IMPACT ASSESSMENT OF NUCLEAR SECURITY EVENTS USING CHEMICAL EXPLOSIVES

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Abstract

Due to the increase accessibility to chemical explosives in recent years, a study to investigate the effects of chemical explosives attaching to nuclear and radioactive materials was conducted by a simulation using ANSYS AUTODYN. A part of PWR assembly was selected as the first analysis system in this project because it turned out that the analyzing a full-scale assembly did not end within a practical time scale. Therefore, a simulation was performed in a range sandwiched between the two grid spacers around the center of the fuel assembly. When the explosive has expanded sufficiently and it can be determined that it has little effect on the fuel assembly, the Euler region was deleted, and the generated debris follows a parabolic trajectory subject to gravity which enables us to calculate the scattering distance.

1. INTRODUCTION

It has become easier for terrorists to obtain chemical explosives in recent years, with the spread of the internet. Also, examples of terrorism at nuclear facilities have been reported around the world. Hence, various measures against terrorism targeting nuclear facilities with chemical explosives have been implemented in many countries. On the other hand, that fact indicates the need of consideration that terrorists steal nuclear and/or radioactive materials and attach chemical explosives to them to increase the scale of the damage, taking large-scale events such as the Olympic Games into account. That is to say, the necessity of the post-dispersion study. In those nuclear security events, it would be assumed that the explosion by chemical explosives destroys objects containing the nuclear and radiological materials, and their debris containing those materials scatters around. Since these debris are radioactive, it is thought that evaluating the scattering behavior of the debris is useful in the radiation exposure evaluation of surrounding environment.

The United States and Japan established a bilateral Nuclear Security Working Group (NSWG) to strengthen nuclear security worldwide. One of the goals that the group developed was Goal 9 “Joint Study on Management of HEU and Plutonium: Reduction of Material Attractiveness,” which establishes through science-based study, a mutual understanding of the risk from non-state actors conducting malicious acts involving nuclear material and facilities. Eventually, the study evaluates the number of deaths, number of injuries, and the economic impacts when nuclear security events occur, in order to consider overall consequences. Therefore, the data of such scattering behavior would be useful. However, such research has not been done or has not been published to date.

ISCN under the JAEA is developing nuclear security technologies by utilizing JAEA's knowledge, experience and technical capabilities in order to contribute to the peaceful use of nuclear energy. Based on the usefulness of the nuclear material scattering behavior mentioned above, ISCN analyzes the explosion and impact behavior of nuclear material in various forms by chemical explosives by simulation using ANSYS AUTODYN. In this paper, we introduce a case of PWR fuel assembly.

2. ANALYSIS MODEL

Figure 1 shows a schematic view of the analysis model. The modeling range was around the center of one PWR fuel assembly which is approximately 210 mm in the width and approximately 4200 mm in the height. The pellets, cladding tubes, and grid spacers were also modelled. The upper and lower ends of the fuel assembly were excluded from the modelling. Table 1 summarizes the shape and thickness of each part. It was created with a 1/4 of the system considering its symmetry.

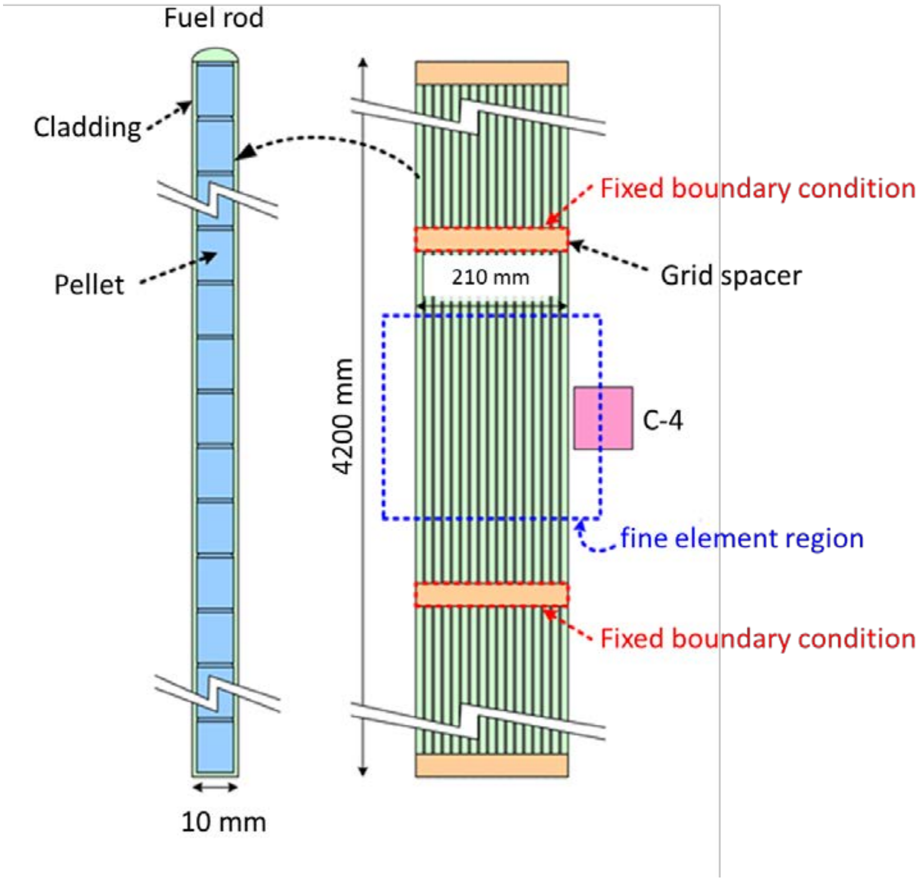

FIG. 1. Analytical model

TABLE 1. SPECIFICATION

Parts	Material	Dimension	Condition
Pellet	UO_2	Radius：4.095mm Height：10mm	There is a gap of 0.082mm between fuel cladding tubes and pellet.
Cladding	Zircaloy-4	Outer radius：4.75mm Inner radius：4.177mm Thickness：0.573mm	The fuel cladding and the grid spacers are rigidly connected. The end of the modeling area is fixed in space.
Grid spacer		Width：210mm Height：40mm Thickness：1mm	

The pellets used solid elements, the fuel cladding and the grid spacers used shell elements. In this work, we did not do some investigations such as the dependence on mesh size, and used a relatively coarse element size to reduce the calculation time. For the same purpose, the cross-sectional shapes of the fuel cladding tube and the pellets were octagonal. The diagonal dimension of the pellet was determined so that the mass of the pellet coincided with that of the real dimension, which is cylindrical. The fuel cladding and the grid spacers were rigidly connected. The end of the modeling area was fixed in space. The type of chemical explosive was a kilogram of C-4. It was to be detonated contacting the center of the fuel assembly. Explosives and surrounding space were modeled by Euler elements. The Euler region was defined as a region sandwiched between two grid spacers around the center of the fuel assembly. A relatively fine element size was set near the explosive, and gradually coarser in the distant place. Outflow boundary conditions were set on the end face of the Euler region.

3. ANALYSIS RESULT

When the calculation is performed with the analysis model of the full scale described in section 2, a huge amount of analysis time was required despite the coarse element size, and it is not possible to obtain results of debris scattering behavior in a practical time scale. Therefore, an analysis model with a limited range was created and a trial analysis was performed. The model is 5×5 fuel rods and a height of 560 mm, which is the area between the two grid spacers around the center of the fuel assembly. In this calculation, the Euler region was deleted when it was determined that the explosive had expanded sufficiently and had little effect on the fuel assembly. Figures 2-5 show velocity vector diagrams of the fuel assembly at main times after the detonation.

It can be seen that the center and/or upper and lower ends of the fuel cladding are broken due to the explosion and the pellets are scattered. Figure 6 shows a schematic diagram of the evaluation method of flying distance. From the coordinates and velocity (divide each component of the momentum by the mass) of each fragment evaluated by the simulation, the distance from the assembly to the point where the debris fall is calculated. We assumed that the debris follows a parabolic trajectory subject to gravity.

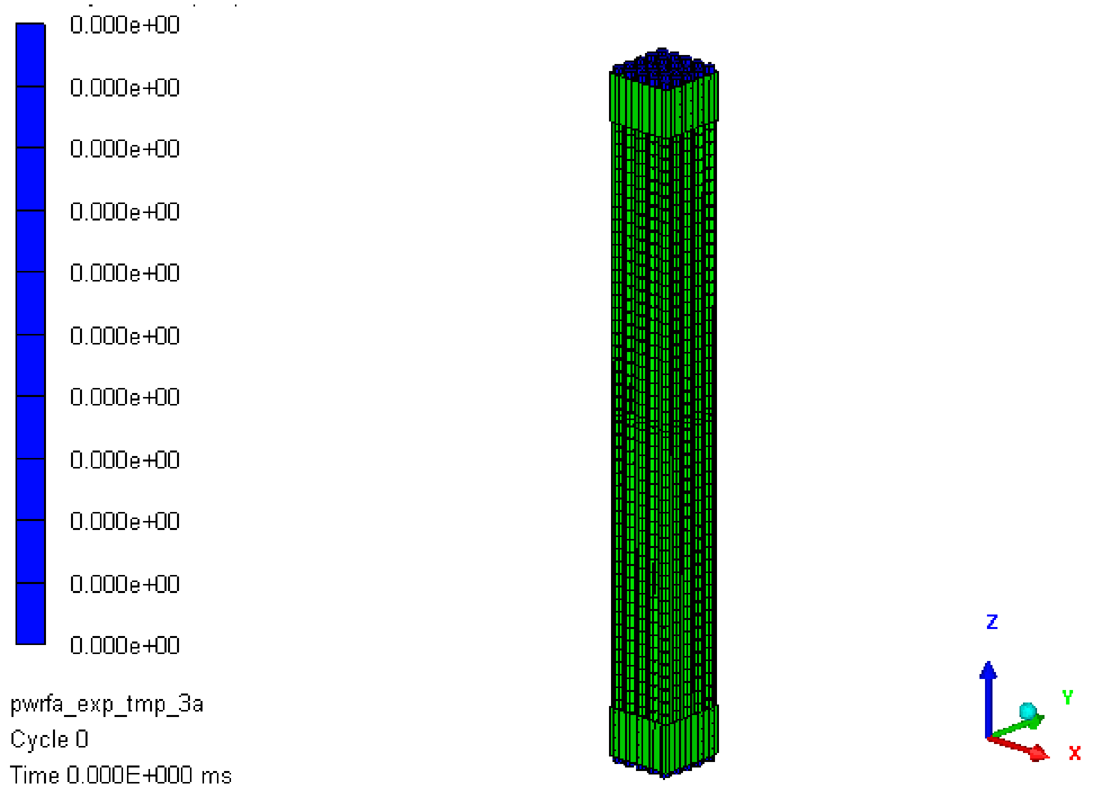

FIG. 2. Velocity vector diagram of the fuel assembly (Just before the detonation)

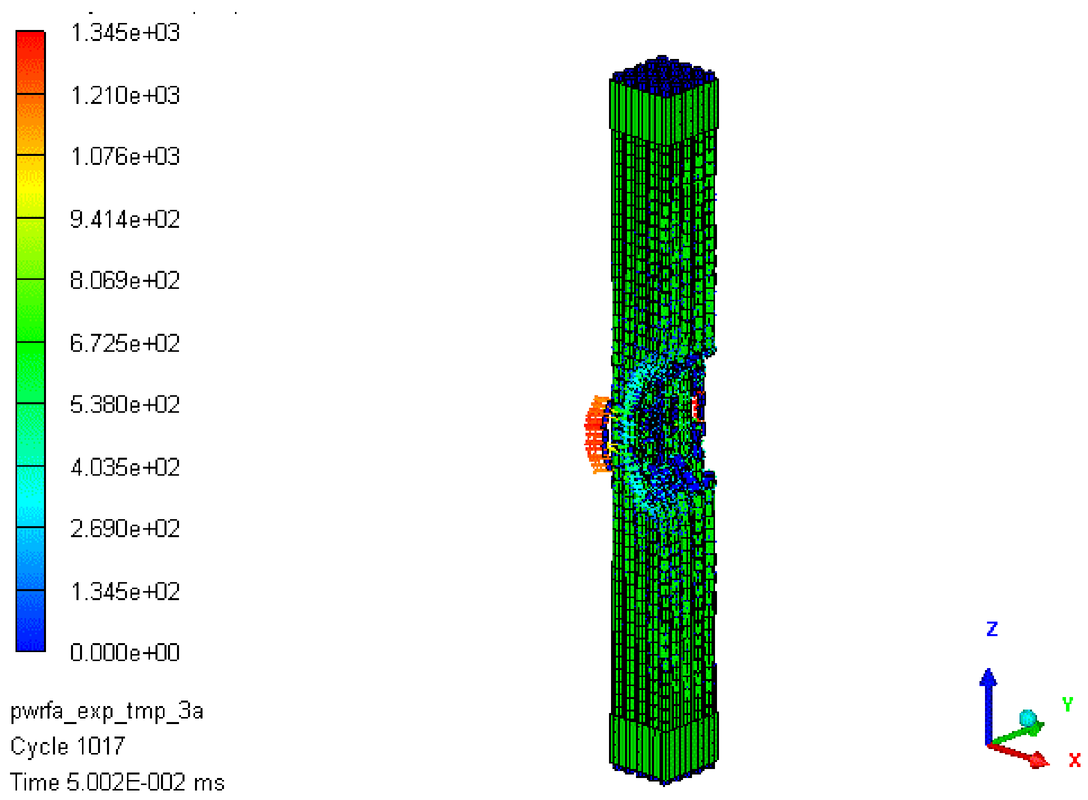

FIG. 3. Velocity vector diagram of the fuel assembly (0.05 ms after detonation)

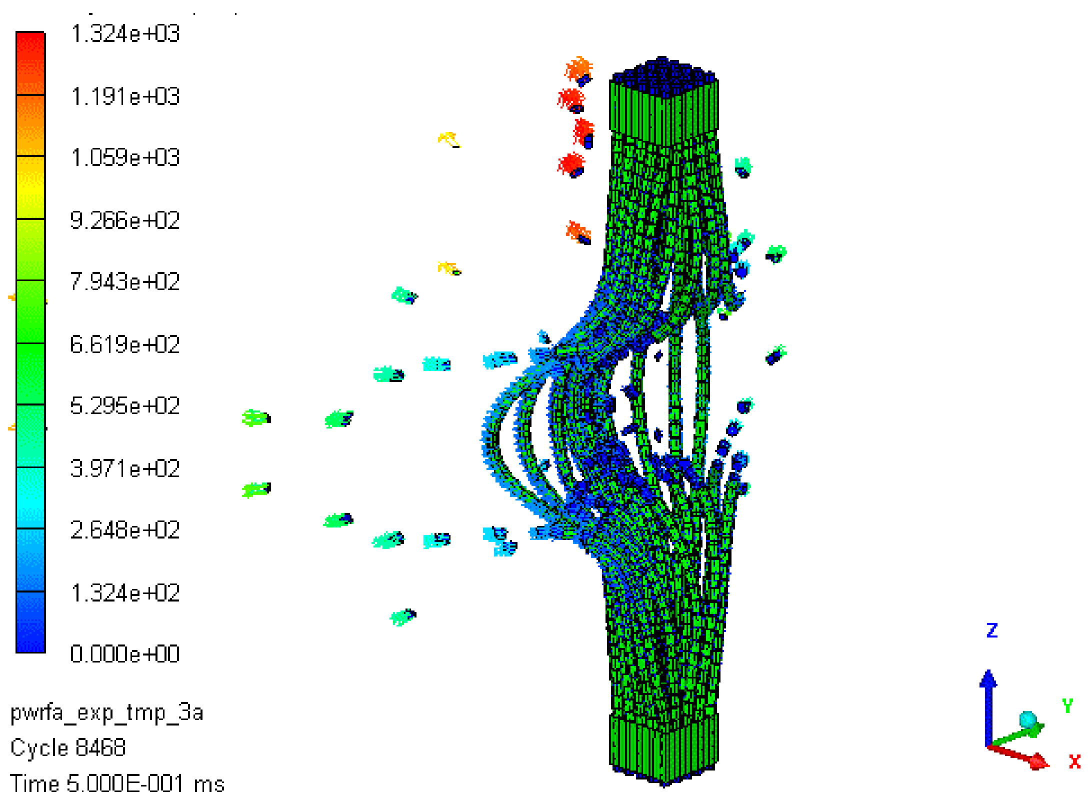

FIG. 4. Velocity vector diagram of the fuel assembly (0.5 ms after detonation)

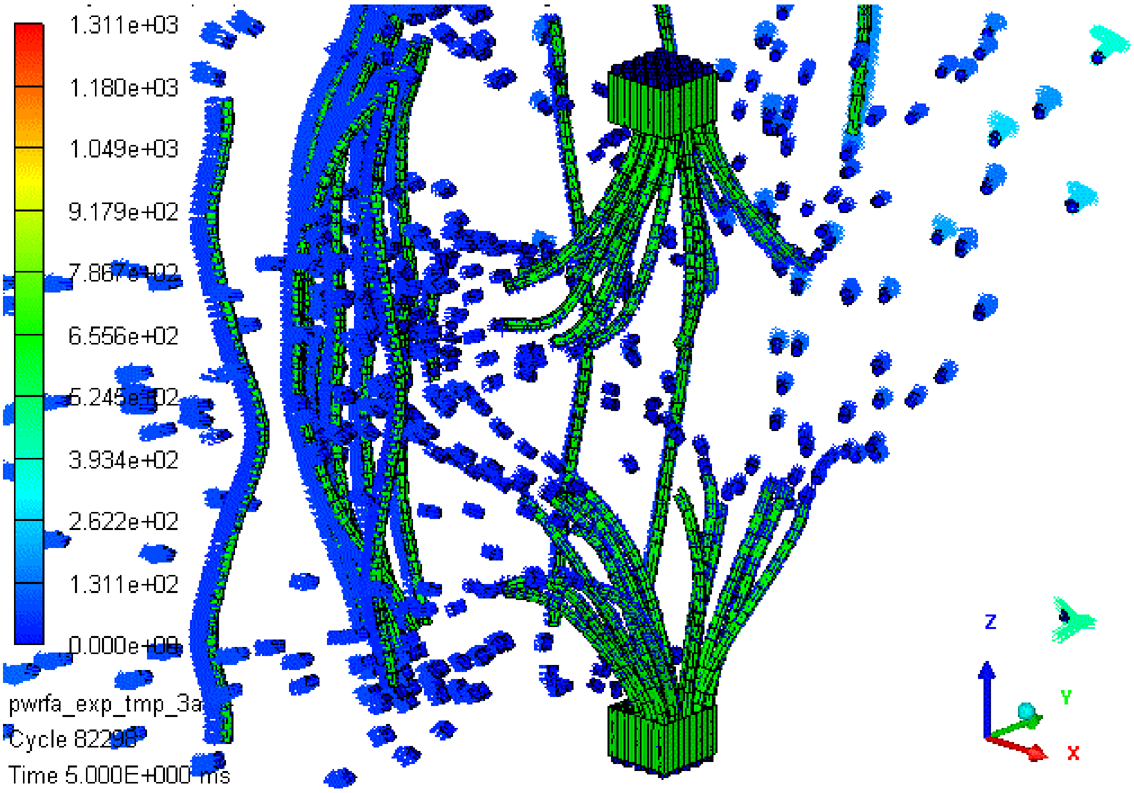

FIG. 5. Velocity vector diagram of the fuel assembly (5 ms after detonation)

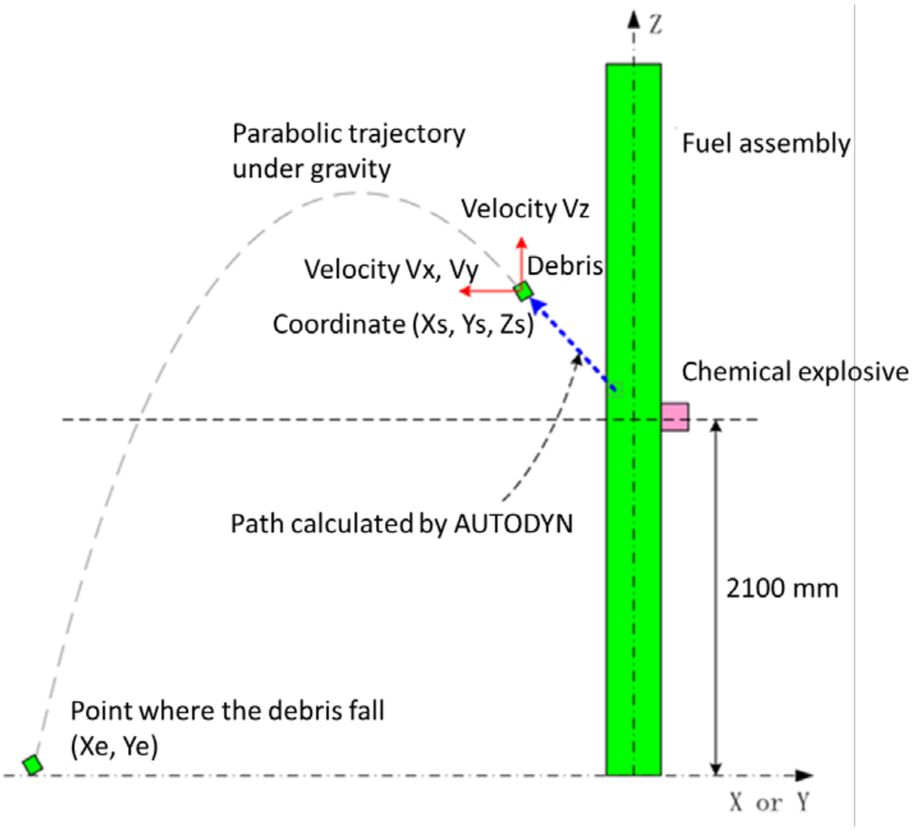

FIG. 6. How to evaluate the flying distance of debris

4. FUTURE PLAN

We introduced an example of blasting off a fuel assembly with a chemical explosive. The forms of nuclear material currently in the project scope are metals, oxides, powders and liquids. A benchmark experiment related to this is also planned. The application of the study would be to do the dose evaluation from scattered debris and create a map that shows the range of lethal dose, which possibly contributes for the Goal 9 study. In addition, based on such maps, it is possible to contribute to create an effective mitigation plan by response unit.

5. CONCLUSION

A study to investigate the effects of chemical explosives attaching to nuclear and radioactive materials was conducted by a simulation using ANSYS AUTODYN. A part of PWR assembly was selected as the first analysis system in this project because it turned out that the analyzing a full-scale assembly did not end within a practical time scale. Therefore, a simulation was performed in a range sandwiched between the two grid spacers around the center of the fuel assembly. When the explosive has expanded sufficiently and it can be determined that it has little effect on the fuel assembly, the Euler region was deleted, and the generated debris follows a parabolic trajectory subject to gravity which enables us to calculate the scattering distance.

Overall, by the methods above, the mass and scattering distance of debris when a fuel assembly was destroyed by chemical explosives were derived. In the future, a benchmark experiment related to this simulation is planned.

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