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A new packaging design for the HEAT CS Sympathetic Detonation test

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Abstract

The Sympathetic Detonation (SD) test is in a majority of Threat Hazard Assessment (THA) investigations considered to be one of the most critical of the Insensitive Munition (IM) standard tests.

When the HEAT CS unit load was tested according to the MIL-standard SD-test regulation, the test response was characterized as a type I reaction. This means that at least one of the neighbouring round warheads was initiated to detonation. This is not acceptable. The HEAT CS SD test was modelled in an ANSYS Autodyn simulation. The result of the simulation confirmed the test result and showed that rounds located in the diagonal direction will be initiated to detonation. From the basic model it was possible to study different types of protection solutions in the transportation box. A satisfactory solution was found that in the simulation showed that no detonation transfer would occur.

A new SD Test of the HEAT CS unit load was performed, with the suggested modifications implemented. The test result was successful and the response was characterised as a type IV/V reaction, which is Deflagration/Burn.

1 Introduction

A Sympathetic Detonation (SD) test of the HEAT CS unit load was performed. In the test the rounds are packed in three twin containers stowed in the transportation box according to figure 1. The unit load consists of nine transportation boxes.

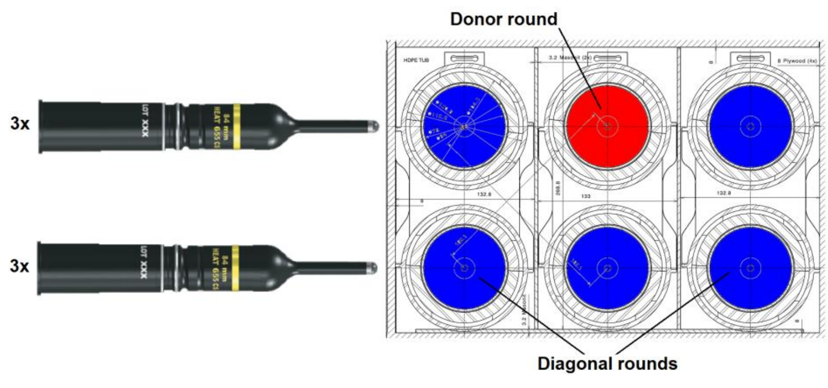

Figure 1. Six rounds packed in the transportation box.

The explosive in the warhead in the donor round, indicated with red, was initiated to detonation in the test and the surrounding rounds were all fully functional. The test result showed that at least two of the surrounding rounds were initiated to detonation. The photo in figure 2 shows more than one pressure wave in the air. This indicates that two diagonal rounds in the lower level are initiated to detonation. The test result was characterized as a type I reaction, which is Detonation, according to STANAG 4439.

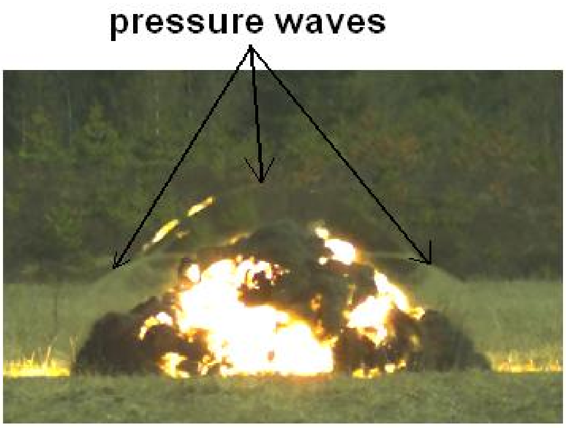

Figure 2. More than one pressure wave in the air indicating an unacceptable test result.

2 Investigation

Due to the unacceptable result in the HEAT CS Sympathetic Detonation test, an investigation was started. The goal was to modify the configuration in the transportation boxes to secure that no surrounding rounds were initiated to detonation during the test.

The first data needed to numerically simulate the setup was to characterise the HMX/binder high explosive, with regard to the shock sensitivity limit for detonation. No Ignition and Growth data were available for the explosive. For the investigation a projectile impact test on the explosive was performed. The projectiles are made of brass and have a diameter of 15 mm and a length of 15 mm. Cylinders of the explosive, with a length of 30 mm and a diameter of 30 mm, are impacted by the projectile with a variable velocity. The purpose is to find the limiting velocity for the explosive were it is initiated to detonation. This test was completed for the explosive, and the critical impact velocity was determined to be 660 m/s. With this result the projectile impact test was modelled in ANSYS Autodyn, in a rotational symmetric model. The explosive was simulated as an inert material, see figure 3. In the explosive a gauge point was introduced to study the pressure as a function time.

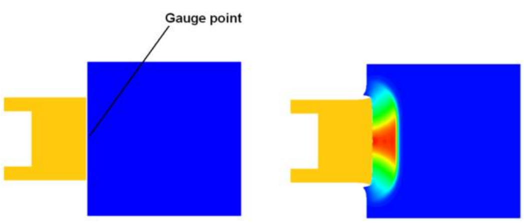

Figure 3. The simulation of the projectile impact test.

The simulated pressure-time curve in the gauge point with a projectile impact velocity of 660 m/s is presented in figure 4.

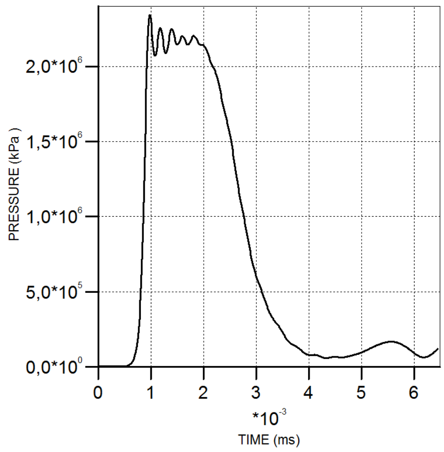

Figure 4. The simulated pressure as a function of time in the explosive at the limiting impact velocity for detonation.

In the simulation it can be seen that the limiting pressure load is approximately 2100 MPa over a time span of about one microsecond, for the explosive to be initiated to detonation in the projectile impact test.

With this basic information it is now possible to study the actual setup to compare the pressure load experienced for the different surrounding rounds with this limiting pressure load for detonation.

A planar lagrange type model of the SD-test setup was created in ANSYS Autodyn, see figure 5.

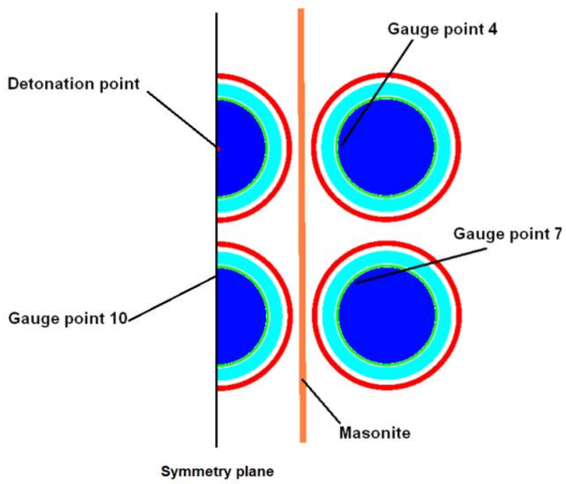

Figure 5. Model of the SD-setup.

Figure 6 shows how the donor warhead expands over time and eventually hits the surrounding rounds. The fringe colours show the current pressure. Red indicates a pressure of 1000 MPa or higher.

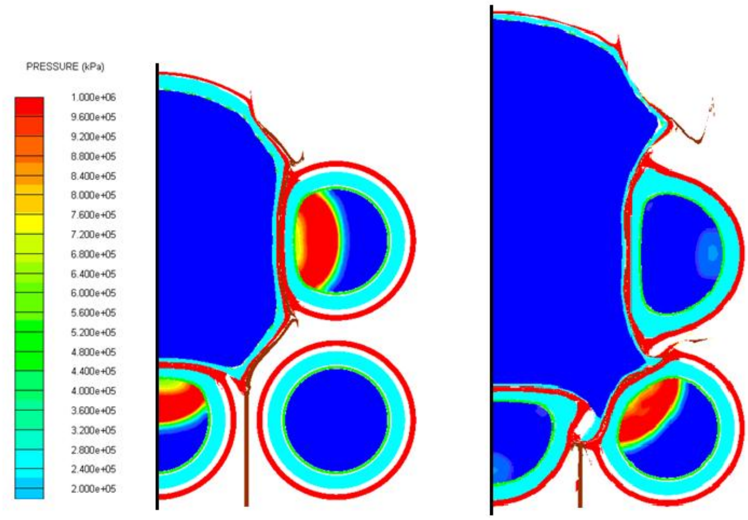

Figure 6. Pressure distribution at times 45 and 75 μs after initiation.

Referring to the gauge point numbers in figure 5, it is now possible to show the simulated pressure as a function of time in the different explosive rounds, see figure 7.

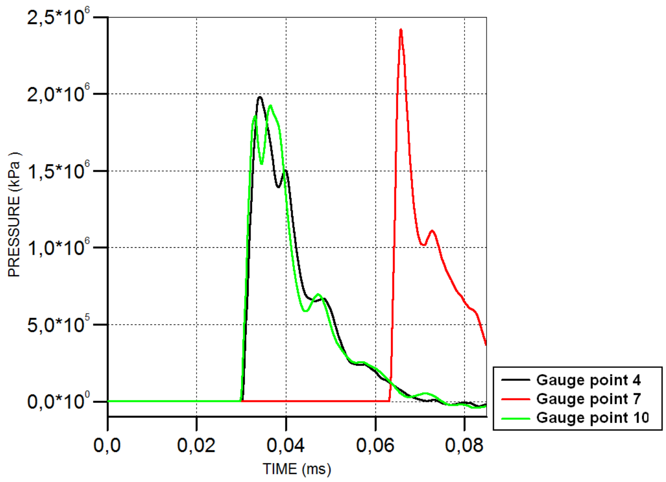

Figure 7. Pressure as a function of time in the different gauge points.

From the simulation it can be seen that the gauge point 7, in the diagonal round experiences the highest pressure during the SD-test. The pressure is also higher, almost 2500 MPa, than the limiting pressure from the projectile impact test in figure 4. This means that simulations indicate that the warheads in the diagonal rounds will detonate in a SD-test. This was what also actually happened in the test, see figure 1. The next step is to see what can be changed in the transportation box configuration to especially protect the diagonal rounds to prevent initiation to detonation.

Secondary explosives can be characterised with a critical energy for initiation to detonation. This requires that the explosive is defined with regard to composition, density etc. and that the dimensions are well above the critical diameter.

This determined critical energy can then be compared to the actual stimuli from an applied pressure wave. The energy is proportional to the time length of the pressure wave Δt and the square of the pressure P^2.

This implies that a rather small reduction in the pressure load introduced to the explosive in the surrounding rounds, will strongly reduce the probability of initiation to detonation. To accomplish this, it is necessary to have some kind of protective material between the different rounds.

A first attempt to reduce the pressure load was suggested by introducing polycarbonate wedges according to the drawing in figure 8. The design was intended to decrease the pressure load on the diagonal rounds.

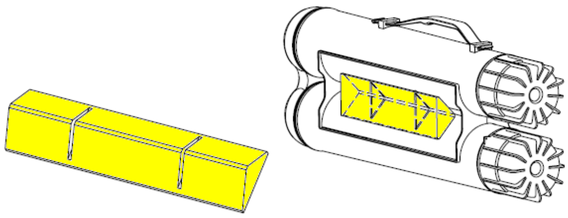

Figure 8. Pressure reducing wedges.

To study the effect of the wedges a simulation model was created, see figure 9.

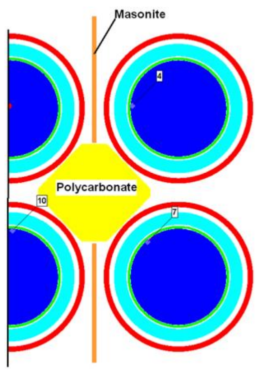

Figure 9. Simulation model with polycarbonate wedges.

In figure 10 the calculated pressure loads are compared in the gauge points 4, 7 and 10. The first diagram is with the original configuration and the second one with the polycarbonate wedges.

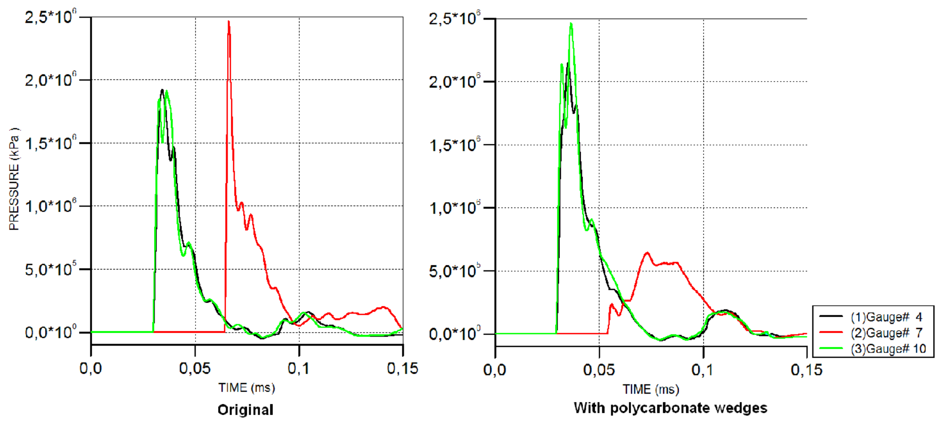

Figure 10. Pressure loads with the original design compared to with the protective wedges.

The simulations indicate that with the introduction of the wedges we indeed get a decreased pressure in the diagonal rounds to a level that is “safe” and not capable to initiate a detonation. On the other hand the pressure affecting the other rounds is clearly increased to a level that will possibly initiate them to detonation, see gauge points 4 and 10. The reason is that the pressure load from the donor round is deflected towards the other rounds, when a protection is introduced towards the diagonal rounds. This also tells us that the issue is complex and that an inventive solution is needed.

After a number of simulations it could be clearly stated that a cross type of protection will give the best overall result. In the next step we studied the cross material and dimensions to get sufficient protection without increasing the unit box weight too much. In the next simulations a 10 mm cross was studied for three materials. The materials were polycarbonate, aluminium and steel, see figure 11. Figure 12 shows the situation 1, 60 and 180 µs after initiation with crosses made of steel.

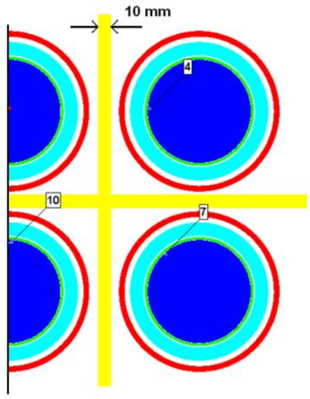

Figure 11. Simulation model with 10 mm cross for three materials.

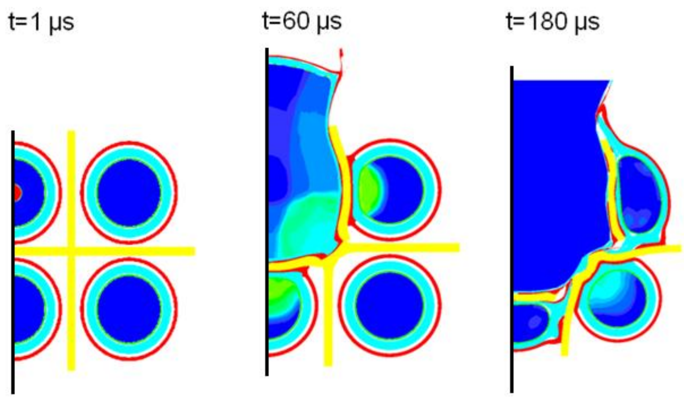

Figure 12. Pressure fringes in the rounds at three times after initiation.

Figure 13 shows the pressure as a function of time in the respective gauge points with the tree different cross materials and for the nominal set up.

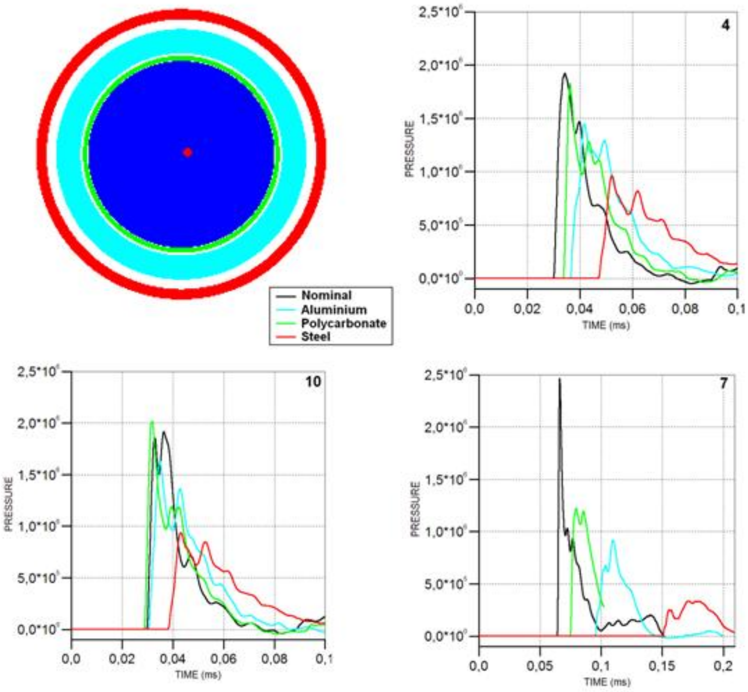

Figure 13. Pressure (kPa) as a function of time in the studied gauge points for three different cross materials compared with the set up without any protection.

From the bullet impact test and the related simulation we know that pressure in the surrounding warhead explosive shall not exceed 2100 MPa. Instead the maximum pressure is recommended to be 1700 MPa or lower to get a sufficient safety margin. From the simulations it can be seen that steel is the favourable protection material. A problem is that steel has a comparably high density. The decision was to use steel as the construction material for the crosses, but study the effect of a reduction in the thickness to try to reduce the weight of the protection material. Material thicknesses of 10, 8 and 6 mm were studied. In figure 14 the result of the simulations are presented.

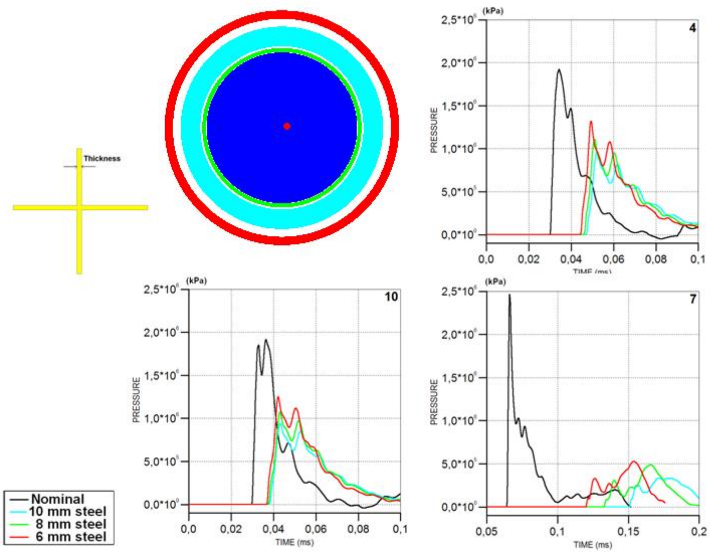

Figure 14. Pressure as a function of time in the studied gauge points with steel thicknesses 10, 8 and 6 mm steel.

To ensure a robust design with satisfactory safety margins, a steel cross with a thickness of 8 mm was chosen. Simulations with two different steel qualities, with regard to strength data, were also studied. The differences as protective materials were neglectable, which means that the steel quality, as expected, is not critical.

Finally the pressure loads on the closest round in the box on top off and at the side of the box with the donor round in the unit load, were studied.

First the case with a box on top the donor round box was simulated. The setup is illustrated in figure 15. Red indicates the donor charge and the blue colour is the closest round on top off the donor box. A gauge point 13 was introduced in the explosive in the studied round in the upper box. Figure 16 shows the simulation model at initiation and after 57 µs.

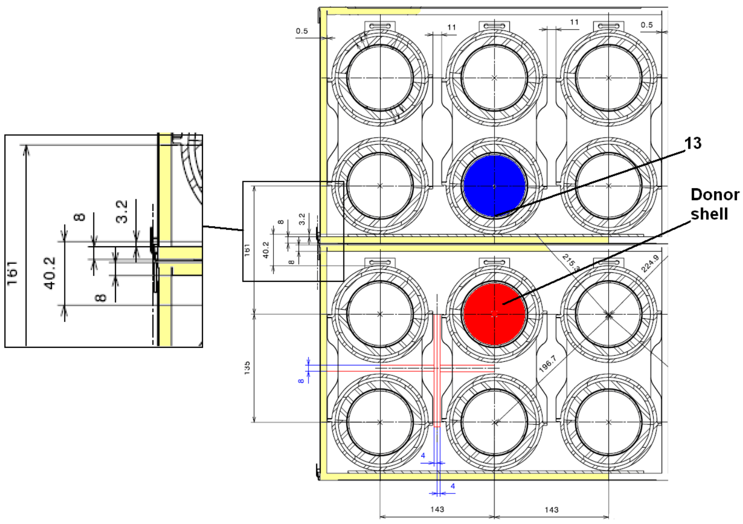

Figure 15. A transportation box standing on top of the box with the donor round.

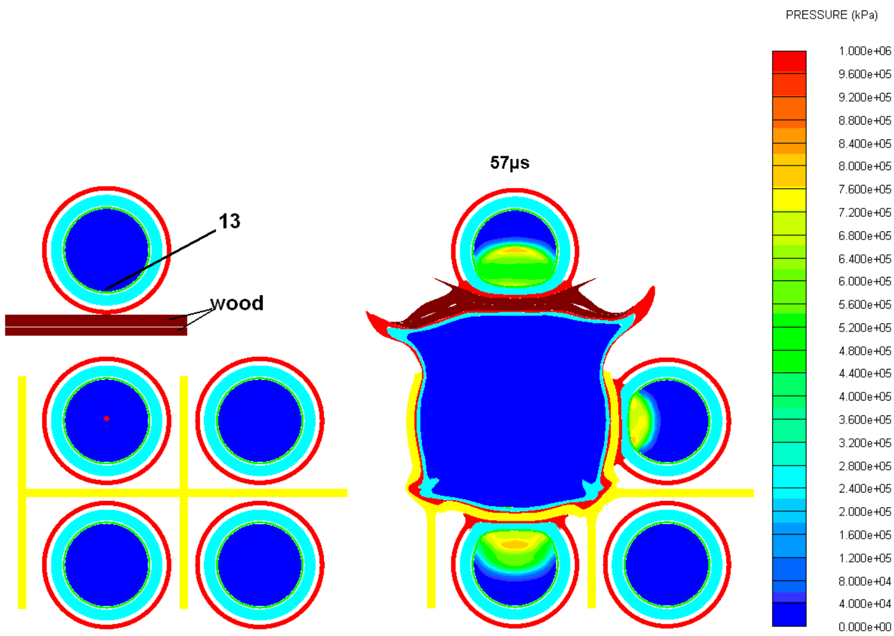

Figure 16. A box standing on top of the box with the donor round.

The maximum pressure level in gauge point 13 is approximately 1600 MPa according to the simulation, and indicates that the round will not be initiated to detonation in the SD-test.

In the same way the pressure loads for the rounds in a transportation box standing beside the box with the donor round was modelled. Figure 17 shows the configuration.

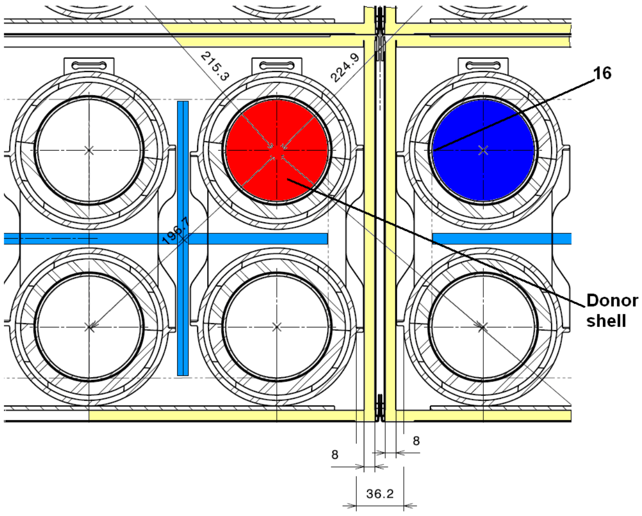

Figure 17. A transportation box standing beside the box with the donor round.

Figure 18 shows the simulation model at initiation time and after 57 µs.

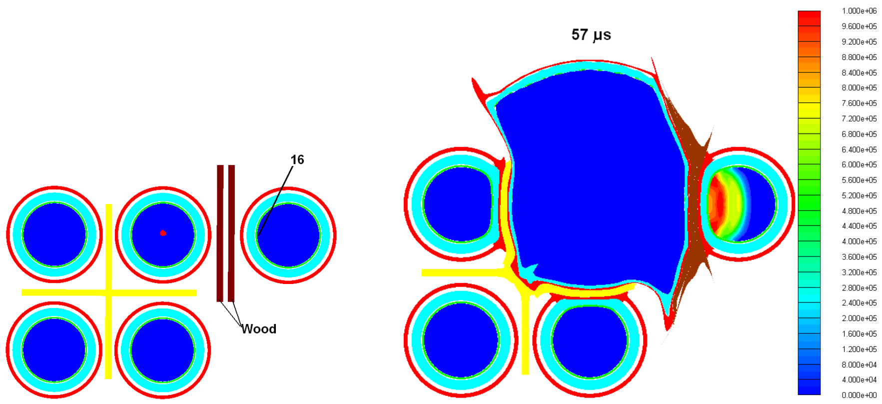

Figure 18. A box standing beside the box with the donor round.

The maximum pressure level in gauge point 16 is below 1500 MPa according to the simulation, and indicates that the round will not be initiated to detonation in the SD-test.

3 SD Test for HEAT CS with the new arrangement

After the modelling, the arrangements in the transportation boxes were changed according to the simulation results. Crosses made of steel with material thickness of 8 mm were introduced. To support the crosses and to facilitate the packaging, a holder made of LDPE 45 (Low Density Polyethylene) was introduced, see figure 19. The figure also shows how the twin containers with the rounds were packed in the transportation boxes in the final testing.

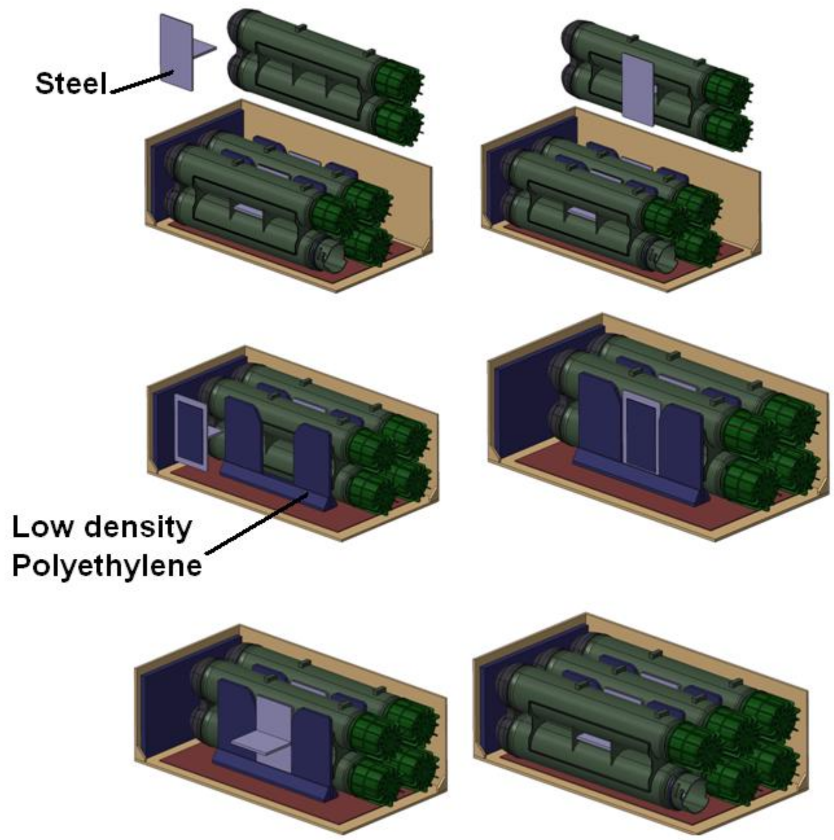

Figure 19. Packaging arrangement for the final testing.

A new SD Test of the HEAT CS complete unit load was performed with the suggested modifications included. The test result was successful and the response was characterised as a type IV/V reaction, which is Deflagration/Burn.

4 Conclusion

With the introduction of the steel crosses in the transportation boxes, the new HEAT CS system is now approved in the Sympathetic Detonation (SD) test. The design with a maximum protection in the diagonal direction, were it is needed, is really favourable. The basic concept is probably applicable to other type of rounds in their unit loads, and hopefully it will be standard procedure in the future to simulate the set up before the costly testing is done.