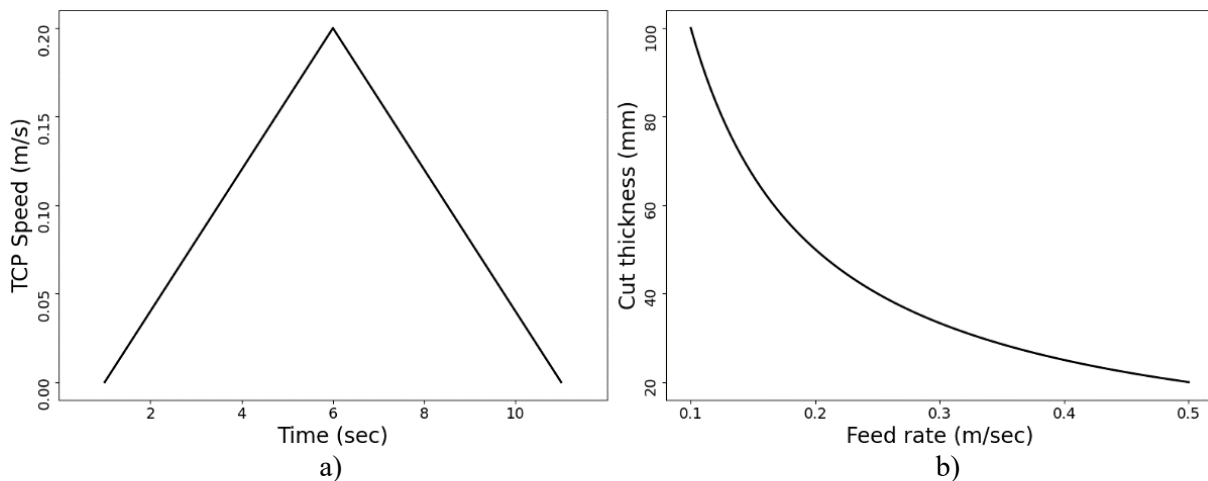


Figure 7: Resources for the cutting simulation; a) measured TCP speed, b) laser cut properties.

During the simulation, the cutting module calculates the variable cut thickness using the tracked device speed and the modelled characteristics of the laser head. At each 20 ms time step, a corresponding cutter profile is dynamically generated (overlaid in Fig. 8 a). Fig. 8 b illustrates the final cut result. Simulating this 11-second sample operation required 550 iterations of the Boolean remove operation. As illustrated in the figure, the cutter profiles are successfully generated based on the traverse speed of the cutter, and the cutting operation is accurately performed.

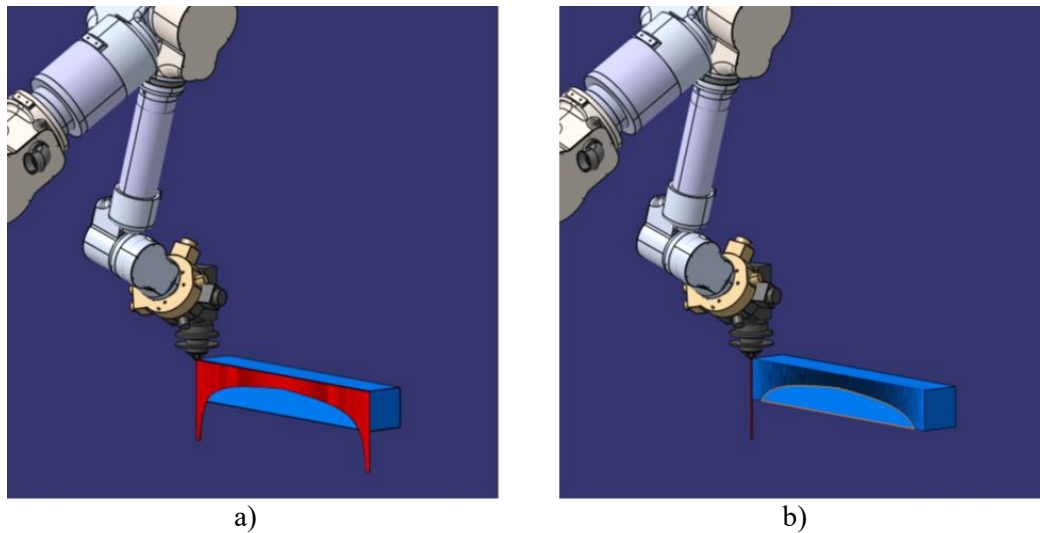


Figure 8: Result of the cutting simulation; a) cutter profiles, b) cut result.

We developed a prototype of the proposed simulation framework within the environment detailed in Table I. DELMIA, developed by Dassault Systèmes, is a prominent process simulation software suite widely utilised for process planning, improvement, and verification. Component Application Architecture (CAA) [19] serves as the primary Application Programming Interface (API) for DELMIA, offering a platform-independent development environment. Additionally, the Rapid Application Development Environment (RADE) [20] was employed as the integrated toolset to facilitate the CAA implementation.

Table I: Implementation environments.

Implementation	Environments
OS	Windows 11 x64
Language	C++
Simulation-SW and Library	Dassault DELMIA V5R26 and CAA
IDE	Visual Studio 2012 and RADE

4.2 Practical application

To validate the proposed methodology, it was applied to simulate the laser cutting process for the internal structures of the Kori-1 reactor in South Korea. This application demonstrates the practical feasibility of the methodology for real nuclear facility decommissioning scenarios.

Fig. 9 shows the overall view of the Kori-1, with Fig. 10 presenting the sectional view that reveals the internal structures of the reactor. The internal components were identified and modelled, as depicted in Fig. 10 c.

For the dismantlement simulation scenario, we selected the lower core support plate located inside the Kori-1 reactor vessel (Fig. 10 c). Laser cutting is particularly advantageous for dismantling highly radioactive components with complex geometry. As the lower core support plate is situated in a high-radiation environment and possesses a complex structural design, it is specifically designated to be dismantled using laser technology in the actual decommissioning scenario. Consequently, it was chosen as the target structure for this study. This component represents a typical internal structure that requires remote, precise cutting during reactor dismantlement operations.

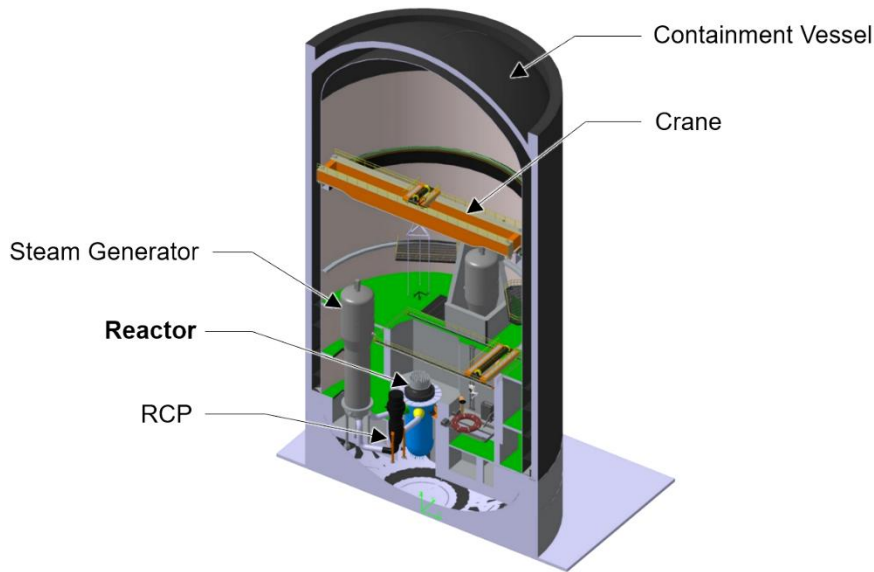


Figure 9: Test model for the Kori-1 nuclear power plant dismantlement.

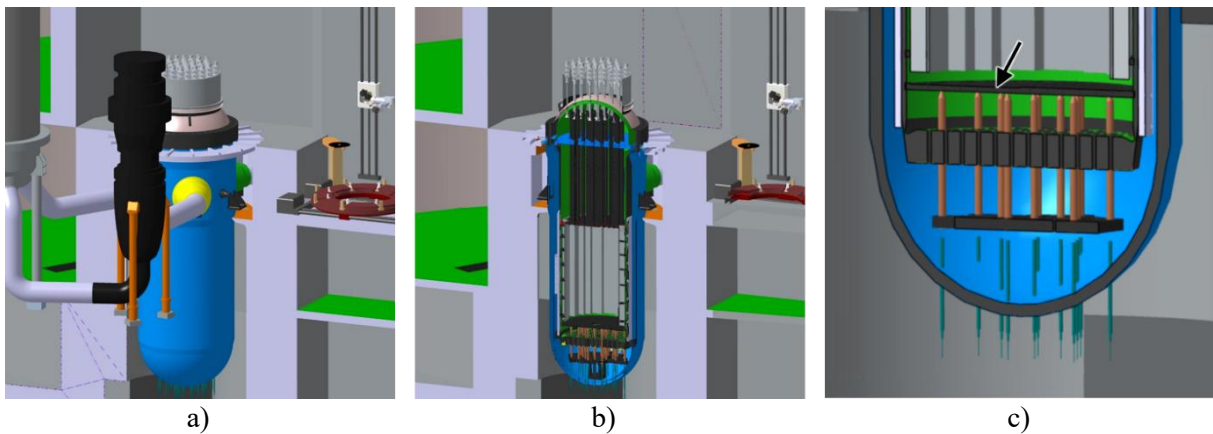


Figure 10: Kori-1 reactor structure; a) reactor, b) section view, c) lower core support plate.

The demonstrated laser cutting path is defined as an L-shape, as illustrated in Fig. 11. The cutting process initiates at a reduced speed of 5 mm/min to facilitate the initial piercing of the 68 mm-thick lower core support plate. Following the piercing phase, the TCP accelerates to a nominal cutting speed of 15 mm/min.

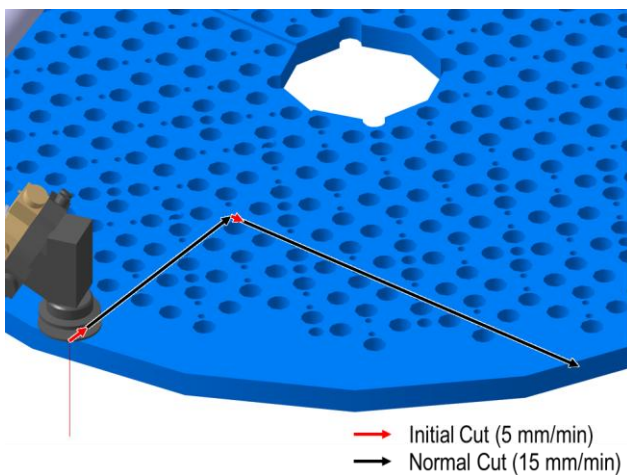


Figure 11: Laser cutting path.

Upon approaching the vertex of the L-shaped path, the TCP decelerates back to 5 mm/min to safely accommodate the 90-degree change in direction. After successfully negotiating the corner and initiating the second cut, the TCP accelerates once more to the nominal speed of 15 mm/min, maintaining this pace until the completion of the cutting process. The corresponding TCP speed profile, measured continuously throughout the process simulation, is presented in Fig. 12 a.

The cutting depth calculations were derived from empirical data obtained through underwater laser cutting experiments previously conducted at our institute [21]. In these foundational experiments, a 6-kW Ytterbium-doped fibre laser was deployed in an underwater configuration. Utilising this specific dataset is highly appropriate for our current simulation scenario; underwater laser cutting is the standard and preferred method for dismantling highly radioactive structures, as the surrounding water provides critical radiation shielding and contamination control. The relationship between feed rate and cut thickness was established through experimental characterisation and mathematical modelling of the laser cutting process parameters (Fig. 12 b). The final cutting geometry was generated by adding a 10 mm laser standoff distance, which means the distance between the nozzle exit and the front surface of the specimen, to the calculated depth values from the speed-depth equation.

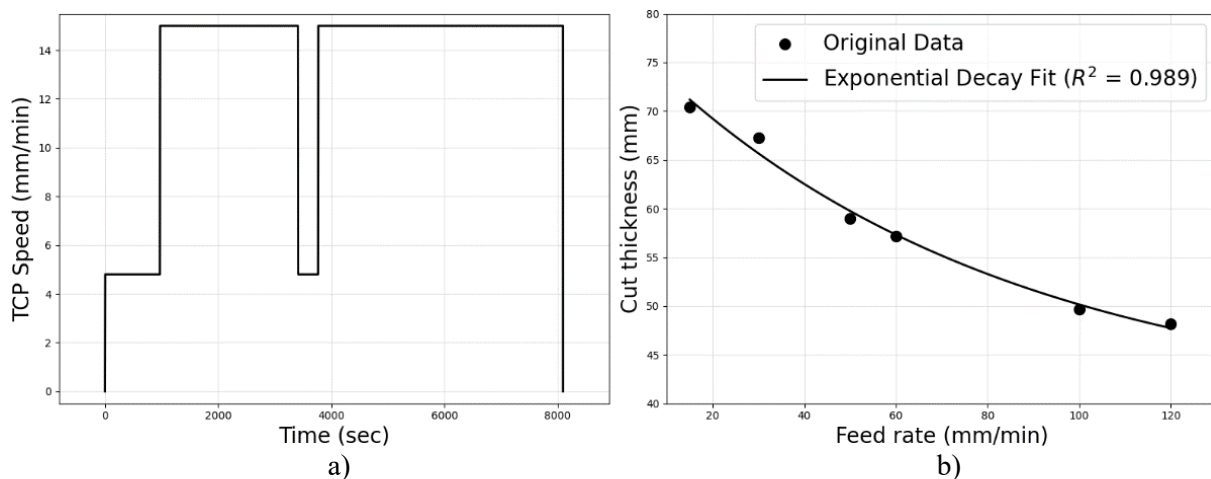


Figure 12: Laser cutting parameters; a) measured TCP speed, b) cut thickness over feed rate.

The dismantlement simulation was designed with an L-shaped cutting path to evaluate cutting geometry, secondary waste generation, and total cutting time. Fig. 13 illustrates the complete cutting trajectory defined through device task programming. The kerf width of the cutting profile was set to 1.5 mm, which is used underwater laser cutting in previous study [21]. Fig. 13 a presents the compilation of all cutting profiles generated throughout the simulation process. While this figure shows all cutting profiles simultaneously for visualisation purposes, each profile was actually generated dynamically at each simulation time step according to the proposed methodology.

The resulting cut geometry obtained from the cutting simulation is shown in Fig. 13 b. The corresponding secondary waste generated through the Boolean intersection operation between the cutter profile and the object model during the cutting simulation is shown in Fig. 13 c.

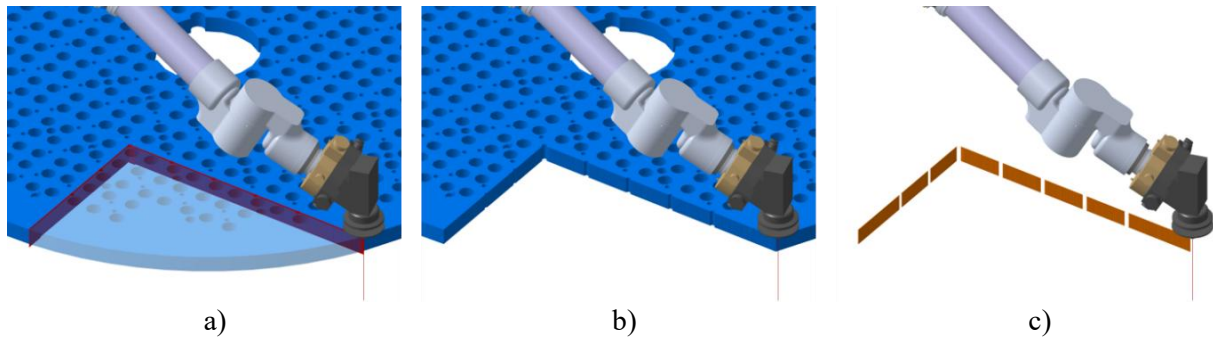


Figure 13: Simulation results; a) cutter profiles and cut piece, b) cut shape, c) secondary wastes volumes

The simulation parameters and results are summarised in Table II. The cutting speed was set to 15 mm/min to achieve complete penetration through the 68 mm-thick core plate. To model realistic cutting conditions, the initial cutting speed was set to 5 mm/min to represent the slower piercing phase that typically occurs at the beginning of laser-cutting operations.

Table II: Simulation results summary.

Parameters	Values
Total simulation steps	1620 steps (step: 5 sec)
Total cutting time	2.248 hour
Total computation time	16 min 46 sec
Secondary wastes quantity	0.000146776 m ³ (1.16 kg)
Cut piece properties	1.805 m ³ (14.32 tons)
Target thickness	68 mm
Kerf width	1.5 mm
Cutting speed (normal)	15 mm/min
Cutting speed (initial)	5 mm/min

The simulation successfully demonstrated the capability to predict cutting geometry, estimate secondary waste generation, and calculate total operation time for the single laser cutting process. The results provide valuable information for planning actual dismantling operations, including logistics for waste handling, radiation exposure time estimation, and equipment positioning strategies.

For instance, the predicted cutting time of 2.248 hours, combined with the laser cutting auxiliary gas consumption rate of 1,310 L/min [21], indicates that approximately 176,690 L of compressed air will be required for the complete operation. The dimensional and weight characteristics of the cut pieces can inform transport robot configuration, including payload capacity requirements and potential cutting path modifications to accommodate robotic handling limitations. Furthermore, the calculated secondary waste volume enables life cycle planning for ancillary systems, such as ventilation and water treatment equipment, by predicting maintenance intervals and consumable requirements.

The dynamic cutting profile generation allowed for accurate assessment of intermediate cutting states, enabling operators to evaluate cutting progress at any specific time during the operation. This capability is particularly important for nuclear dismantlement scenarios where precise planning is essential for safety and efficiency.

5. CONCLUSION

In this study, we proposed a novel process simulation methodology tailored for nuclear facility dismantling and implemented a prototype system to validate its performance.

Specifically, we developed a simulation framework that dynamically calculates the variable cutting depth of a laser cutter based on its real-time traverse speed at each time step. To ensure rapid computational efficiency while maintaining the ability to easily manipulate the results, our approach utilises a Boundary Representation (B-rep) solid model rather than computationally intensive numerical methods. To demonstrate its practical feasibility, we successfully applied this framework to a realistic decommissioning scenario involving the laser cutting of the lower core support plate from the Kori Unit 1 reactor.

Traditional methods typically pre-generate cutting volumes prior to execution, assuming a constant cut thickness and relying solely on the positional path, which fails to account for variations in the cutter's transverse speed. In contrast, our methodology dynamically generates the cutter profile progressively throughout the simulation. This key contribution enables the accurate assessment of intermediate cutting states, the precise geometric modelling of cut products, and the continuous tracking of cumulative secondary waste generation at any given moment during the operation.

The proposed framework provides a highly effective tool for planning remote decommissioning operations in high-radiation environments, where operators cannot make real-time adjustments. By precisely predicting the cutting geometry and estimating secondary waste generation, this system facilitates rigorous planning for waste handling logistics, radiation exposure time estimation, and equipment positioning strategies. Furthermore, evaluating the dimensional and weight characteristics of the cut pieces allows for optimised transport robot configurations and more accurate overall decommissioning cost predictions. Ultimately, this capability ensures real-time visualisation of cutting progress, providing essential feedback to ensure safety and efficiency in nuclear dismantlement operations.

As demonstrated in our results, even a brief 11-second cutting simulation required 550 iterations of the Boolean remove operation. To mitigate such heavy computational loads when scaling to highly complex dismantlement targets or extended cutting operations, future research will focus on optimising the dynamic cutting module. Furthermore, we plan to conduct actual laser cutting experiments in the near future. A comprehensive comparative study between these empirical results and our simulation outputs will be performed to rigorously validate and further refine the accuracy of the proposed framework.

ACKNOWLEDGEMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Climate, Energy & Environment (MCEE) of the Republic of Korea (No. RS-2023-00242345).

REFERENCES

- [1] Shin, J. S.; Oh, S. Y.; Park, S.; Park, H.; Kim, T.-S.; Lee, L.; Kim, Y.; Lee, J. (2020). Underwater laser cutting of stainless steel up to 100 mm thick for dismantling application in nuclear power plants, *Annals of Nuclear Energy*, Vol. 147, Paper 107655, 9 pages, doi:[10.1016/j.anucene.2020.107655](https://doi.org/10.1016/j.anucene.2020.107655)
- [2] Kim, I.; Lee, J.; Hyun, D.; Joo, S.; Ha, J. (2025). Error detection in underwater laser cutting for nuclear facility dismantlement using hydrophone and AI techniques, *Annals of Nuclear Energy*, Vol. 222, Paper 111590, 9 pages, doi:[10.1016/j.anucene.2025.111590](https://doi.org/10.1016/j.anucene.2025.111590)
- [3] Halm, U.; Nießen, M.; Schulz, W. (2021). Simulation of melt film dynamics in laser fusion cutting using a boundary layer approximation, *International Journal of Heat and Mass Transfer*, Vol. 168, Paper 120837, 13 pages, doi:[10.1016/j.ijheatmasstransfer.2020.120837](https://doi.org/10.1016/j.ijheatmasstransfer.2020.120837)
- [4] Unni, A. K.; Vasudevan, M. (2023). Computational fluid dynamics simulation of hybrid laser-MIG welding of 316 LN stainless steel using hybrid heat source, *International Journal of Thermal Sciences*, Vol. 185, Paper 108042, 17 pages, doi:[10.1016/j.ijthermalsci.2022.108042](https://doi.org/10.1016/j.ijthermalsci.2022.108042)

- [5] Li, W.; Wu, J.; Li, Y.; Wu, L.; Fu, B. (2024). Simulation study on the thermal effect of continuous laser heating quartz materials, *Frontiers in Chemistry*, Vol. 12, Paper 1435562, 14 pages, doi:[10.3389/fchem.2024.1435562](https://doi.org/10.3389/fchem.2024.1435562)
- [6] Ma, H. W.; Xue, L. M.; Wang, C. W. (2024). Cutting vibration response of a shield-type tunnelling robot system, *International Journal of Simulation Modelling*, Vol. 23, No. 4, 656-667, doi:[10.2507/IJSIMM23-4-705](https://doi.org/10.2507/IJSIMM23-4-705)
- [7] Buchmeister, B.; Palcic, I.; Ojstersek, R.; Kovic, K.; Javernik, A. (2024). Multicriteria optimisation of machining operations using a spreadsheet model, *Technical Journal*, Vol. 18, No. 3, 445-451, doi:[10.31803/tg-20240514150731](https://doi.org/10.31803/tg-20240514150731)
- [8] Wu, D.; Zhao, C. L.; Huang, C. L.; Luo, X. (2025). Micro-texture optimization for titanium cutting tools via simulation, *International Journal of Simulation Modelling*, Vol. 24, No. 2, 333-344, doi:[10.2507/IJSIMM24-2-CO7](https://doi.org/10.2507/IJSIMM24-2-CO7)
- [9] Kim, I.; Hyun, D.; Joo, S.; Lee, J. (2020). A methodology for digital mockup update based on the 3D scanned spatial information for the automated dismantling of nuclear facilities, *Annals of Nuclear Energy*, Vol. 139, Paper 107238, 5 pages, doi:[10.1016/j.anucene.2019.107238](https://doi.org/10.1016/j.anucene.2019.107238)
- [10] Hyun, D.; Kim, I.; Lee, J.; Kim, G.-H.; Jeong, K.-S.; Choi, B. S.; Moon, J. (2017). A methodology to simulate the cutting process for a nuclear dismantling simulation based on a digital manufacturing platform, *Annals of Nuclear Energy*, Vol. 103, 369-383, doi:[10.1016/j.anucene.2017.01.035](https://doi.org/10.1016/j.anucene.2017.01.035)
- [11] Hyun, D.; Lee, S.-U.; Seo, Y.-C.; Kim, G.-H.; Lee, J.; Jeong, K.-S.; Choi, B.S.; Moon, J.-K. (2014). Seamless remote dismantling system for heavy and highly radioactive components of Korean nuclear power plants, *Annals of Nuclear Energy*, Vol. 73, 39-45, doi:[10.1016/j.anucene.2014.06.020](https://doi.org/10.1016/j.anucene.2014.06.020)
- [12] Kim, I.; Choi, B.; Hyun, D.; Moon, J.; Lee, J.; Jeong, K.; Kang, S. (2016). A framework for a flexible cutting-process simulation of a nuclear facility decommission, *Annals of Nuclear Energy*, Vol. 97, 204-207, doi:[10.1016/j.anucene.2016.07.004](https://doi.org/10.1016/j.anucene.2016.07.004)
- [13] Rojek, J.; Oñate, E.; Labra, C.; Kargl, H. (2011). Discrete element simulation of rock cutting, *International Journal of Rock Mechanics and Mining Sciences*, Vol. 48, No. 6, 996-1010, doi:[10.1016/j.ijrmmms.2011.06.003](https://doi.org/10.1016/j.ijrmmms.2011.06.003)
- [14] Eberhard, P.; Gaugele, T. (2013). Simulation of cutting processes using mesh-free Lagrangian particle methods, *Computational Mechanics*, Vol. 51, No. 3, 261-278, doi:[10.1007/s00466-012-0720-z](https://doi.org/10.1007/s00466-012-0720-z)
- [15] Madić, M.; Gostimirović, M.; Rodić, D.; Radovanović, M.; Coteață, M. (2022). Mathematical modelling of the CO₂ laser cutting process using genetic programming, *Facta Universitatis, Series: Mechanical Engineering*, Vol. 20, No. 3, 665-676, doi:[10.22190/FUME210810003M](https://doi.org/10.22190/FUME210810003M)
- [16] Blake, R. C.; Khairallah, S. A. (2026). Accelerating laser ray tracing in high fidelity physics simulations of laser melting using squeeze U-net, *Additive Manufacturing*, Vol. 118, Paper 105087, 8 pages, doi:[10.1016/j.addma.2026.105087](https://doi.org/10.1016/j.addma.2026.105087)
- [17] Mejia-Parra, D.; Arbelaiz, A.; Ruiz-Salguero, O.; Lalinde-Pulido, J.; Moreno, A.; Posada, J. (2020). Fast simulation of laser heating processes on thin metal plates with FFT using CPU/GPU hardware, *Applied Sciences*, Vol. 10, No. 9, Paper 3281, 23 pages, doi:[10.3390/app10093281](https://doi.org/10.3390/app10093281)
- [18] Nascimento, E.; Magalhães, E.; Azevedo, A.; Paes, L. E. S.; Oliveira, A. (2024). An implementation of LASER beam welding simulation on graphics processing unit using CUDA, *Computation*, Vol. 12, No. 4, Paper 83, 18 pages, doi:[10.3390/computation12040083](https://doi.org/10.3390/computation12040083)
- [19] Dassault Systèmes. Developer Training – CAA V5 for CATIA and DELMIA Simulation, from <https://www.3ds.com/partners/resources/developer-training>, accessed on 07-01-2026
- [20] Dassault Systèmes. Catia V5, Driving Design Excellence – RADE Development Toolkit, from <https://www.3ds.com/products/catia/catia-v5>, accessed on 07-01-2026
- [21] Shin, J. S.; Oh, S. Y.; Park, S.-K.; Park, H.; Lee, J. (2021). Improved underwater laser cutting of thick steel plates through initial oblique cutting, *Optics & Laser Technology*, Vol. 141, Paper 107120, 9 pages, doi:[10.1016/j.optlastec.2021.107120](https://doi.org/10.1016/j.optlastec.2021.107120)