LEUPA

Container for low-enriched uranium

ANALYSIS OF THE LEUPA PACKAGE DROP POSITION CAUSING MOST DAMAGE

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1 PURPOSE

1. To determine the angle with respect to the floor causing most damage in the drop test to the package of the fissile material (FM) container called LEUPA. That test is the test normalized by the Standard stated in REF1.

2 SCOPE

1. This document evaluates the behavior of the LEUPA package in the event of a normalized impact. The study is focused solely on accident conditions during transport.

3 APPLICABLE DOCUMENTS

1. APL1 - 0908-LE01-3AEIN-010 LEUPA – PACKAGING – MAIN BODY.
2. APL2 - 0908-LE01-3BEIN-024 LEUPA – CRITICALITY ANALYSIS.

4 REFERENCE DOCUMENTS

1. REF1 - Standard AR 10.16.1 “Transport of radioactive materials”. Revision 2.
2. REF2 - ASME B31.1

5 ACRONYMS

1. LEUPA Package for the transport of low-enriched uranium.
2. CM Center of mass.
3. FM Fissile material.

6 DEVELOPMENT

6.1 DESCRIPTION OF THE PACKAGE

1. The container is designed for the transport of FM, and shall be equipped to protect your cargo from accidental impacts and high outdoor temperatures.
2. In summary, the container is composed of a double layer stainless steel interior container with cadmium between layers. That is the container with the FM, sealed with a bolted cover.
3. There is an external 3 mm thick stainless steel containment. This containment is reinforced with L profiles and there are also 8 sheets with radial configuration to center the internal container. Empty spaces are filled with thermal insulation material called "kaolite".
4. APL1 contains a list of the elements of the container.

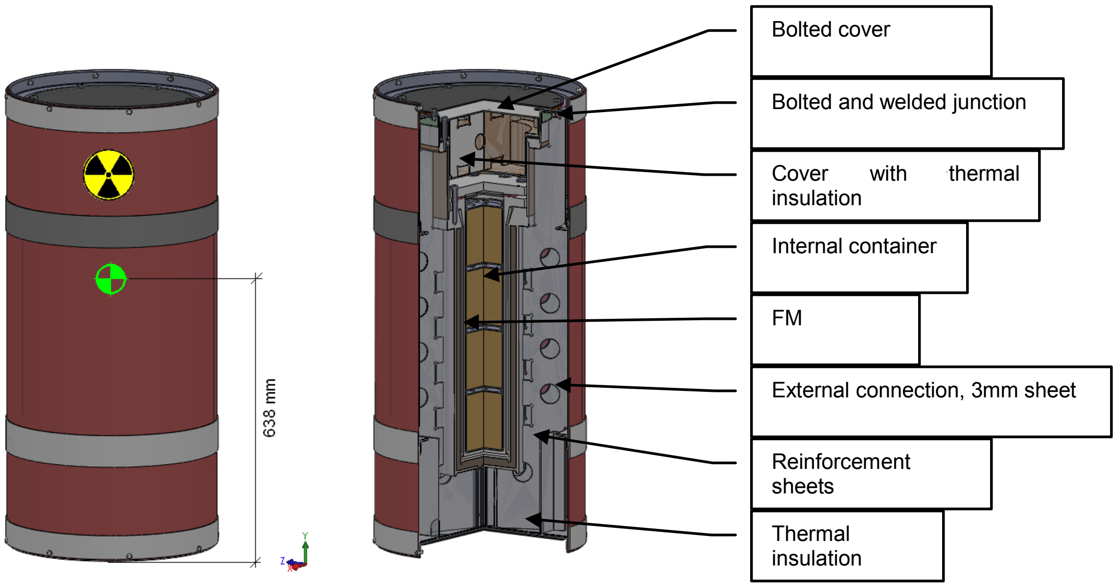


Figure 1. Internal view of the package.

6.2 IMPACT TEST

1. One of the impact tests the package is subject to consists of a free drop to the floor. The drop height is 9 m, impacting on a flat and rigid surface, pursuant to REF1 paragraph 727.
2. Since the package can impact in different positions, as shown in Figure 2, the purpose of this document is to determine which one will cause the most deformation. It is presumed that the degree of deformation is directly related to the damage caused.

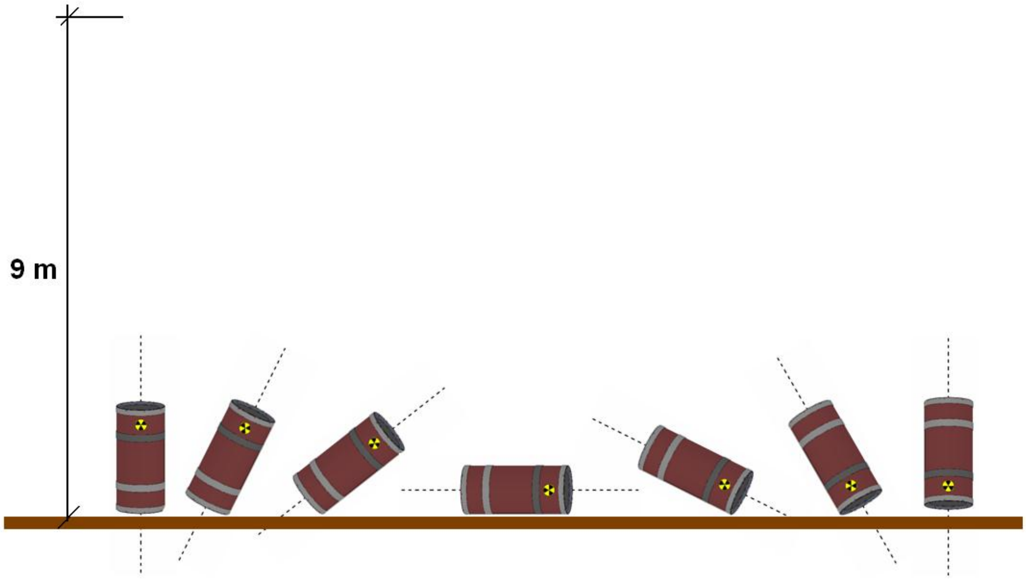


Figure 2. Potential impact positions of the package.

6.3 SIMPLIFICATION HYPOTHESIS

6.3.1 Model

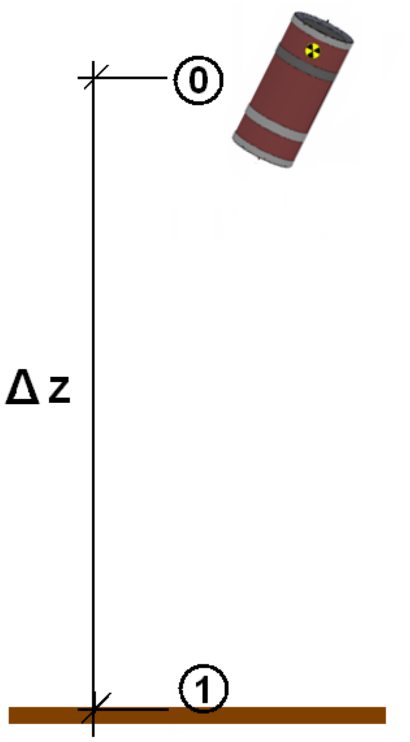
1. The dynamic impact test was modeled following the finite elements method with static simulation applying acceleration equal to the drop impact.

2. The magnitude of acceleration was set and applied to the container in several directions, setting it in different positions (refer to Figure 2).
3. To determine the equivalent acceleration, the speed prior to the moment of the impact was estimated, and it was assumed that upon impact the container decelerates until it stops.
4. For the purposes of obtaining the acceleration order equivalent to the impact, the same stop time was assumed in all cases. Considering that the time in all cases will be the same would not be a valid hypothesis, but this allows us to assume one same acceleration value equivalent, since the drop height is a constant.
5. Applying the energy preservation principle, the final speed after the 9m drop is determined.

$$\mathbf{E = m\ a\ z + \tfrac{1}{2}\ m\ V^2}$$

Where:

E = Total energy
m = mass
a = Acceleration
z = Distance
V = speed



(0) - Container hanging prior to the drop.

(1) - Container stopped in the floor, after impact.

Δ z - Drop heigth.

Figure 3. Scheme of drop test.

6. Applying the energy preservation principle from points 0 to 1 of Figure 3, we can determine the V_1 speed prior to impact. In this case, the acceleration corresponds to the gravitational acceleration. Note that the container starts from rest (**V_0** = 0).

$$\mathbf{m\ g\ z_0 + \cancel{\tfrac{1}{2}\ m\ V_0^2} = m\ g\ z_1 + \tfrac{1}{2}\ m\ V_1^2}$$

$$\mathbf{g\ (z_1 - z_0) = \tfrac{1}{2}\ V_1^2}$$

$$\mathbf{V_1 = \sqrt{(2\ g\ (z_1 - z_0))} = \sqrt{(2\ g\ \Delta z)}}$$

$$V_1 = \sqrt{(2 \times 9810\ [mm/s^2] \times 9000\ [mm])} = 13288\ [mm/s]$$

7. Applying the second Newton law upon the shock, we can estimate the deceleration upon impact, assuming a consolidated time of t = 0.03 s in the first instance.

$$\mathbf{F = \cancel{m}\, a = \cancel{m}\, (\Delta V / \Delta t)}$$

$$\mathbf{a = (\cancel{V_{final}} - V_1) / (t_2 - \cancel{t_{initial}})}$$

$$\mathbf{a = -V_1 / t_2}$$

$$a = -13288\ [mm/s] / 0.03\ [s] = 441427\ [mm/s^2]$$

$$\boxed{\mathbf{a_{equivalent} = 45\ g}}$$

8. The acceleration calculated above shall be used as the acceleration of reference to find the most unfavorable angle for impact. The magnitude of the damage shall depend on the impact time assumed, but it is not the subject matter of this analysis, only angle and position are included.
9. The point or surface of contact of the package with the floor upon impact was assumed as a fixed contact. This hypothesis was necessary to define the model and carry out the statistical study.

6.3.2 Simplification of the container

1. To facilitate the meshing of the model, the details of some elements were simplified. Simplifications are detailed below
    - Bolts were replaced with circular section linear elements with the applicable diameter.
    - FM and insulation materials: since they have a complex geometry and radial symmetry, they were placed as point masses in the revolution axis of the package at the height of their related mass center. This way, the mass of the container is the same, but contributions to the structure provided by the insulation are lost. This omission is a conservative simplification hypothesis due to the loss of such contribution. It is assumed that the omission will not be significant because the insulation has no significant mechanical properties.

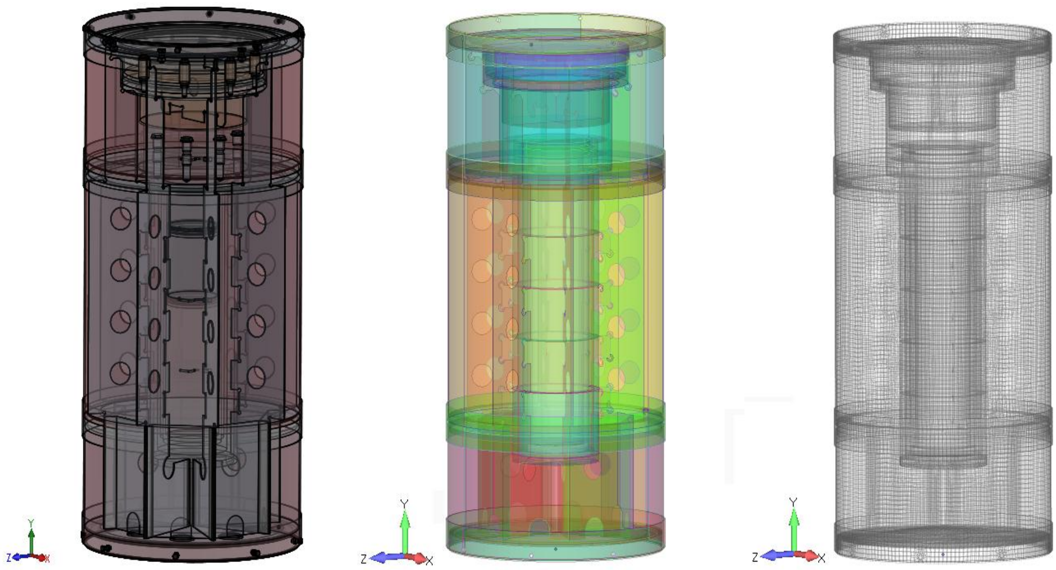


Figure 4. Simplification of the model and meshing

6.4 MESHING

1. Shell elements were used, assigning the related thickness to each part. The container was meshed with an average element size of 10 mm, generating a mesh with 86596 nodes and 88751 rectangular elements. See Figure 4.

7 MATERIALS

1. According to the APL2 the approximate total mass of the package is 430 kg, and can carry a useful load of 50 kg of FM. The materials of the package are those stated in Table 1.

Material	Approximate mass [kg]	Density [g/cm^3]
Metallic uranium	50	18.9
Polyethylene	0.4	0.9
KAOLITE 1600	85	0,405
AISI 304L	244	7.9
Cadmium	58	8.65

Table 1. Materials obtained from APL2.

2. The container is made of type 304L stainless steel, with the properties listed in Table 2, obtained from REF2 (ASME B31.1 Table A-3).

Material	A312-TP304L
Modulus of Elasticity	192708 [MPa]
Tensile Strength	482.6 [MPa]
Yield Strength	172.3 [MPa]
Admissible Stress at 93°C	92.4 [MPa]
Density	7825 [kg/m^3]

Table 2. Properties of 304L steel.

8 RESULTS

1. As described in section 6.2, the goal was to find the impact angle generating most damage to the package. For such purposes, drop simulations were carried out applying the acceleration of reference.
2. It is considered that when the package rests on the base on the floor, the angle of its symmetry axis is 0°, a 90° angle would correspond to a horizontal drop (impact on one side of the package), and a 180° angle an inverted vertical drop (on the cover). Among the range of potential positions, certain angles detailed in Table 3 were evaluated.
3. Of all potential impact cases, there are four critical cases where all the energy of the drop is transformed into deformities in the package. Those cases are: drop on the base, the cover, one side and over one vertex (of the cover or base, aligned with the CM). In the remaining cases, part of the energy causes deformations and part causes the container to rollover. This analysis will study critical cases.

Equivalent acceleration 45g = 441450 [mm/s2]			
Case	**Symmetry axis angle - vertical plane**	**Area of the container subject to impact**	**Type of balance**
1	0	Base	Stable
2	23 (*)	One base vertex	Metastable
3	90	One side line	Stable
4	153.3 (*)	One cover vertex	Metastable
5	180	Cover	Stable

(*) Cases where the package impacts one vertex (cover or base) vertically aligned with the center of mass.

Table 3. Cases of study.

8.1 RESULTS OF CASES STUDIED

8.1.1 Case 1: Vertical fall. Angle = 0°

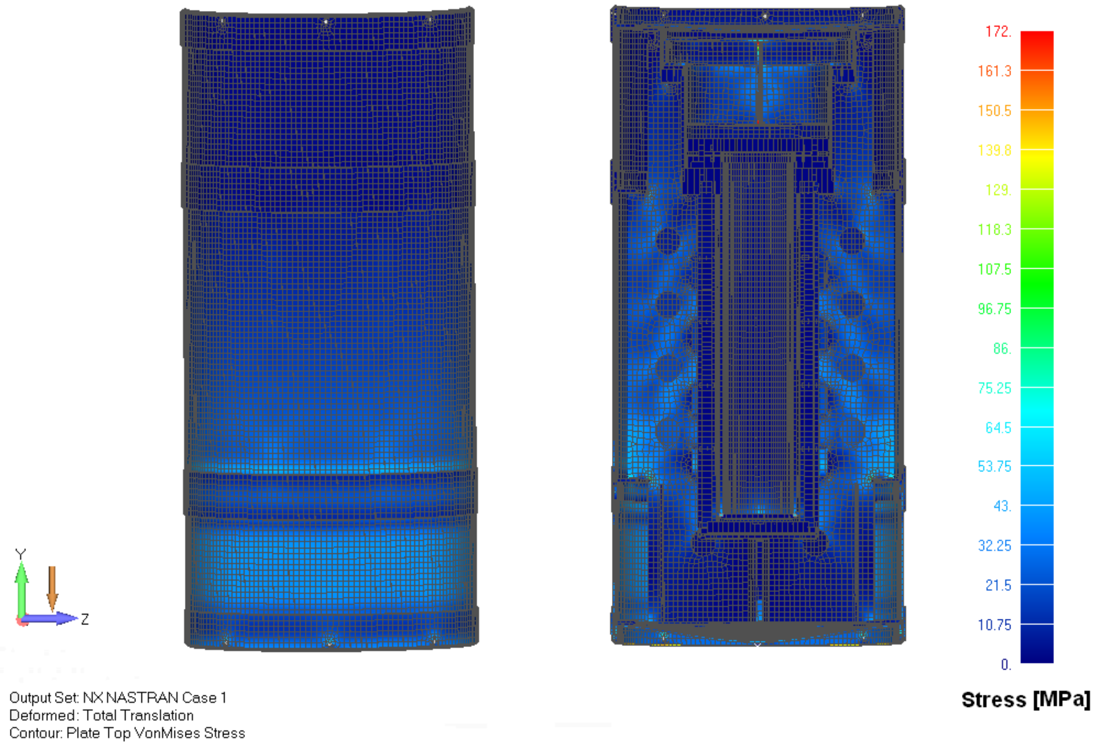


Figure 5. Stresses in the package upon impact.

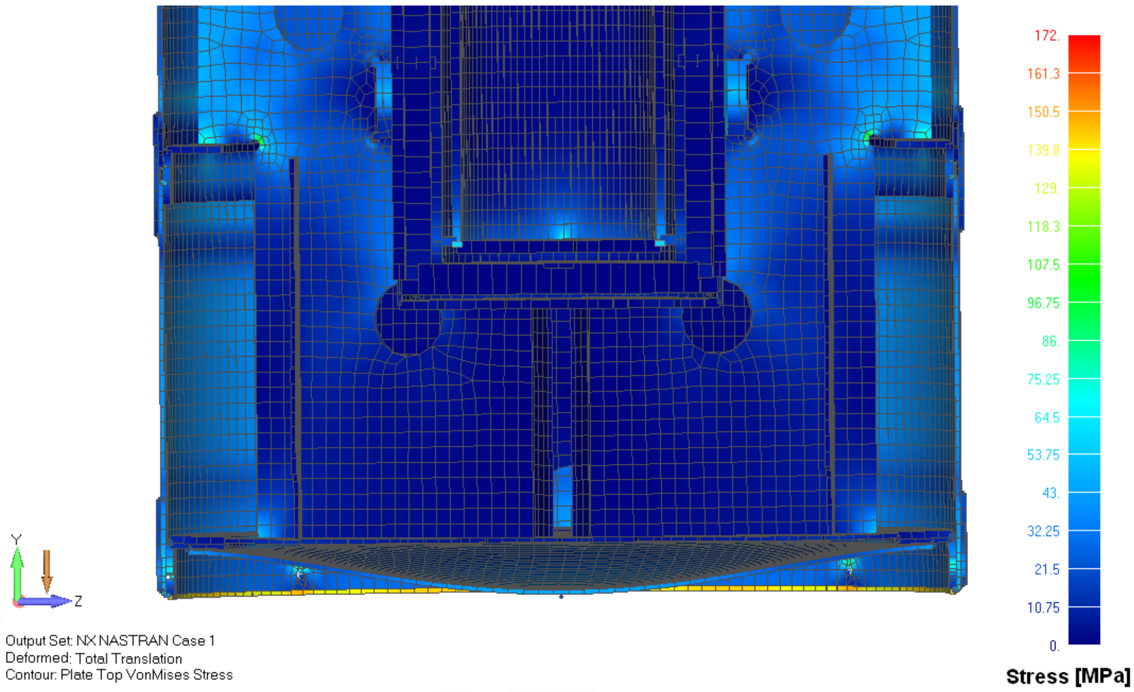


Figure 6. Expanded view of major stresses in the package upon impact.

8.1.2 Case 2: Drop on the base vertex, aligned with GC. Angle = 23°

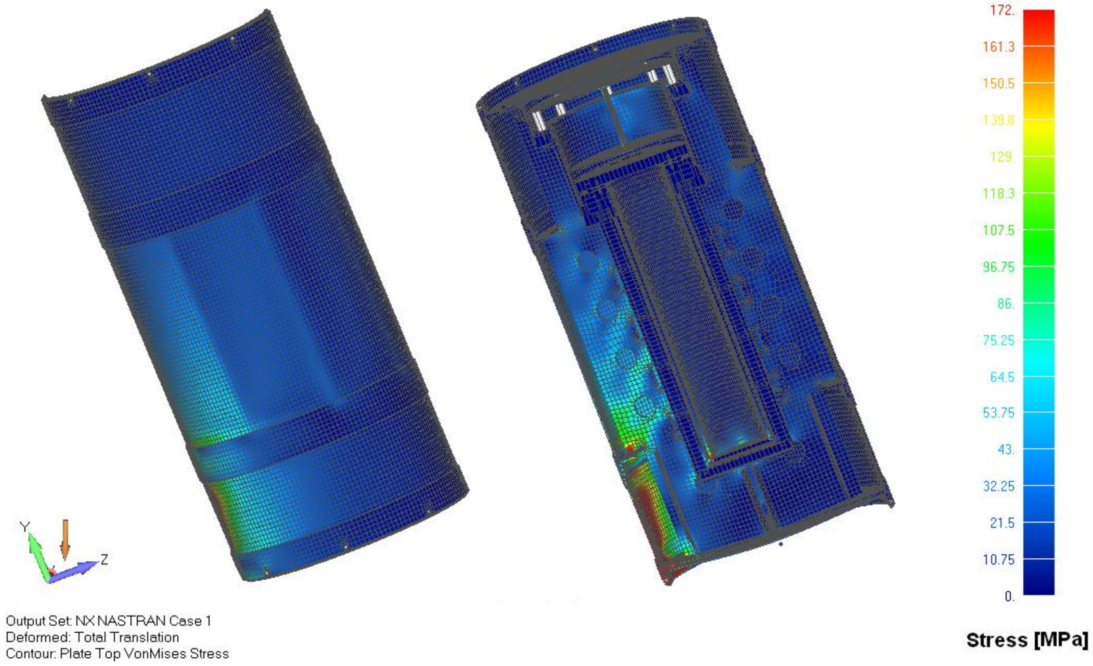


Figure 7. Stresses in the package upon impact.

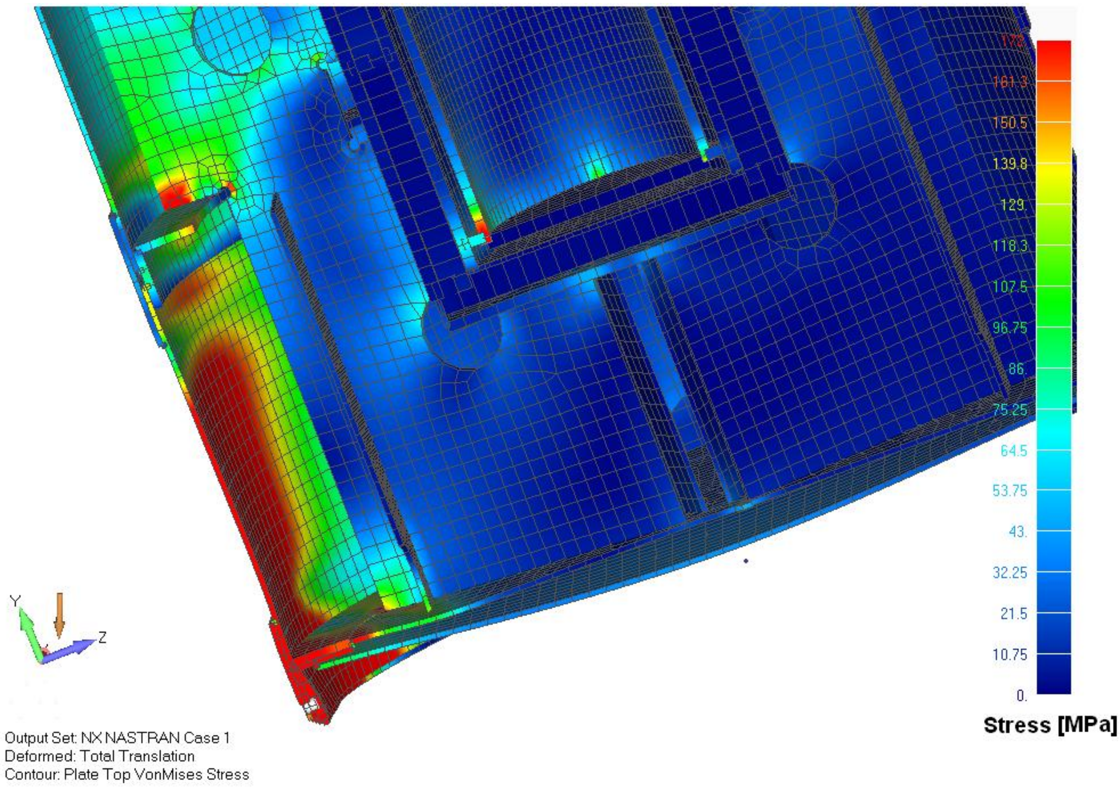


Figure 8. Expanded view of major stresses in the package upon impact.

8.1.3 Case 3: Drop on the side. Angle = 90°

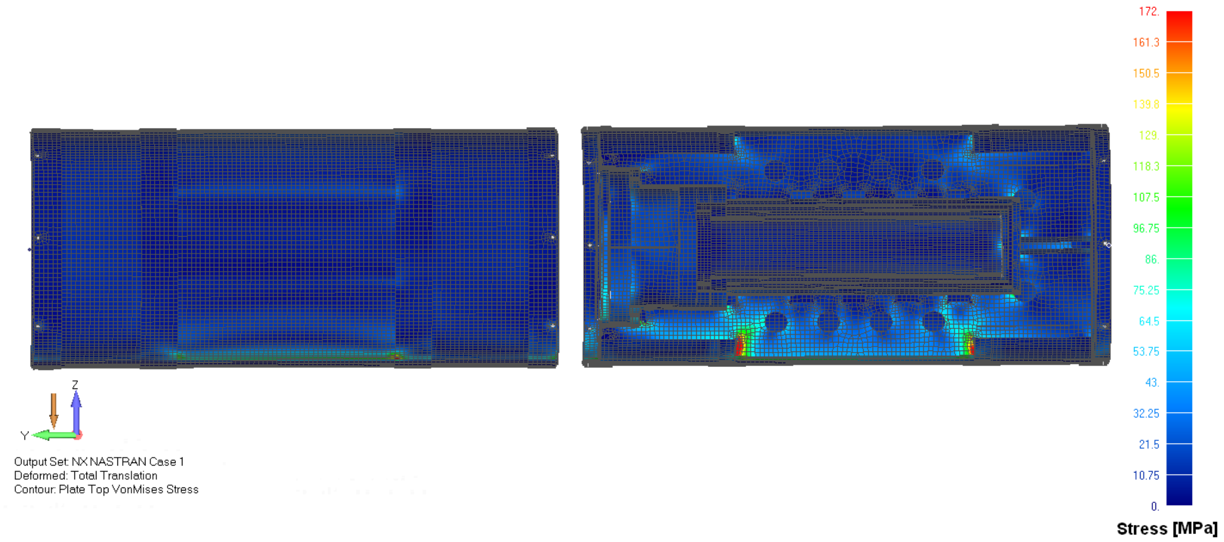


Figure 9. Stresses in the package upon impact.

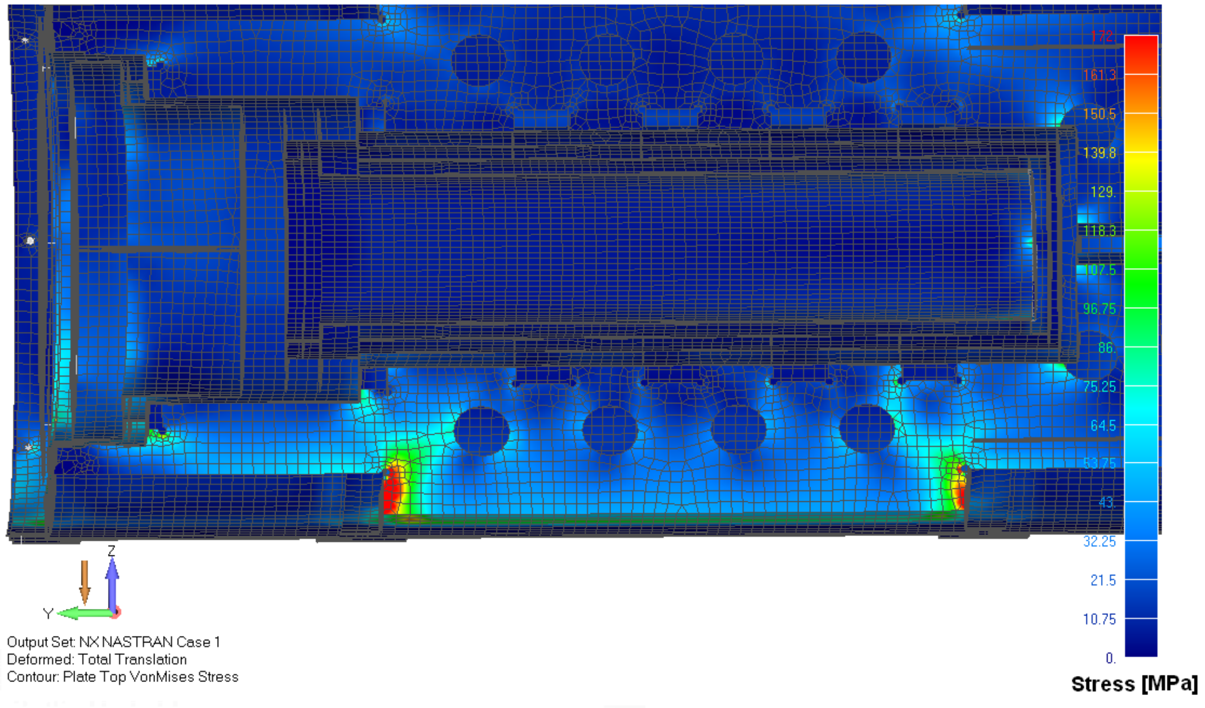


Figure 10. Expanded view of major stresses in the package upon impact.

8.1.4 Case 4: Drop on the cover vertex, aligned with GC. Angle = 153.3°

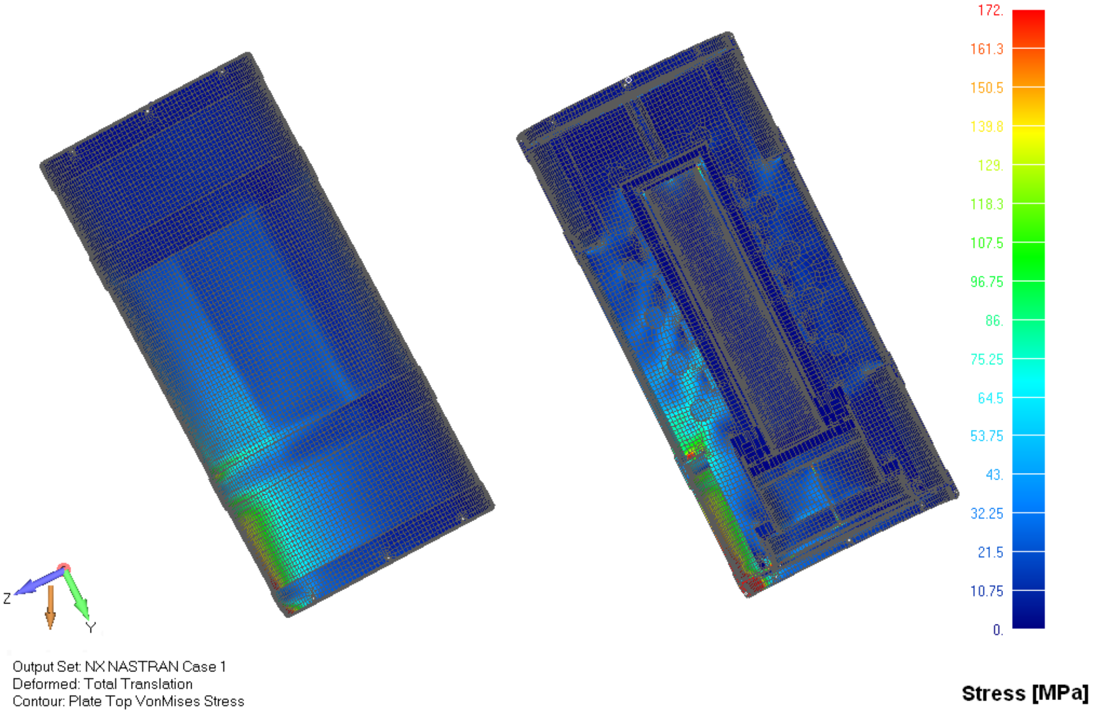


Figure 11. Stresses in the package upon impact.

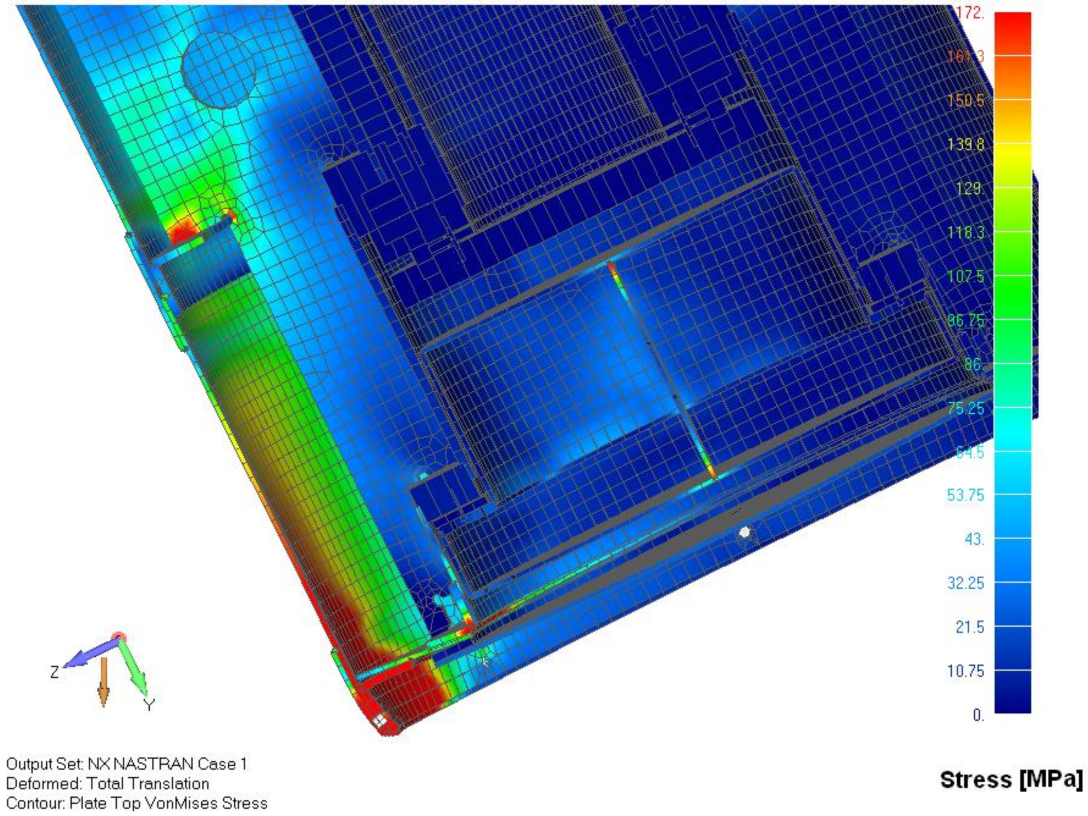


Figure 12. Expanded view of major stresses in the package upon impact.

8.1.5 Case 5: Vertical fall. Angle = 180°

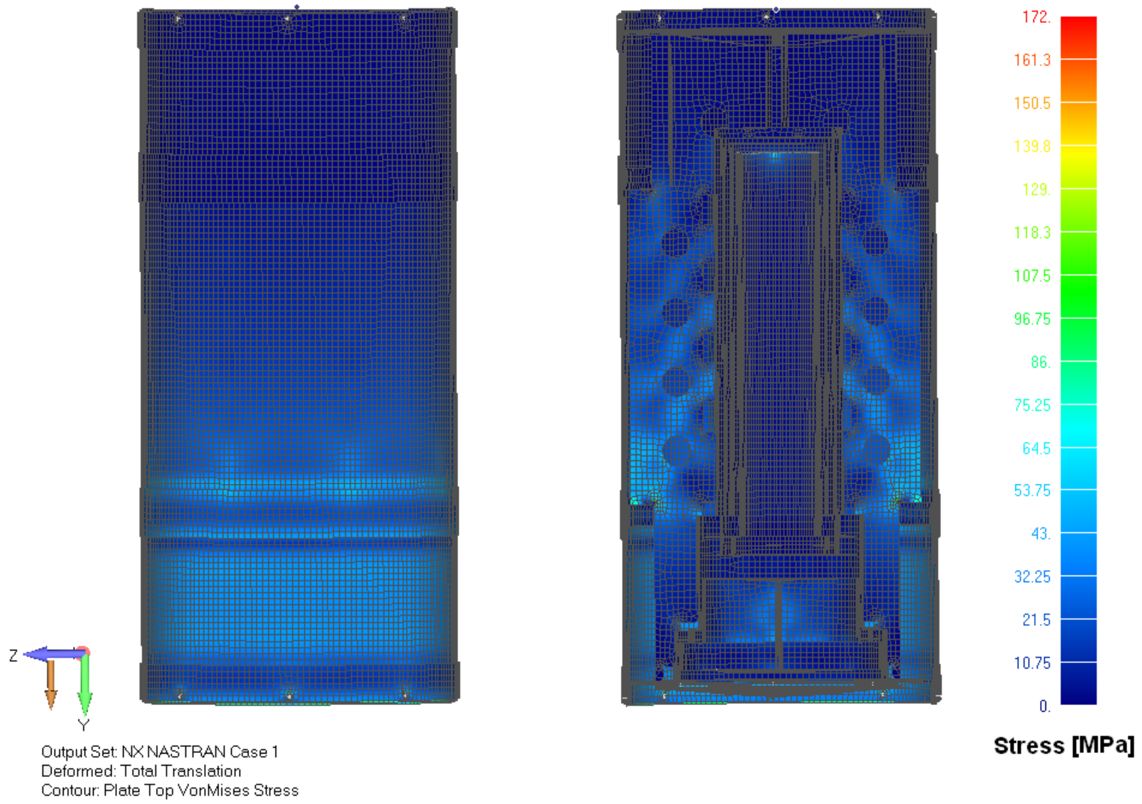


Figure 13. Stresses in the package upon impact.

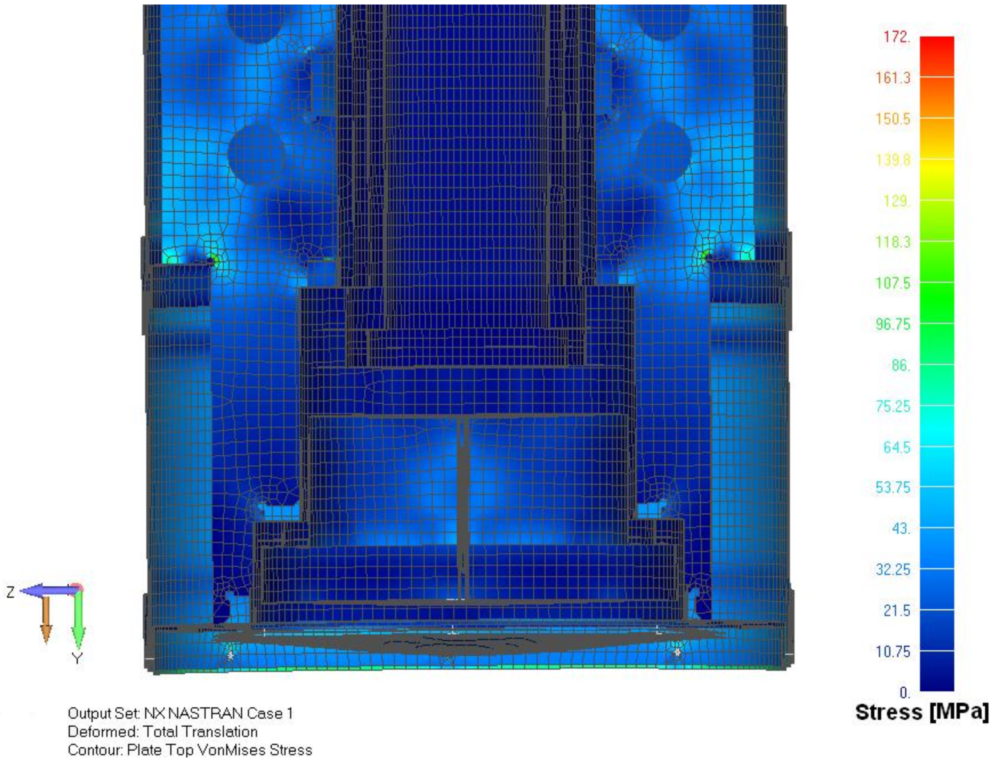


Figure 14. Expanded view of major stresses in the package upon impact.

8.2 COMMENTS ON THE RESULTS

1. A maximum value of 172 MPa was set on the colors map (to the right of each figure). That value relates to the yield stress of A312-TP304L steel, material used for almost all the package.
2. By comparing the critical cases analyzed, we can see that most damage occurs in the images of cases 2 and 4, drops where the center of mass is vertically aligned with the contact vertex. Changes in external geometry, such as dents, are observed. Also, based on the results, a generalized yield state occurs in the area close to the point of contact with the floor.

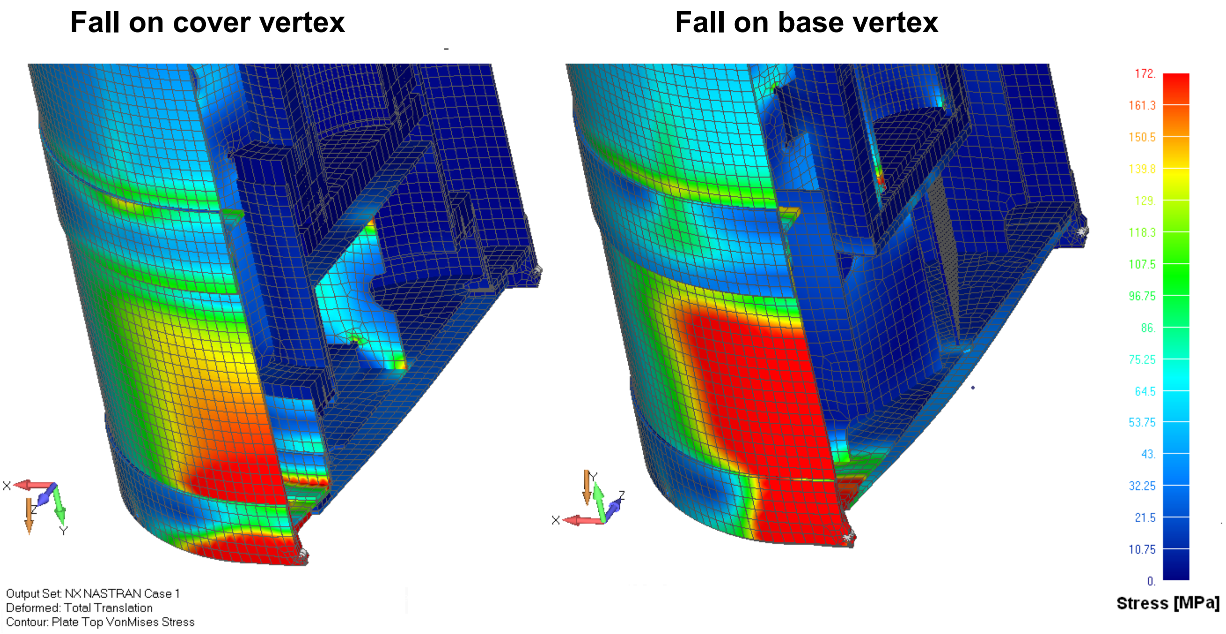


Figure 15. Comparison of stresses in the package in more unfavorable drops.

3. Figure 15 includes a comparison of the two most unfavorable critical cases. It was discovered that when the package impacts on a vertex of the base (23° angle), the package is more compromised than in the opposite case, where it makes contact with a cover vertex (153° angle).

9 CONCLUSIONS

1. Under the stated conditions, the geometric characteristics and properties of the stated materials, the conclusions are as follows:
    1. Based on the results obtained, the drop causing most damage occurs when the symmetry axis and the vertical plane form a 23° angle (see Case 2, Figure 8), due to the dents in the external cover and the stress state. The drop with a 153.3° angle ranks second among most unfavorable drop cases.
    2. Drops on the side, base and cover follow the previous cases in terms of deformities caused.
    3. This study indicates an orientation of more deformation, deformity values are not in real magnitudes. To have more certainty regarding those magnitudes, the time of impact and equivalent acceleration shall be defined precisely and simulations shall be carried out again.