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THE BEHAVIOR OF CONTENTS OF A SPENT FUEL PACKAGE DURING A 9M VERTICAL DROP TEST WITH LID SIDE DOWNWARDS

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ABSTRACT

Regarding a safety evaluation of a spent fuel package, it was reported that several times of acceleration occurs to the contents compared to the body during the 9 m drop test. This phenomenon creates a safety concern about leaktightness. The greater acceleration is seemed to be produced by the delayed impact of the contents. The delayed impact of the contents is seemed to occur due to a gap between the contents and the inner surface of the lid that is created during the 9 m drop test.

In this research, the behaviour of the contents during a 9 m free fall was clarified using EFM analysis that is simulated the 9 m vertical drop test with lid side downwards.

Moreover, the 9 m drop analysis was performed to confirm the influence on a package when the gap existed. In this analysis, two types of models were used, the difference between them lies in how the contents are represented, in one the contents are modelled as one body whereas in the other it's divided into the basket and the simplified fuel assemblies.

From the results of the analysis, it was confirmed that the greater the gap caused the greater influence on a package. However, we found the maximum gap height is not the only condition that could happen according to the analysis of the behavior of the contents during a 9 m free fall. Moreover, we concluded that a more realistic behavior of the package would be evaluated when the contents are modelled individually compared to the case that the contents are represented as one body.

INTRODUCTION

Regarding a safety evaluation of a spent fuel package, it was reported that several times of acceleration occurs to the contents compared to the body during the 9 m drop test. This phenomenon creates a safety concern about leaktightness. The greater acceleration is seemed to be produced by the delayed impact of the contents. The delayed impact of the contents is seemed to occur due to a gap between the contents and the inner surface of the lid that is created during the 9 m drop test. In this research, the behaviour of the contents during a 9 m free fall was clarified using EFM analysis that is simulated the 9 m vertical drop test with lid side downwards.

We defined this gap as the *initial gap*. : *see Figure 1.b*, and the *upper gap* as the gap between the contents and the bottom inner surface at the moment of the packaging suspension just before the drop. : *see Figure 1.a.*
In this study, firstly, we simulated the 9 m vertical drop test with lid side downwards of a spent fuel package to verify the assumption above using FEM analysis. Secondly, to check the influence on the package, we analyzed the reaction forces at the moment of impact produced by the content on the packaging lid.

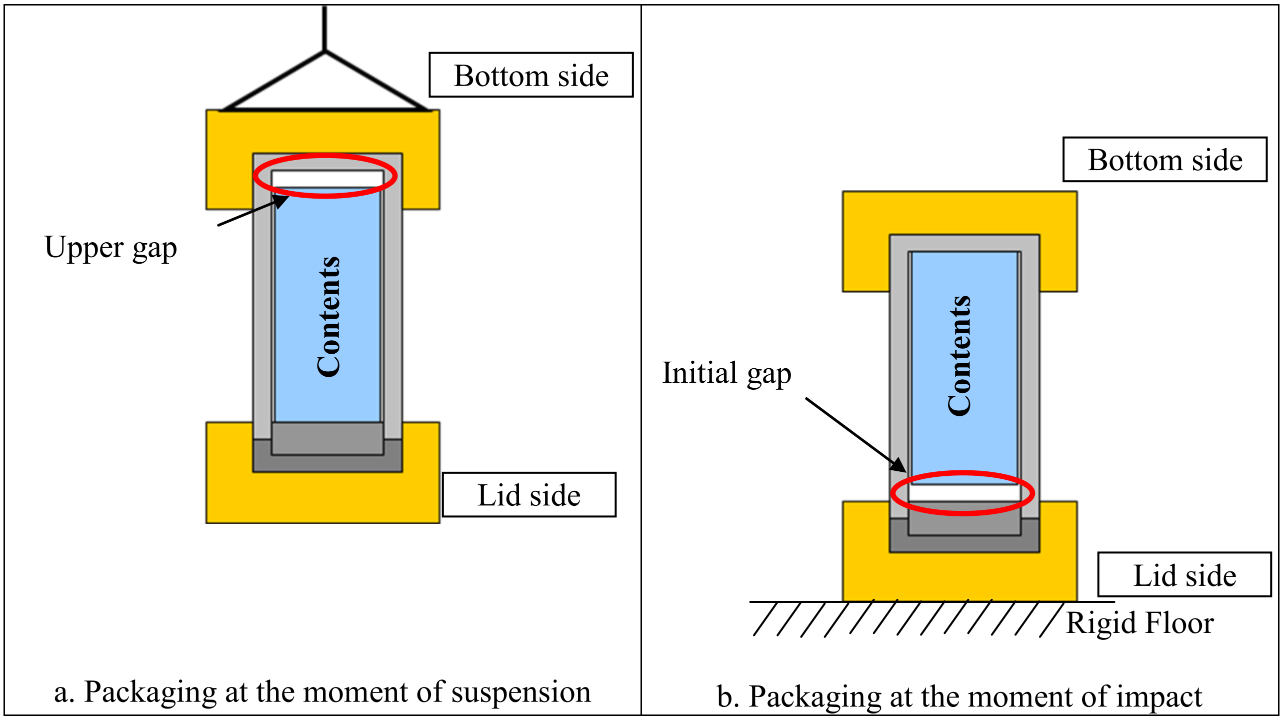

Figure 1.Definittion of the upper gap and initial gap

1. SIMULATION OF THE 9M VERTICAL DROP TEST WITH LID SIDE DOWNWARDS

To clarify the mechanism of the gap phenomenon that occurs between the contents and the inner surface of the lid during the 9 m vertical drop test with lid side downwards, we performed the simulations using FEM analysis. On the other hand, we researched the reaction forces that are generated on the inner surface of the lid to check the influence on the leaktightness of a package when the existence of the gap is confirmed.

1.1 Observing the beginning of a free fall

Firstly, we simulated the beginning of a free fall using FEM analysis with LS-DYNA [1] to clarify the behavior of the contents during the 9 m vertical drop test with lid side downwards. The FEM model is composed of packaging, shock absorbing covers and content. This model is produced as a 3D half model. In this model the basket and the fuels are modeled as one body. : *see Figure 2*
For the first step, the state of suspension of the drop test model was simulated. For the second step, the beginning of the free fall was simulated for the first 10 ms to observe the behavior of the content.

Figure 3 and Figure 4 show the positional relationship between the content and the inner surface of the lid. As shown in Figure 3, it was found that the content contacts with the lid at only its edge during the state of suspension because the lid slightly deforms into a concave shape due to the content weight and self-weight. As shown in Figure 4, it was found that the content was pushed up momentarily as the lid spring back, and then was separated from the lid. Figure 5 shows the variation of the gap between the content and the inner surface of the lid. According to Figure 5, we estimated how much the gap increased during the free fall based on the time increment of the gap. Since there was a 20 mm upper gap in this model and the gap increment as shown in Figure 5, it could be assumed that the content would touch the inner bottom surface of the packaging during the 9 m free fall.

1.2 Observing the 9 m free fall

The FEM analysis of the 9 m free drop was performed to observe the behavior of the content while the package is falling. The FEM model is composed of packaging and content. This model is produced as an axis-symmetry model. In this model the upper gaps are set to 10, 15 and 20 mm to consider the influence of the height of the upper gap. : *see Figure 6*
Same as beginning of the simulation performed in section 1.1, the state of suspension was simulated, and then the 9 m free fall was simulated to observe the behavior of the content. The variation of the gap height between the content and the lid is shown in Figure 7. It was found that the content elevated to the direction of the inner bottom surface of the packaging, and moved back down towards the initial position after contacting with the inner bottom surface of the packaging. Thus, when the upper gaps were 10, 15 and 20 mm the initial gaps were 0.3, 6.0 and 12.3 mm respectively. According to this result, it was confirmed that the initial gaps depend on the packaging design.

1.3 9 m drop analysis considering the initial gap

The simulation was performed to confirm the influence on a package when an initial gap existed. In order to achieve this, the reaction forces generated on the inner surface of the lid were studied. The FEM model is same as the 3D half-model that is used in the simulation performed in section 1.1.: *see Figure 2*
Several analysis cases were performed for the different initial gaps which changed from 0 to 19 mm. The variations of the reaction forces generated to the lid are shown in Figure 8. Moreover, the relationship between the initial gap and the maximum reaction force on the lid is shown in Figure 9. It was found that increasing the initial gap creates greater impact force to the lid of the packaging. However, as the initial gap approaches 20 mm the increment rate of the reaction force slows down.

2. STUDY OF THE BEHAVIOR OF THE INDIVIDUAL CONTENTS

It was researched that in what degree the impact to the lid can be decreased using a more realistic analysis model. In order to achieve this, we performed a simulation using the analysis model that divide the content into the basket and the individual fuel assemblies.

2.1 Calculation model

We created the analysis model that divide the content into the basket and the individual fuel assemblies. For simplification in this model the fuel assemblies are modeled as square rods. : *see Figure 10*

2.2 Behavior of the individual contents at the beginning of a free fall

A simulation same as section 1.1 was performed using the individual contents model instead of the model that is used in section 1.1 and the behavior of the contents was observed. According to the results, it was found that the basket and fuel assemblies elevated as the lid spring back. Figure 11 shows the variation of the gap height between some representative fuel assemblies and the lid for the first 10 ms of the free fall. Moreover, Figure 12 shows the variation of the gap height between the basket and the lid. According to these figures, it was found that the elevating height of each content is different. The relationship between the elevating height and the distance of some representative contents to the center of the lid at the 10 ms after starting the free fall is shown in Figure 13. It was found that the elevating height is high at the central part of the lid and gradually decreases as the distance from the center of the lid increases.

2.3 Initial gaps of the individual contents

The initial gaps of each individual content were estimated in order to simulate the 9 m vertical drop test with lid side downwards considering these initial gaps. It was predicted that there are two cases to estimate these gaps depending on the behavior of the content during the 9 m free fall. The procedures to estimate these gaps are described as follows:

a. In case when the content doesn't contact with the inner bottom surface of the packaging before impact. *see Figure 14*
   1. Calculate the elevating height of the basket and each fuel assembly during the 9 m free fall using time increment from the results of Figure 11 and 12.
   2. Set the elevating height as an initial gap.

b. In case when the content contacts with the inner bottom surface of the packaging before impact. *see Figure 15*
   1. Assume a *drop gap*, defined as the height created after the content contacts with the inner bottom surface of the packaging. In order to evaluate this, we assumed that the gap variation is same as the negative slope of the case of the 20 mm upper gap of Figure 7.
   2. Calculate the initial gap by the upper gap minus the drop gap.

2.4 Effect of the individual contents

A 9 m drop analysis was performed in order to consider the influence of modeling the contents individually, and its effect to the impact to the packaging. The initial gap of each individual content that determined in section 2.3 was used in the model. The reaction forces that were generated to the lid are shown in Figure 16. In order to compare the influence of different initial gap, we indicate the results when the initial gap for all contents is set to 0 mm and 20 mm. 20 mm corresponds to the maximum gap height of the model.

Firstly, comparing Figure 16 and Figure 8 that is the result of when the contents are represented as one body, it was found that the peak value of the reaction force does not change so much. However, the behavior of the reaction force during impact changes dramatically and also the second impact force decreases drastically when the contents are modeled individually. According to this result, we concluded when the contents are modeled as one body it would gives an excessively conservative evaluation whereas when the contents are modeled individually it gives a more realistic evaluation of the influence on the package during the 9 m drop test.

Secondly, from the comparison of the case when the maximum initial gap condition and when the individual initial gap condition as shown in Figure 16, it was found that the peak value of the reaction force does not decrease. Therefore, to check the influence on the leaktightness of a package, we observed the deformation of the lid as shown in Figure 17. It was found that the deformation of the lid is smaller using the individual initial gap condition than setting the maximum initial gap to all contents. According to this result, we concluded the influence on the leaktightness of the package would be decreased by using the individual initial gap condition.

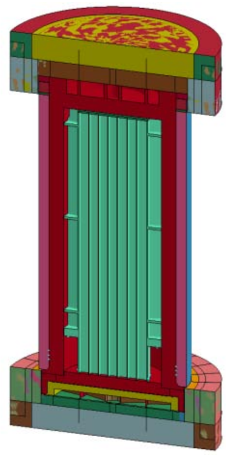

Figure 2. FEM model to observe the beginning of the free fall

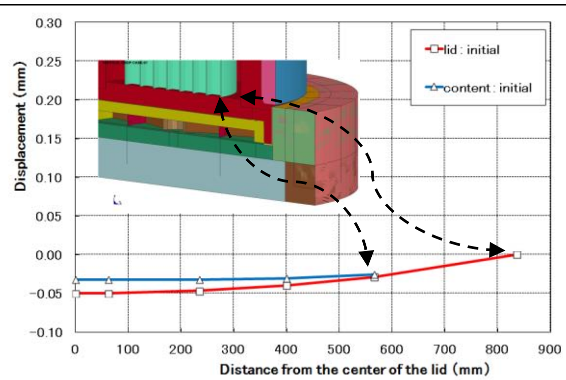

Figure 3. Positional relationship between the lid surface and the content during suspension

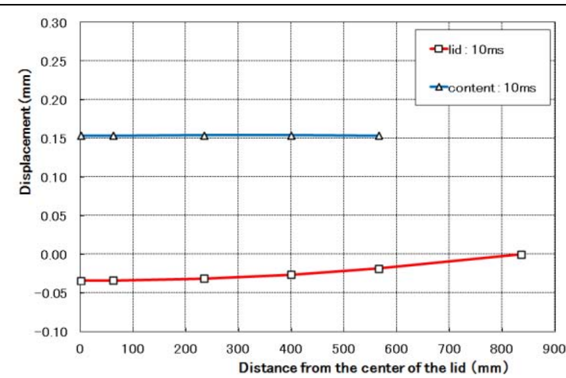

Figure 4. Positional relationship between the lid surface and the content at 10 ms after the free fall starting

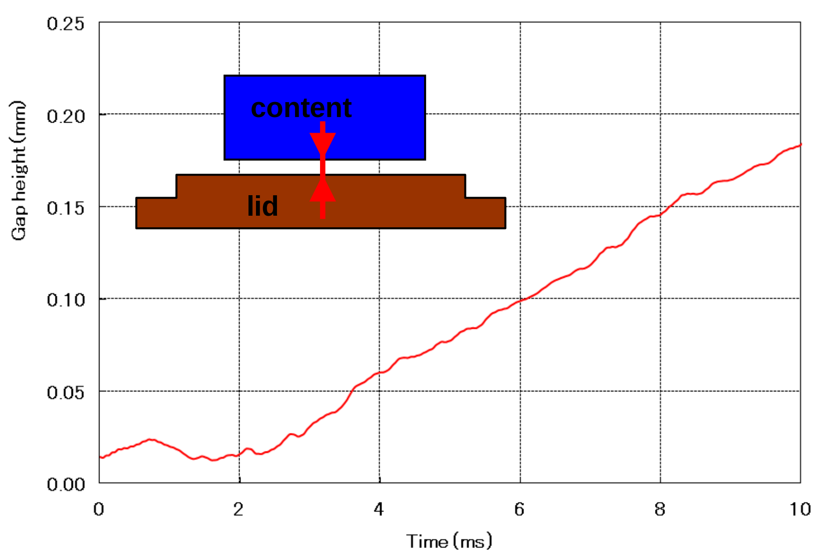

Figure 5. Variation of the gap height between the lid and the content at the beginning of the free fall

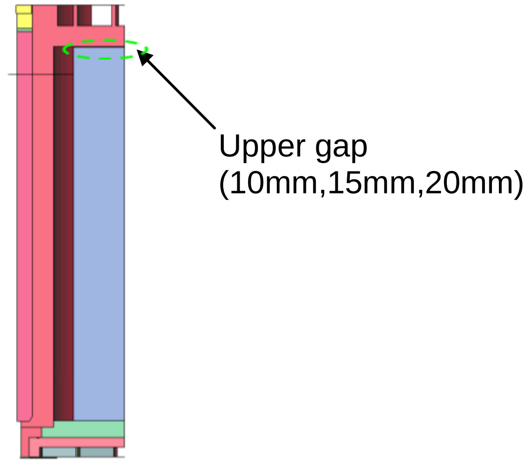

Figure 6. FEM model to observe the 9 m free fall

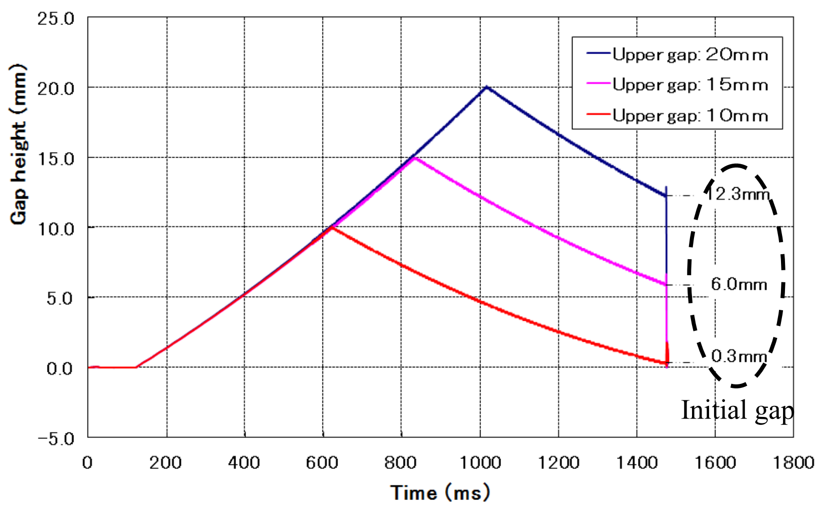

Figure 7. Variation of the gap height between the lid and the content during the 9m free fall

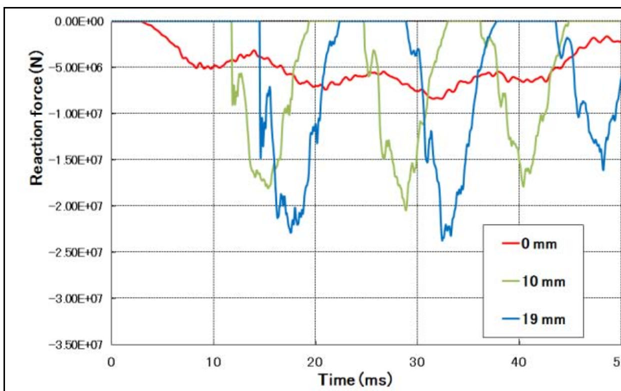

Figure 8. Variation of the reaction forces to the lid

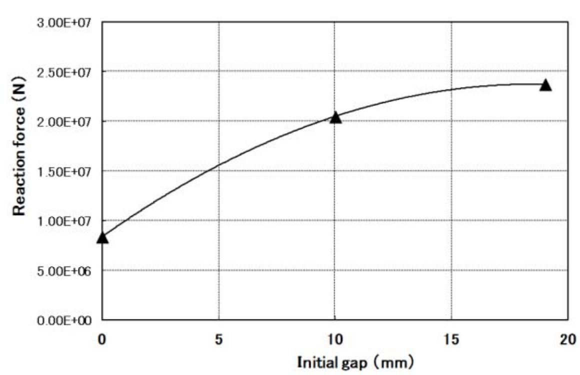

Figure 9. Relationship between the initial gap and the maximum reaction force

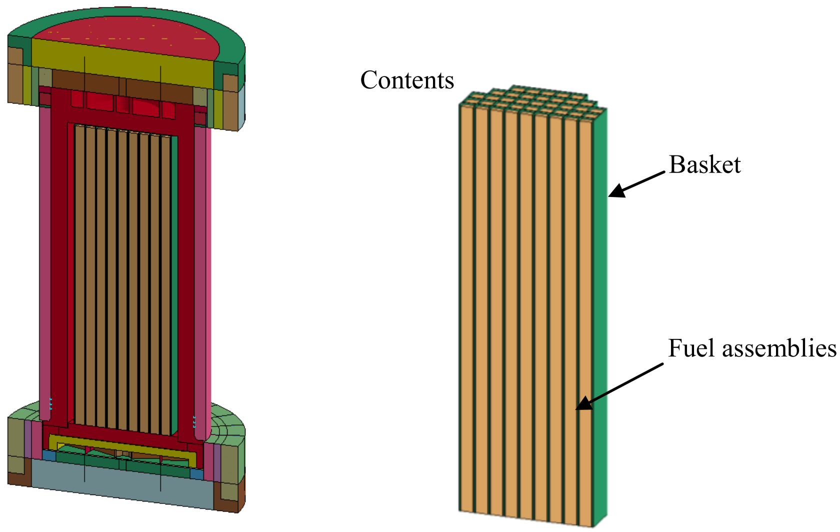

Figure 10. FEM model to observe the behavior of the individual contents

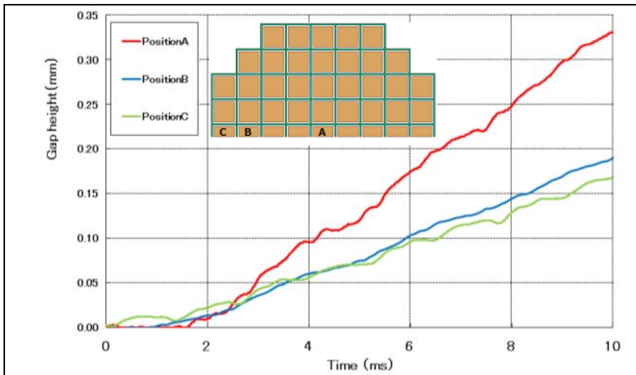

Figure 11. Variation of the gap height between the fuel assemblies and the lid

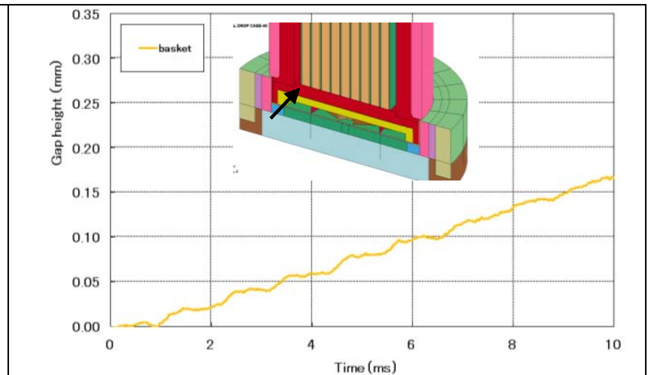

Figure 12. Variation of the gap height between the basket and the lid

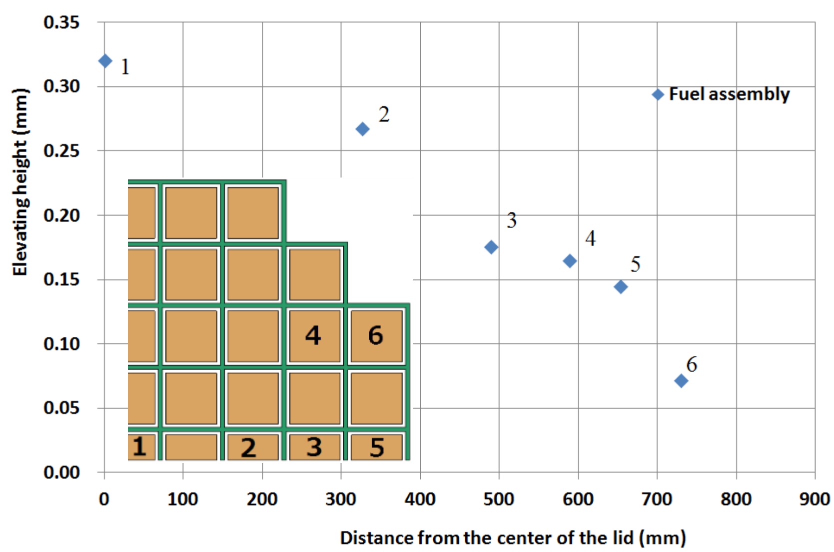

Figure 13. Relationship between the elevating height and the distance of the contents to the center of the lid

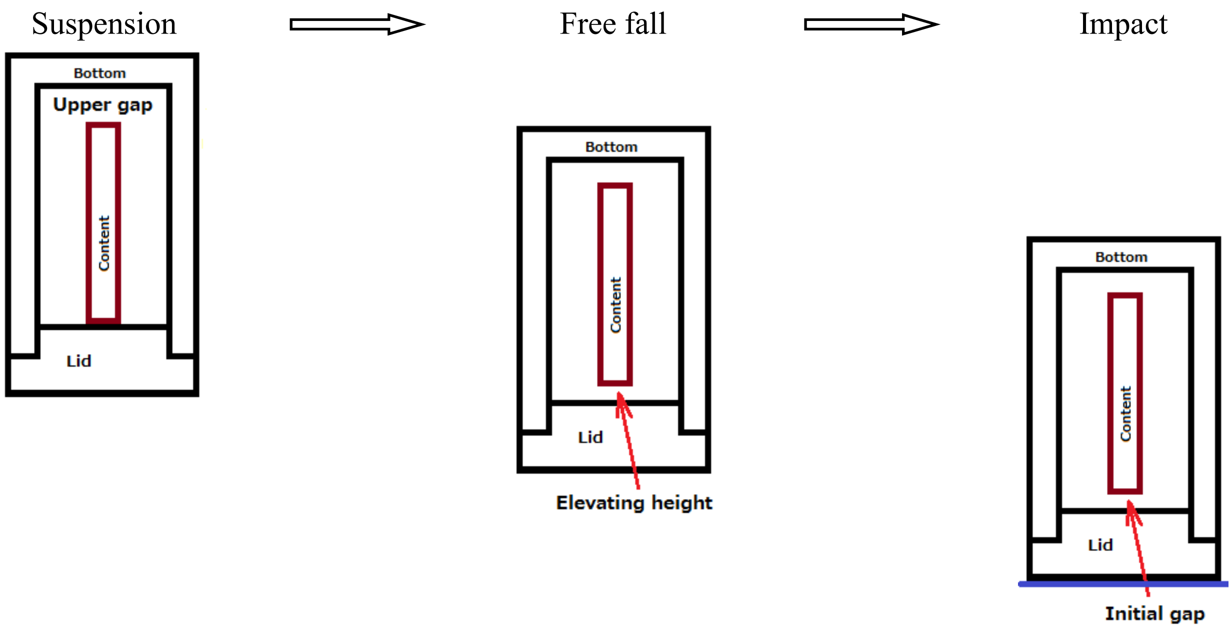

Figure 14. Outline of the behavior of the content for the initial gap "case a"

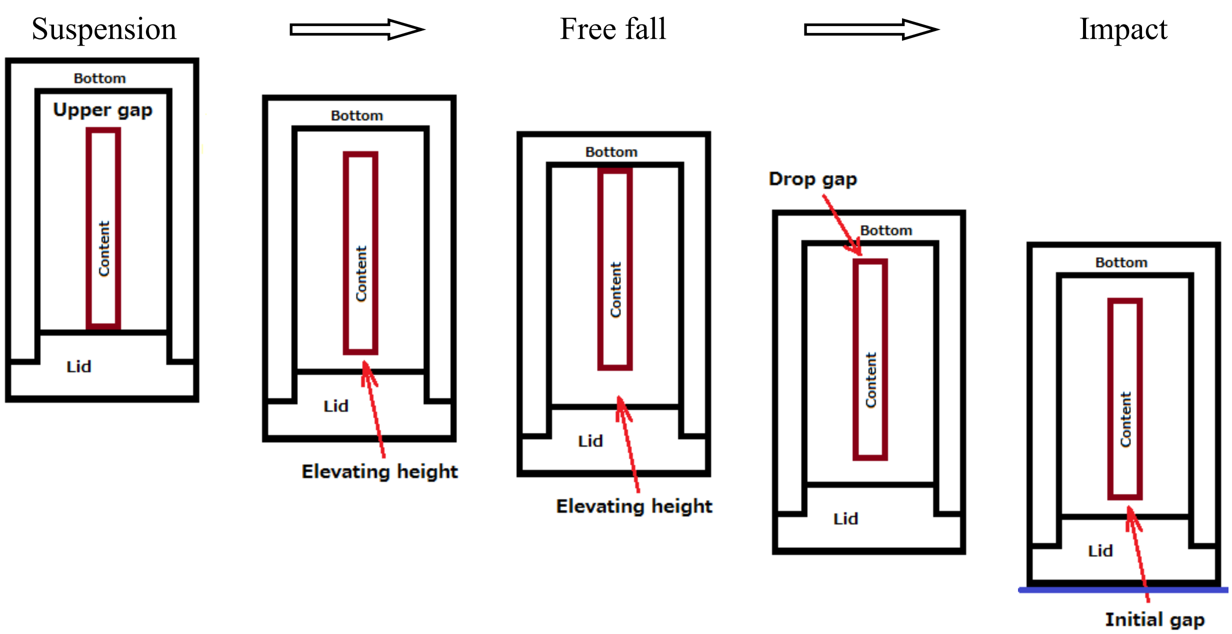

Figure 15. Outline of the behavior of the content for the initial gap "case b"

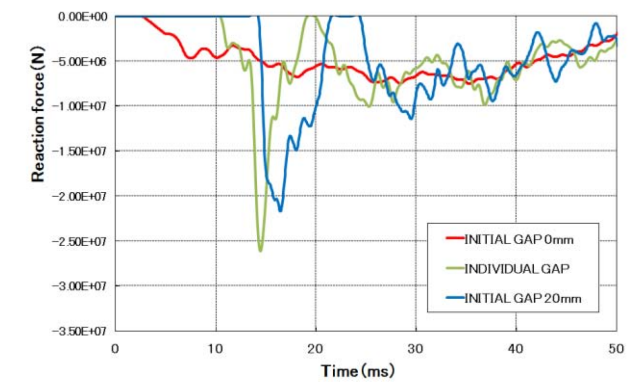

Figure 16. Variation of the reaction forces to the lid (low pass 600 Hz)

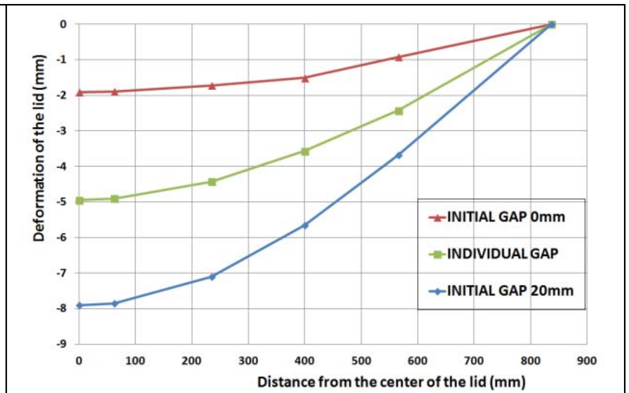

Figure 17. Deformation of the lid

CONCLUSIONS

In this study, we clarified the behavior of the contents during the 9 m vertical drop test with lid side downwards that influences the leaktightness and its effect to the safety evaluation of the package by the simulation. It is found that:

1. The content was pushed up momentarily by the lid spring back at the beginning of a free fall, and then elevated from the inner surface of the lid.
2. Depending on the packaging design, some of the contents could contact with the inner bottom surface of the packaging during the 9 m free fall, and move back down towards its initial position.
3. The basket and fuel assemblies behaved independently during the 9 m free fall. Namely, the elevating speed is higher at the central part of the lid and gradually decreases as the distance from the center of the lid increases.
4. The behavior described above causes the different height of the initial gaps of each content.
5. Although the simplified model was used, the behavior of the reaction force changes drastically when the contents were modeled individually.
6. When the individual initial gap is used, the deformation of the lid decreases

We can say that the influence of the delayed impact by contents on the leaktightness of the package would be decreased when using the individual initial gap condition. However, to perform the analysis of the leaktightness of the package including the behavior of the contents, further research is needed.

REFERENCE

[1] LS-DYNA THEORY MANUAL, John O. Hallquist, March 2006