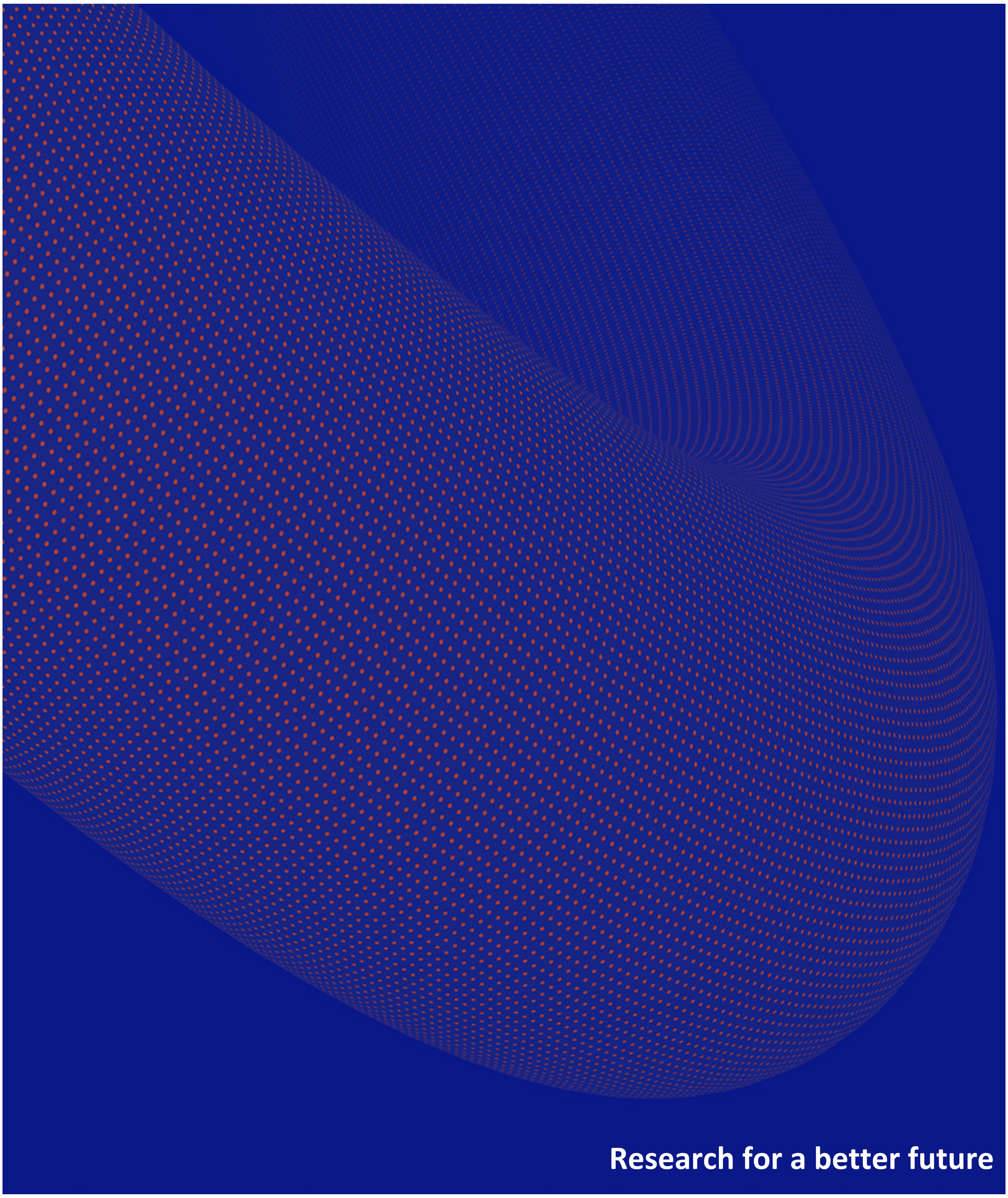
Overpack for disposal of 200 liter drums in boreholes

IFE/F-2021/032



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Title: Overpack for disposal of 200 liter drums in boreholes

Summary:

A conceptual design of an overpack with a reliable sealing mechanism and equipped with a device that will allow an overpack (containing 4 x 200 l drums of ILW) to be lowered into a borehole via a wireline is provided.

Strength calculations, using finite element models, were performed in order to determine the overpack ability to support the 4 x 200 l drums with ILW waste and to endure forces incurred during placement of the overpack and contents in a borehole. Compressive stresses / buckling that could be introduced by upper stacks of overpacks were taken into account. The possibility of strengthening the overpack by means of light flowing concrete was evaluated.

The shielding ability of the overpack with respect to envisaged ILW radioactivity levels (in the form of C-60 and also in the form of Cs-137) was assessed using VRdose, based on the combined overpack and drum wall thicknesses and based on a contact dose of 2 mSv/h outside the waste drums.

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1 Overpack Design and Cost Estimate

The conceptual design for an overpack accommodating four 200-litre ILW waste drums is shown in the enclosed Drawing No. 510850 (Appendix A).

The design is based on the following boundary conditions and criteria:

- the ability to accommodate the 200-litre waste drums which have a maximum outer diameter of 630 mm and each weighing 700 kg;
- the possibility for installing the overpack in a borehole with a diameter of 667 mm;
- the overpack is to be equipped with a device that will allow the overpack to be lowered into a borehole via a wireline;
- the overpack must have a reliable sealing mechanism.

As shown in the drawing, the overpack has a total length of 3700 mm, an inner diameter of 635 mm and an outer diameter of 645 mm (wall thickness 5 mm). Both the base and lid of the overpack are prepared from 60 mm thick plates. The lid is equipped with four hooks to enable lifting and lowering of the overpack into a borehole via a wireline and it is envisaged that the lid will be welded to the body of the overpack.
The overpack (the tube itself as well as the base and lid are all made from the carbon steel X52 which is commonly used for pipeline transportation of petroleum / natural gas. The supplier of the material is Rolf Lycke (Germany).

All welding is performed by means of tungsten inert gas (TIG) welding.

The as-fabricated overpack will be subject to Nondestructive Testing (NDT) to ensure weld integrity (absence of cracks) and dimensional / straightness measurements to ensure the ability of the overpack to accommodate the four 630 mm diameter waste drums. Lifting tests are not included in the cost estimate since suitable lifting equipment is currently unavailable for testing of a unit with the length (3660 mm) in question.

The indicative cost for the production of one overpack (prototype) is 137000 NOK + MVA.

The cost covers direct materials costs, labour, paperwork and testing. The cost would decrease with the production of a series of overpacks, the reduction in cost being dependent on the number to be produced. It should however be noted that the indicative cost currently does not take into account the presence of radioactive material (i.e. the ILW waste drums) inside the tube, with the associated radiation protection / equipment that would be required in order to enable welding of the lid to overpack.

2 Strength Calculations

Strength calculations, using finite element modelling, were performed, taking into account the following:

- forces incurred during placement of the overpack and contents in a borehole which is filled with borehole fluid exerting a pressure of 11 MPa on the external surface of the overpack;
- compressive stresses / buckling that could be introduced by upper stacks of overpacks emplaced in the borehole.

The results are presented below.

Calculations of NND Overpack for 200 litre Drums.

To calculate elastic buckling and plastic deformation we used formulas from:

Norsk Standard NS-EN 13445-3, unfired pressure vessels. Shell under external pressure (8.5.2.2) and from TBK1. Rules for pressure vessels. (Den Norske Trykkbeholderkomite).

Unsupported channel length = 3570 mm and OD=645 mm. Plastic deformations are calculated with OD 645 +/- 5 mm and for wall thicknesses of 5 mm and 10 mm. (No safety factor used, normal safety factor is 3 for elastic buckling and 1.6 for plastic deformation).

The calculations were made for the X52 steel and for AISI 316L stainless steel for comparison.
Material properties used:
X52: E= 205000 GPa, Yield strength = 360-530 MPa (min. used), Tensile strength = 570-760 MPa, Welds 460 MPa (min), v=0.3.

AISI 316L: E= 193000 GPa, Yield strength = 205-290 MPa (min. used), Tensile strength = 515-(580) MPa, v=0.3.

Calculations with AISI 316 stainless steel (using min. values and no safety factor).

- A 5 mm thick wall can end up with elastic bucking before ~2 bar and plastic deformation before ~8 bar outer pressure.
- A 10 mm thick wall can end up with elastic bucking well before ~16 bar and plastic deformation well before ~25 bar outer pressure.

Calculations. with X-52 steel (using min. values and no safety factor).

- A 5 mm thick the wall can end up with elastic bucking before 2.2 bar and plastic deformation well before 18 bar outer pressure
- A 10 mm thick the wall can end up with elastic bucking well before 17.5 bar and plastic deformation well before 44 bar outer pressure.

If we assume that we can use stiffeners in-between the drums, the unsupported length becomes L = 870 mm.

- Then a 5 mm wall gives elastic bucking before 4.5 bar over pressure (for X52 steel). A 10 mm wall gives elastic bucking before 36 bar; with a safety factor 3, it can hold 12 bar over pressure (X52 steel).The model set-up is shown in Figure 1 and the plastic deformation on an overpack with a 5 mm thick wall, exposed to 5.2 MPa from drilling fluid in a borehole, are shown in Figure 2 (no safety factor) and in Figure 3 (safety factor shown). The plastic deformation on an overpack exposed 11 MPa rock pressure in a borehole is shown in Figure 4 (no safety factor) and in Figure 5 (safety factor shown).

- A 10 mm wall for the overpack is a possibility. The largest drum dimension (with clamp) is specified as being 630 mm. There are two possibilities: i) if the "rough" 630 mm clamp type is changed to a "fine" type or, ii) the clamp was modified and secured by welding, a diameter of 610 mm can be achieved. (Nominal clamp measure seems to be 625 mm, in which a 10 mm wall might be considered). Centred drum positioning will simplify modelling and avoid unnecessary biases.

In a 400 m deep bore hole with drilling fluid (density 1.3) this represents 5.2 MPa. This means that an unsupported overpack wall will buckle and will collapse. (This is before stacking of the overpacks is considered).

One overpack weighs ~4 tons, consisting of 4 drums each of weight ~700 kg, weight of overpack with 5 mm wall=600 kg and *concrete filling (see below) =600 Kg (density 1,9)*.
Weight of 400 m stacked overpacks (4t) in drilling fluid gives a weight on the lower one of 262 ton.

One solution for strengthening the overpack is to fill the free space in-between the overpack and the stacked drums with *light flowing concrete* (see Drawing No. 511009 (Appendix B)). This will also support the overpack flat ends which can be prone to deflection. (Use of discs in-between drums may be necessary to ensure better stacking guidance and force transfer and to avoid air gaps between drums.).

Concrete filled steel tubes (CFST's) are widely used in the construction industry and give larger strengths than steel tubes and concrete columns individually.

A well supported concrete supported wall will not, in this case, buckle because of outer wall pressure itself. However, loads to the ends, transfer of these, biases (out of centre loaded drums), air gaps, and load positions (stacking and lifting points), need to be looked in to.

Modelling of a perfectly filled, no gaps, and centred overpack (inside drums not modelled) shows that concrete filled overpacks may be a way to go. The concrete properties used are E= 19500 MPa (calc.), Yield strength 30 MPa, v= 0.15. The modelling results are shown in Figures 6 -10.

Figure 11 shows the modelling set-up of for a concrete filled overpack in a borehole, subjected to stresses from stacked overpacks. The results are shown in Figures 12 and 13 for the shortened model and Figures 14 and 15 show the results for a full-length model.

Some additional modelling results are shown in Figures 16 -25, where stronger concrete has been used. Concrete properties used (28 days hardened) are as follows:

- Standard Portland C35: 30 MPa pressure, (6 MPa flexural), E= 25000 MPa (Calc.), v= 0,15.
- Hey'di Flytstøp: 50 MPa pressure, (7 MPa flexural), E= 31000 (Calc.), v=15.

Figure 16 shows the set up for a model where an inner drum has been added and a stronger concrete filling has been selected. Figures 17 and 18 show the results of the stresses for the shortened model of the drum at 11MPa borehole pressure.

Exposed to 5.2 MPa (borehole pressure), an overpack would most likely survive a borehole loading. An out of centre drum (6,5 mm) full length model with a top filling gap (5 mm) shows acceptable overpack tensions, even if tensions are not fully uniform. Figure 19 show the plastic deformation on the full length overpack, while Figure 20 shows the inside stresses on the same full length overpack, while Figure 22 shows the displacement in the overpack.

When exposed to 11 MPa (rock pressure) under idealised borehole rock loads, it can't be ruled out that crippling (buckling) will occur, but it's not considered likely that we will have a full collapse, even if tensions should exceed yield, when overpack inside is well supported and free space is occupied, although local concrete crushing can occur. Figure 23 shows the plastic deformation on the full length overpack at 11 MPa pressure, while Figures 23 and 24 show the inside stresses and displacement respectively.

Finally, when exposed to 5.2 MPa borehole pressure and stacking, there may be a limited number of overpacks that can be stacked on top of each other to ensure overpack integrity. Figure 25 shows an overly conservative model of an overpack stacked with 25 overpacks on top. Based on the simplified finite element models, which are somewhat conservative, it is estimated that the lowermost overpack in a borehole will manage to carry approximately 50 stacked overpacks, which are ~100% concrete filled. Local deformations may occur, without, however, putting overpack integrity at risk.

In summary, the main conclusions are that:

- an overpack with no support between the drums and overpack wall in a 400 m deep bore hole with drilling fluid will buckle and will collapse.
- An overpack with concrete filling in the gap between the drum outer wall and the overpack inner wall will strengthen the overpack enabling it to endure the stresses from a 400 m deep borehole.
- An overpack with concrete filling and out of centre drums and a top filling gap will also be exposed to acceptable overpack tensions.
- The modelling results also show that there will be a limit to the number of overpacks that can be stacked on top of each other without securing them from overlying stacks in a borehole.

Overpack design is still conceptual and needs to be developed and refined. There are uncertainties and assumptions linked to data input for the finite element modelling and as to what is considered, e.g. concrete filling ratio could be an issue, both in drums and overpack.

Finally, we suggest that downscaled (1:5) and shortened overpacks are produced and tested, to demonstrate and validate that assumptions, calculations and modelling are good, with and without a concrete filled overpack. Such a test can be done in a pressurized autoclave where 5.3 MPa (drilling fluid) and 11 MPa (rock pressure) can be demonstrated.

Effective

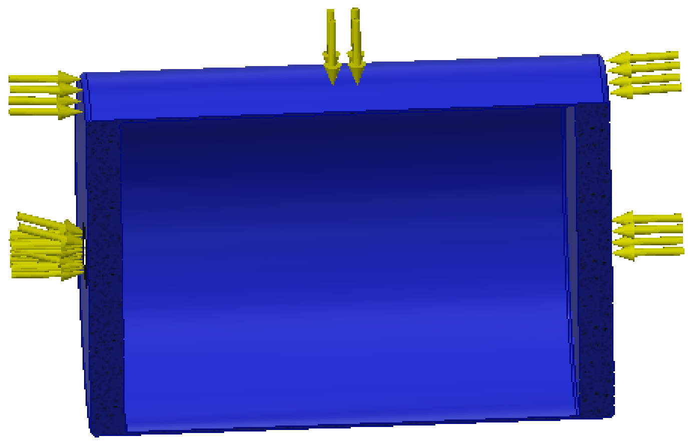


Figure 1. Overpack (shortened) exposed to outer pressure.

Plastic deformations in the following finite element models do not consider overpack ovality or other diametral forces than pressure.

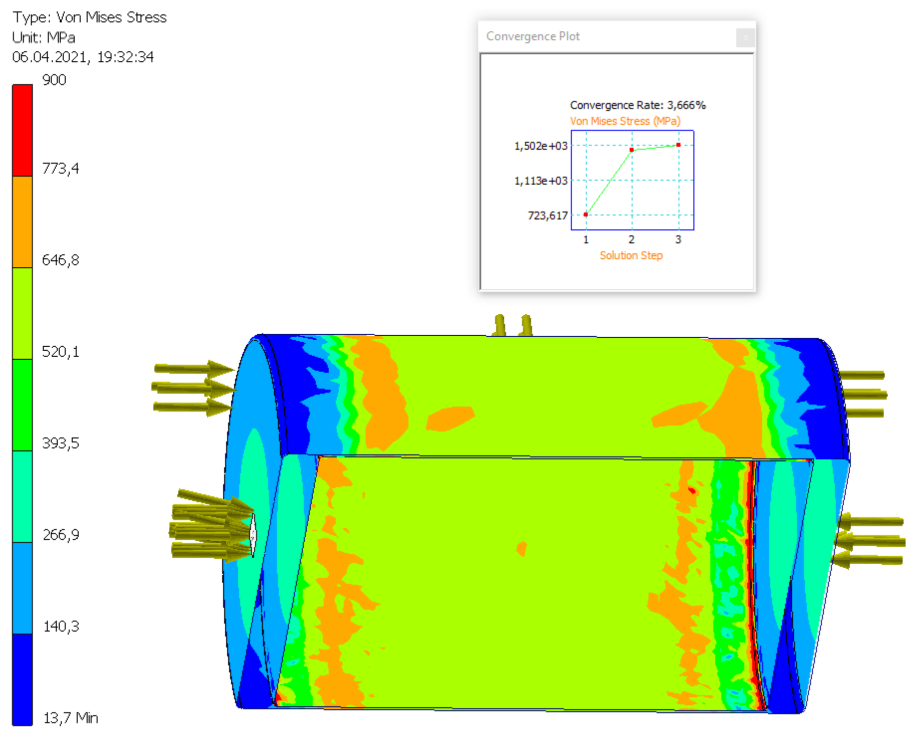


Figure 2. Plastic deformation of overpack exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

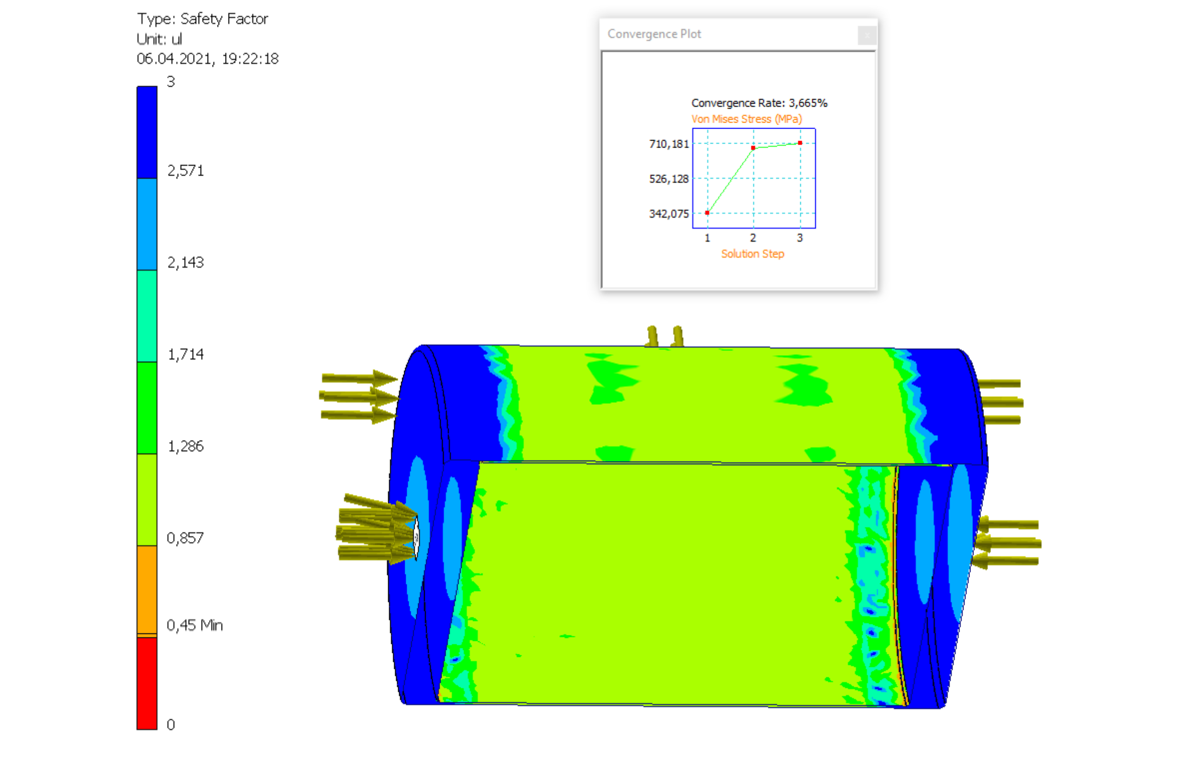


Figure 3. Plastic deformation of overpack exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

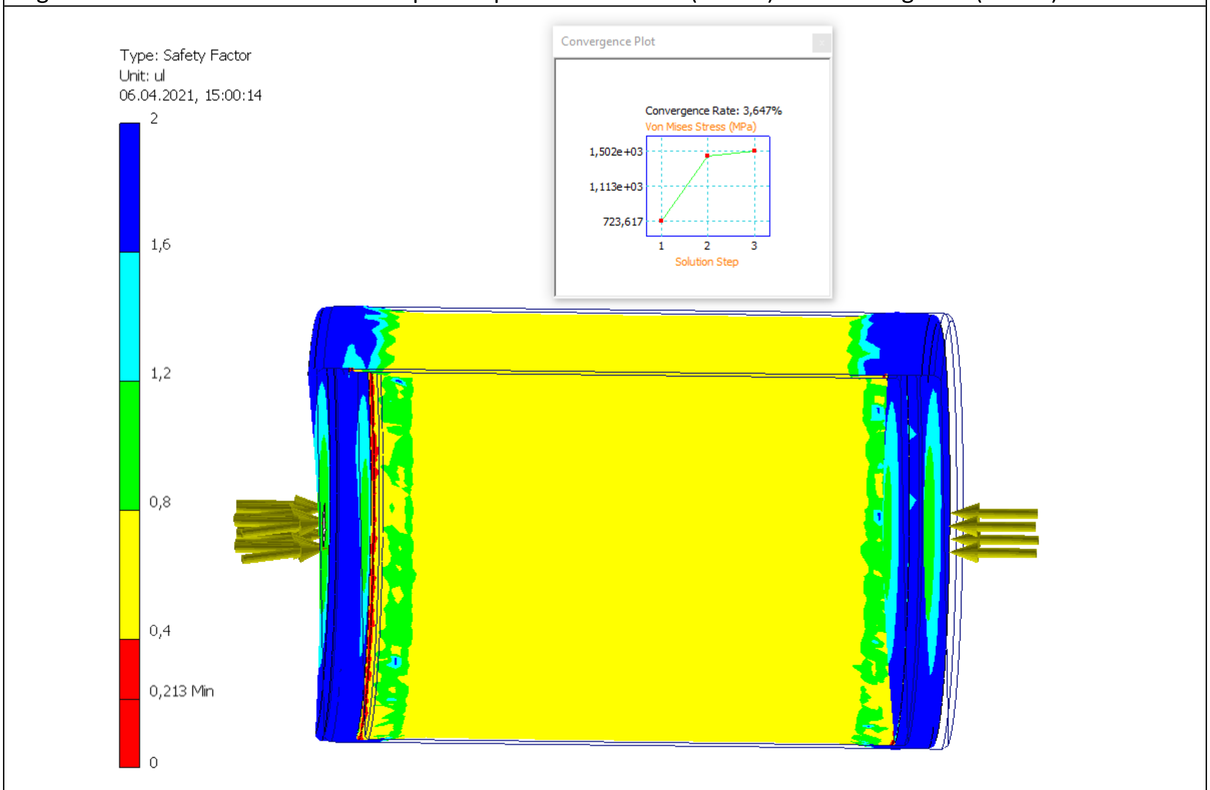


Figure 4. Plastic deformation of overpack exposed to 11 MPa (110 bar) rock-pressure (400 m).

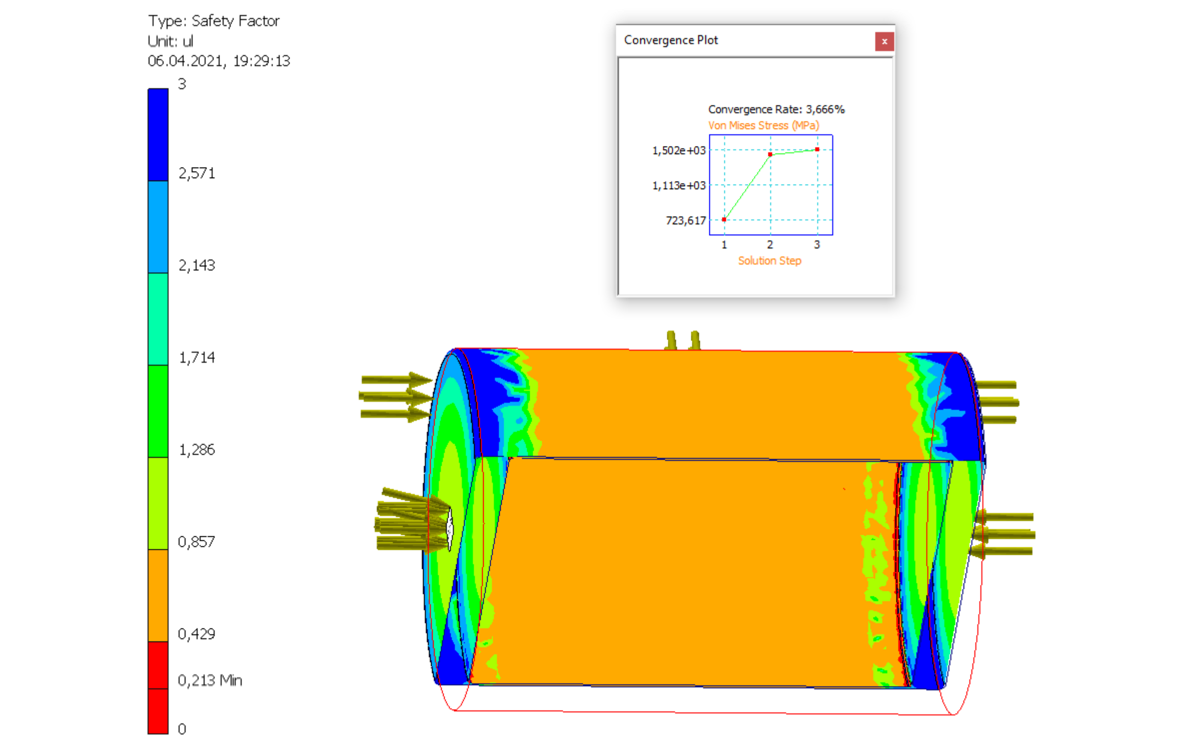


Figure 5. Plastic deformation of overpack exposed to 11 MPa (110 bar) rock-pressure (400 m).

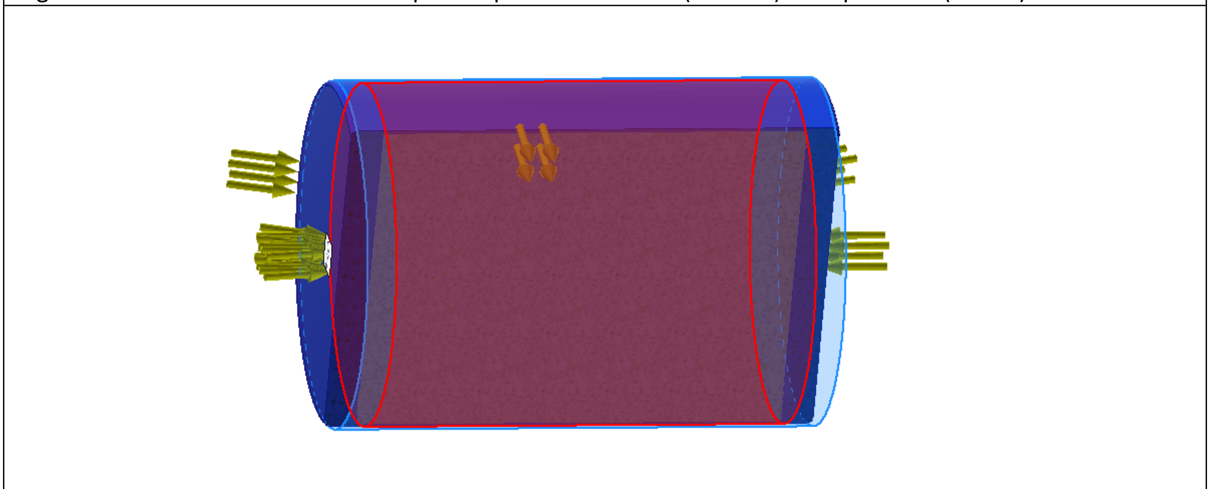


Figure 6. Overpack (shortened) filled with liquid concrete exposed to outer pressure

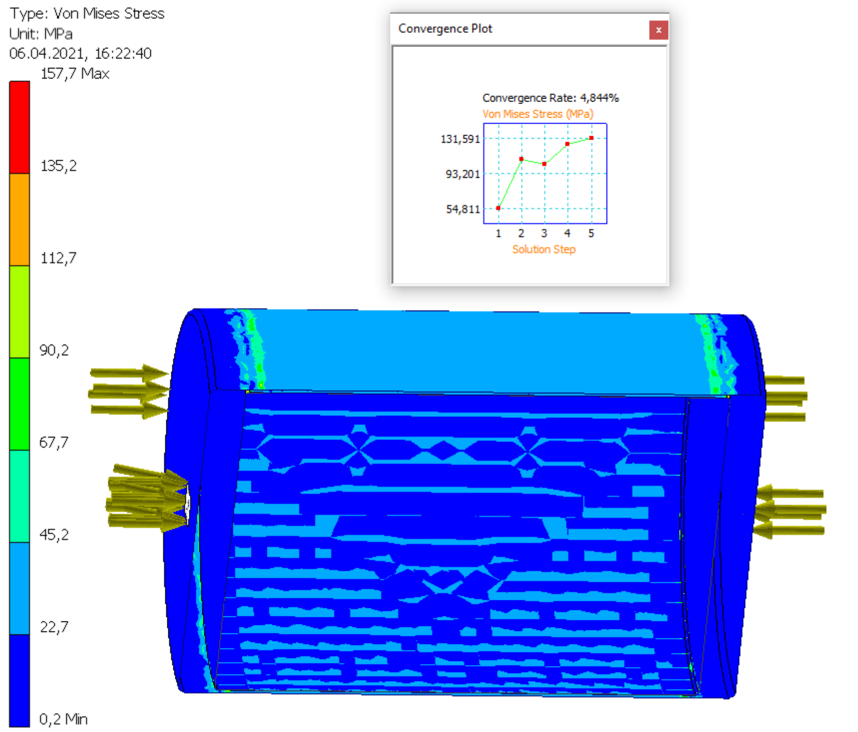


Figure 7. Plastic deformation of concrete filled over pack exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

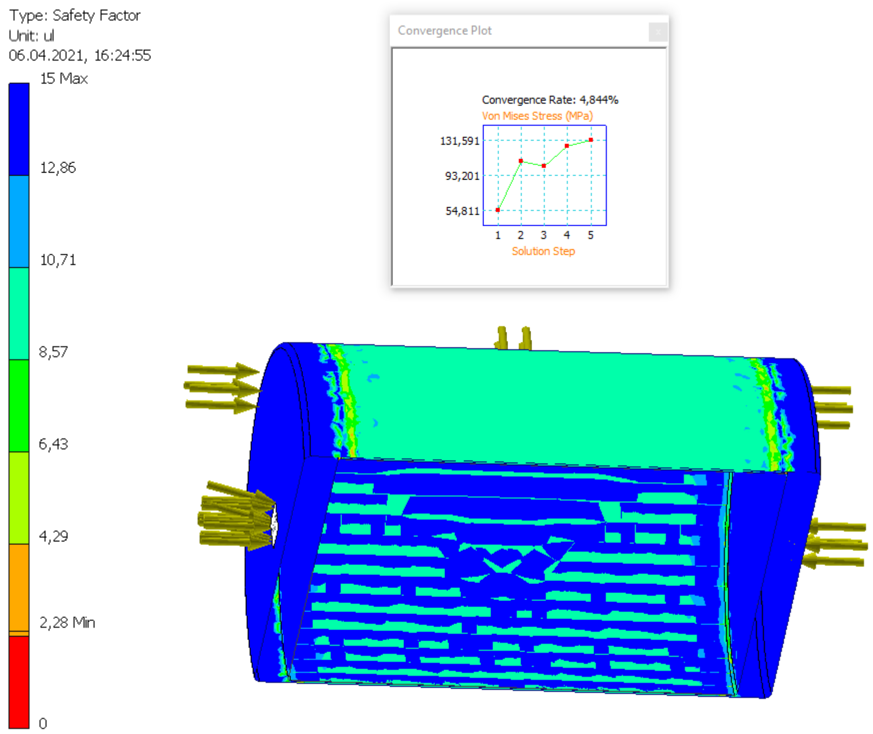


Figure 8. Plastic deformation of concrete filled overpack exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

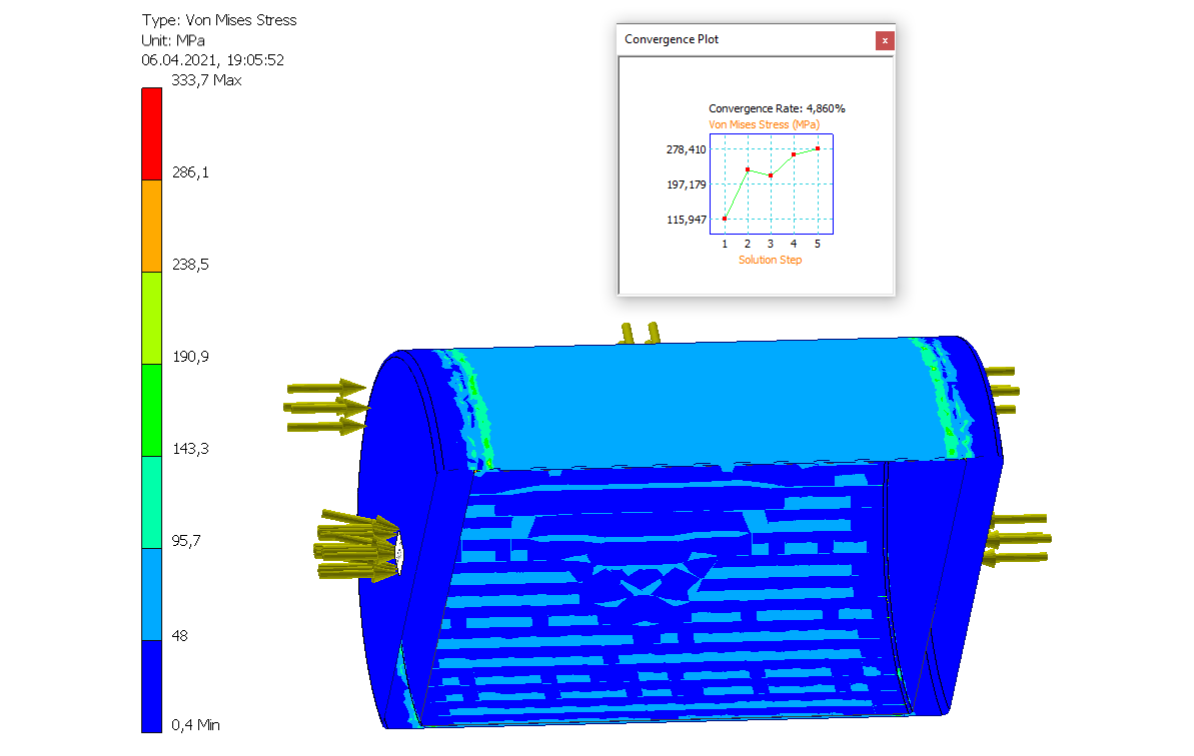


Figure 9. Plastic deformation of concrete filled overpack exposed to 11 MPa (110 bar) rock pressure (400 m).

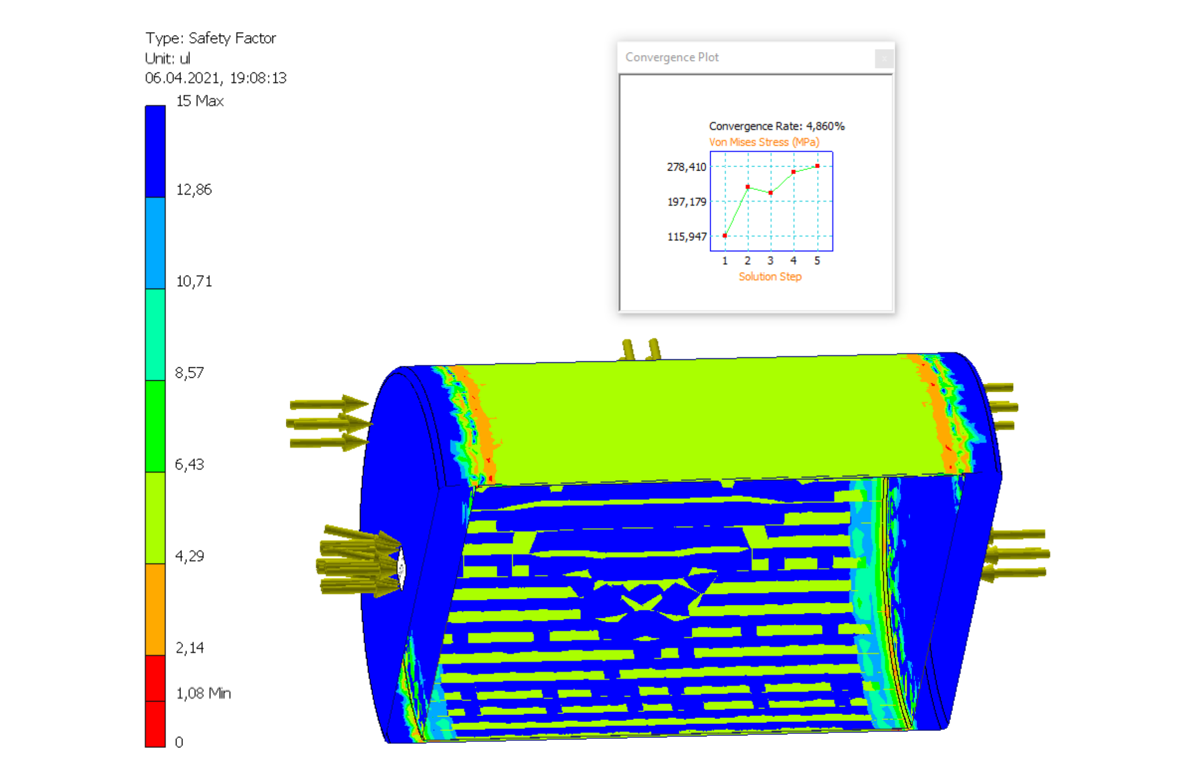


Figure 10 Plastic deformation of concrete filled overpack exposed to 11 MPa (110 bar) rock pressure (400 m).

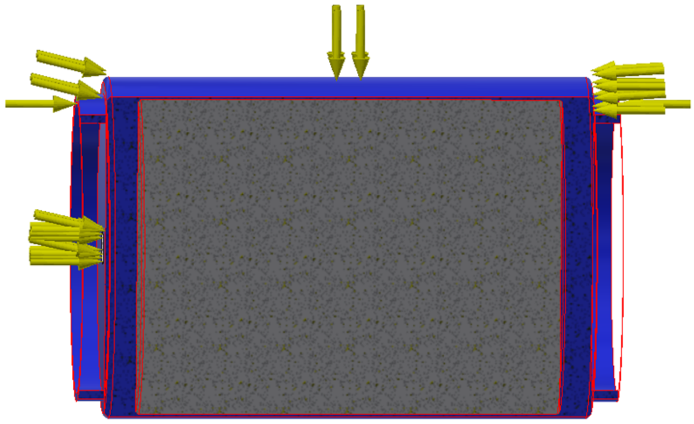


Figure 11. Stacked overpack (shortened) filled with liquid concrete exposed to outer pressure and forces from stacked over packs in a 400 m bore hole.

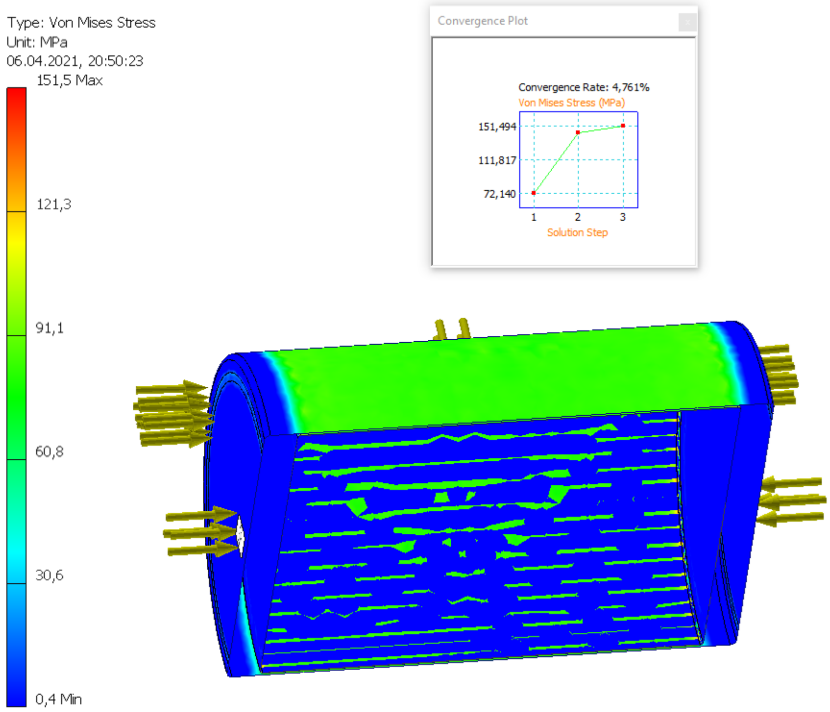


Figure 12. Plastic deformation of stacked concrete filled overpacks exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

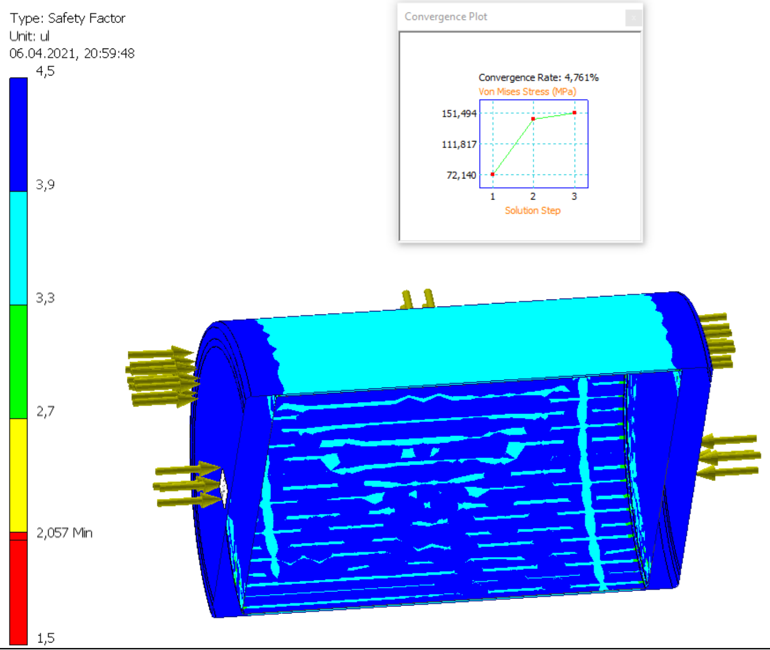


Figure 13. Plastic deformation of stacked concrete filled overpacks exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

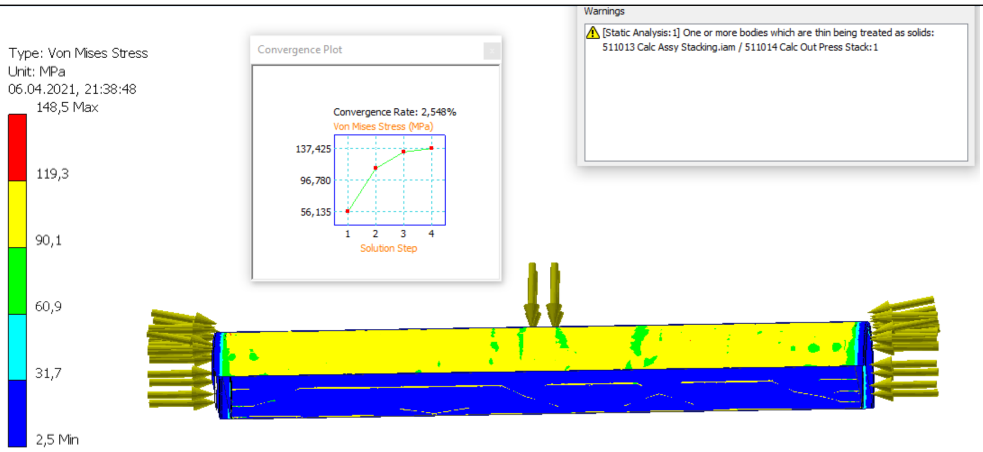


Figure 14 Plastic deformation of full-length stacked concrete filled overpacks exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

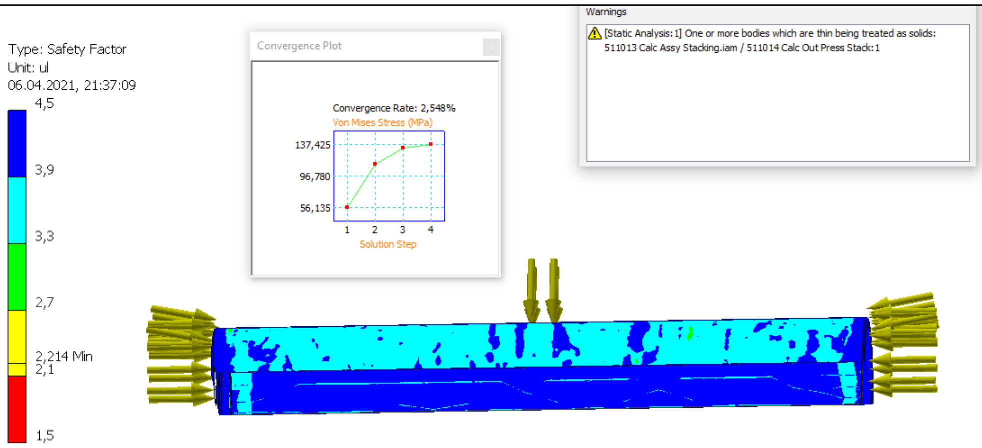


Figure 15. Plastic deformation of full-length stacked concrete filled overpacks exposed to 5.2 MPa (52 bar) from drilling fluid (400 m).

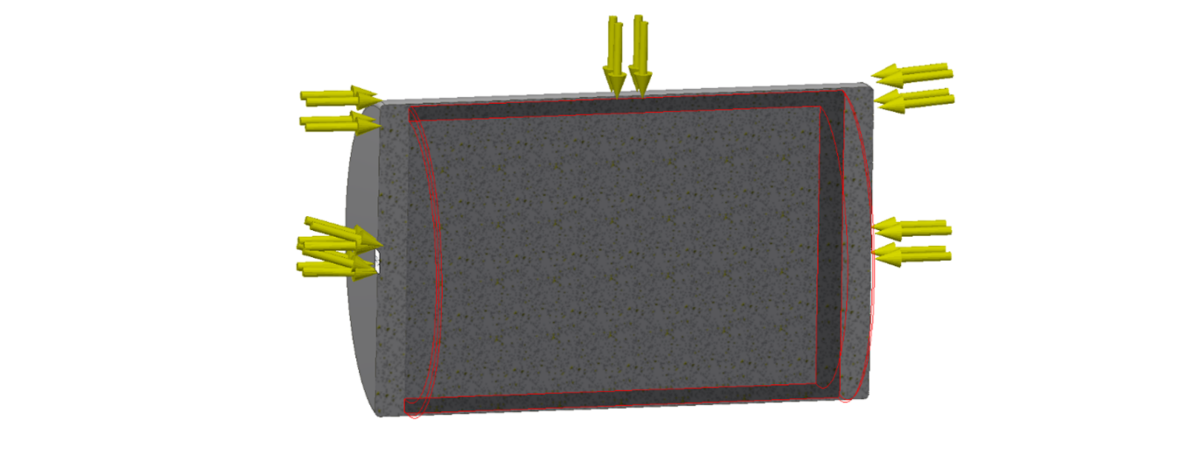


Figure 16. Overpack model with concrete filled drum filled with liquid concrete exposed to borehole/rock pressure (shortened).

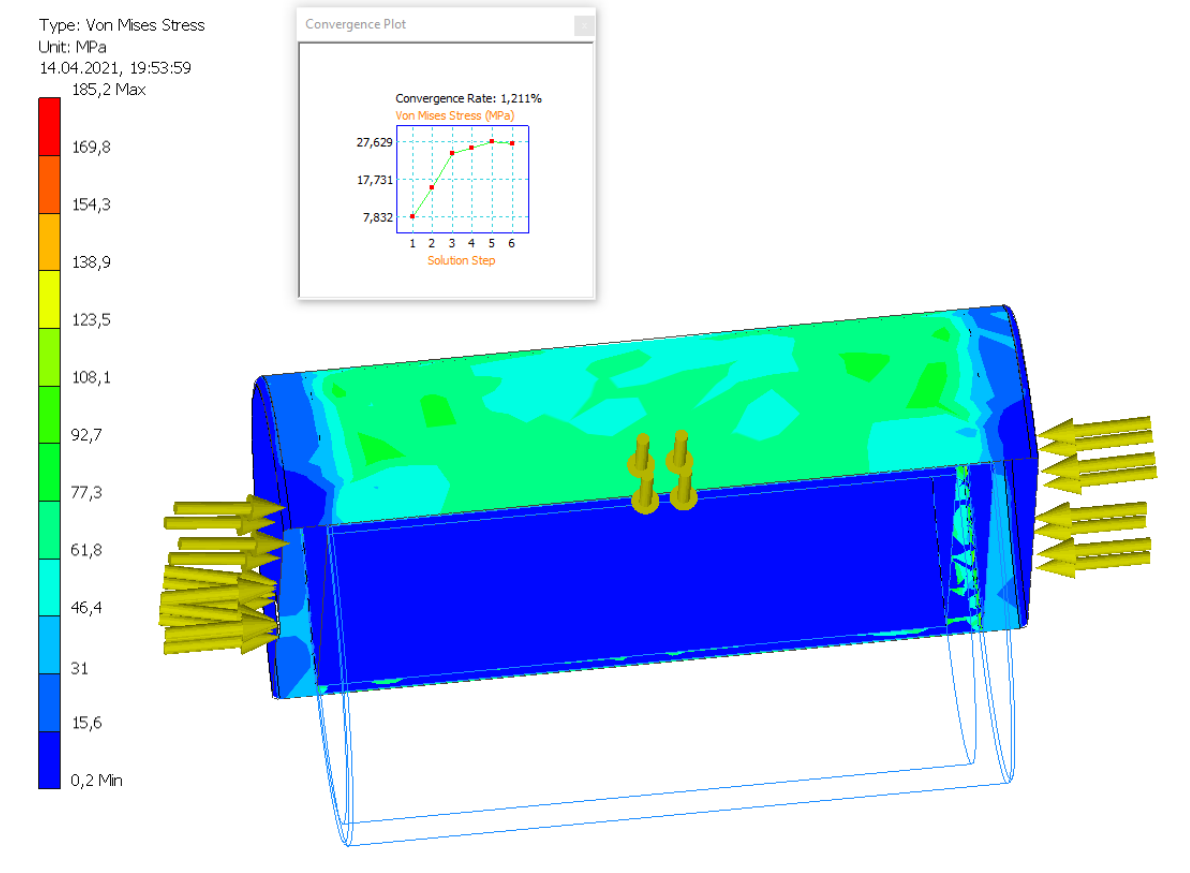


Figure 17. Overpack with drum and filled with liquid concrete exposed to rock pressure 11 MPa. Detail view.

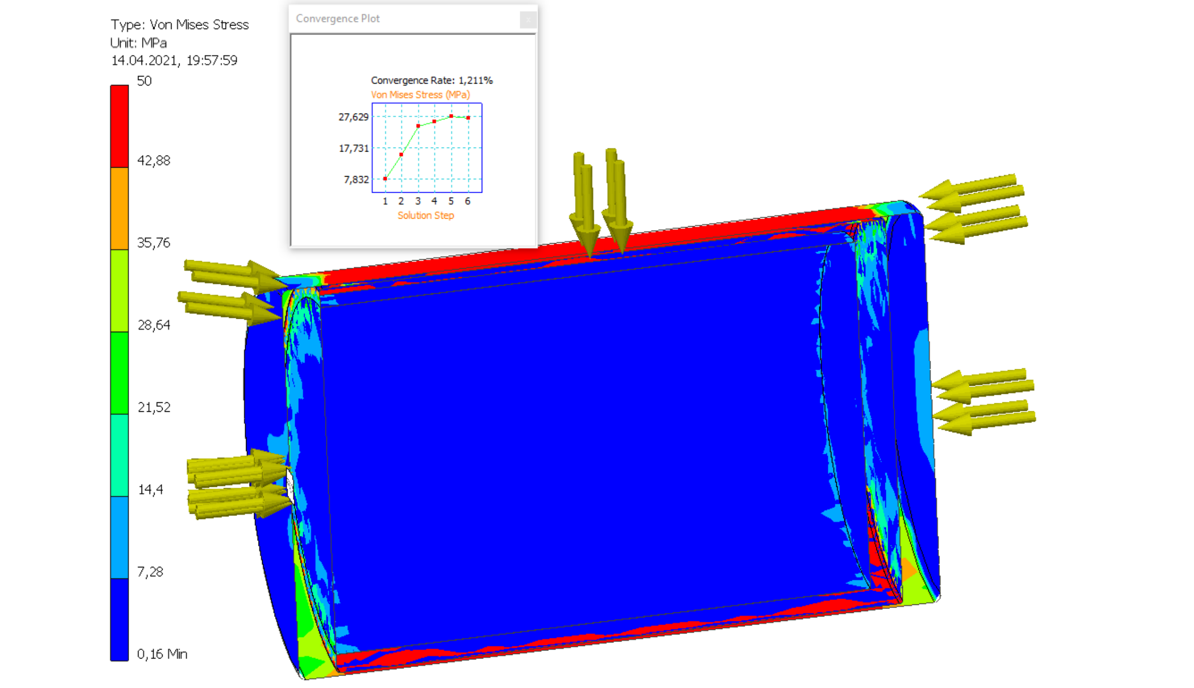


Figure 18. Overpack with drum filled with concrete exposed to rock pressure 11 MPa. Detail stress view.

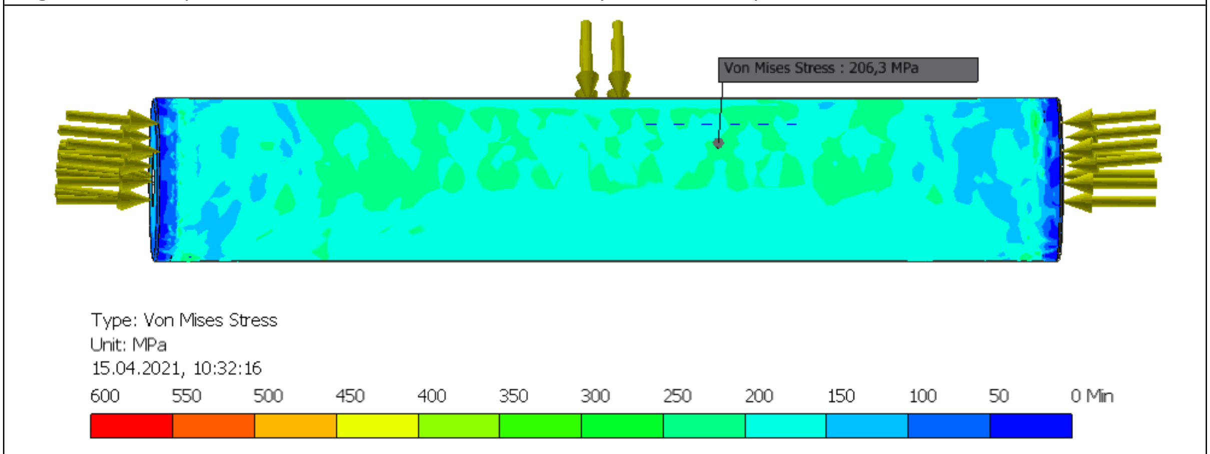


Figure 19. Full length overpack with out of centre drums with a top gap and concrete filled exposed to 5.2 MPa. Stress.

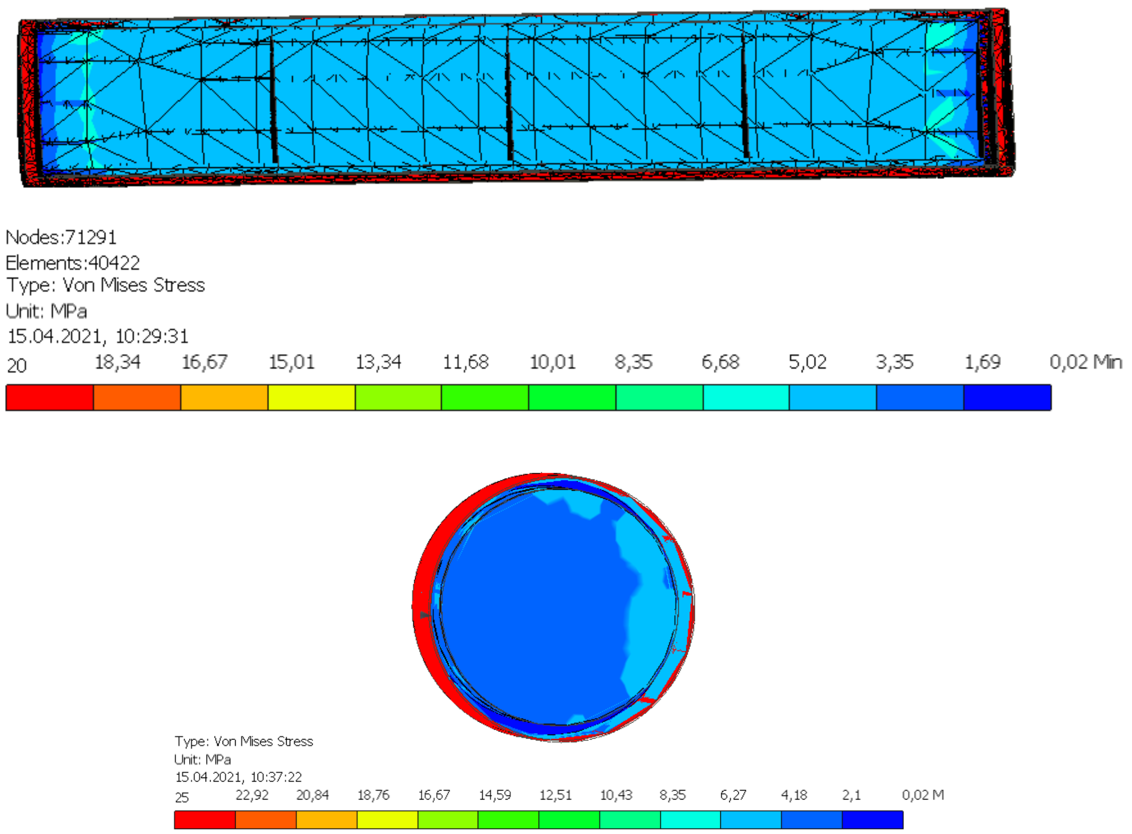


Figure 20. Full length overpack without of centre drums with a top gap and concrete filled exposed to 5.2 MPa. Inside Stress.

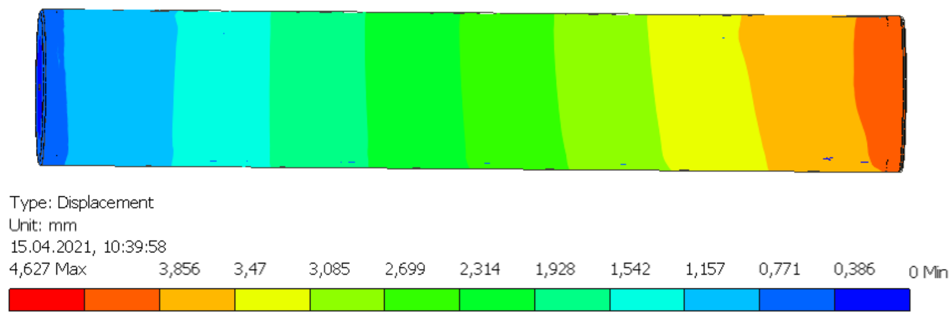


Figure 21. Full length overpack with out of centre drums with a top gap and concrete filled exposed to 5.2 MPa. Displacement.

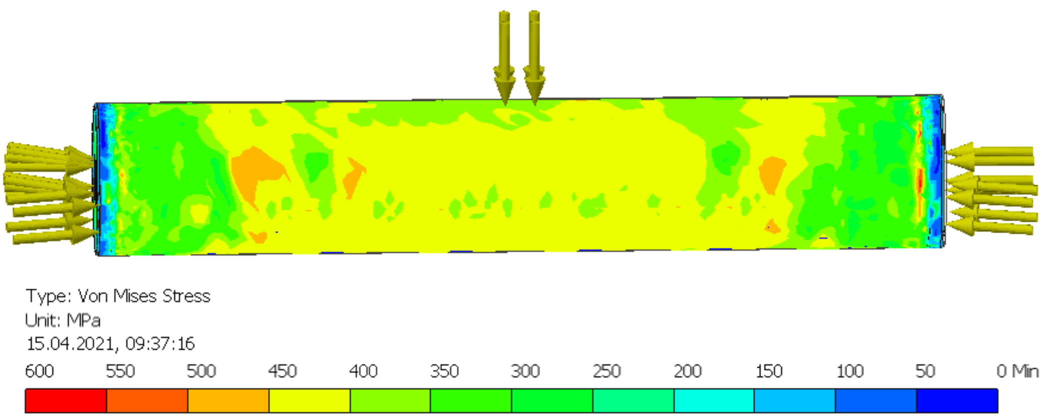


Figure 22. Full length overpack with out of centre drums with a top gap and concrete filled exposed to 11 MPa. Stress.

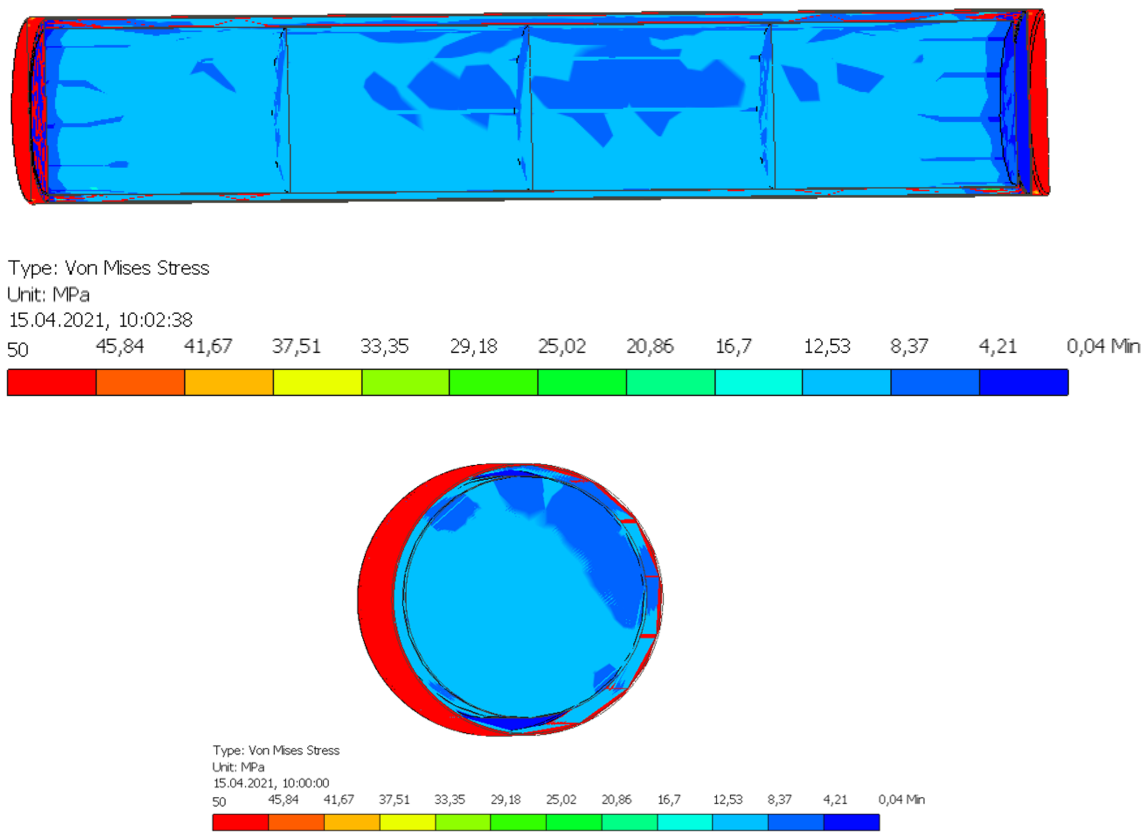


Figure 23. Full length overpack without of centre drums with a top gap and concrete filled exposed to 11 MPa. Inside stress.

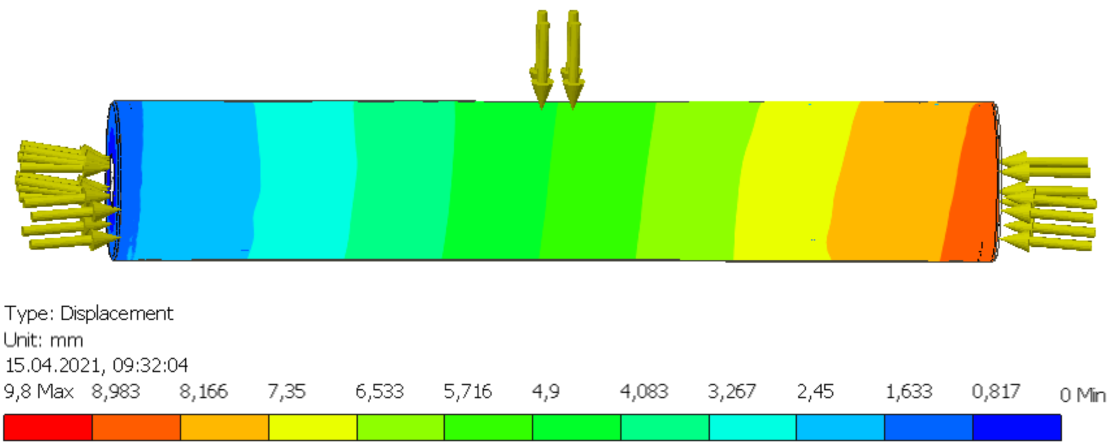


Figure 24. Full length Overpack w. out of centre drums with a top gap and concrete filled exposed to 11 MPa. Displacement.

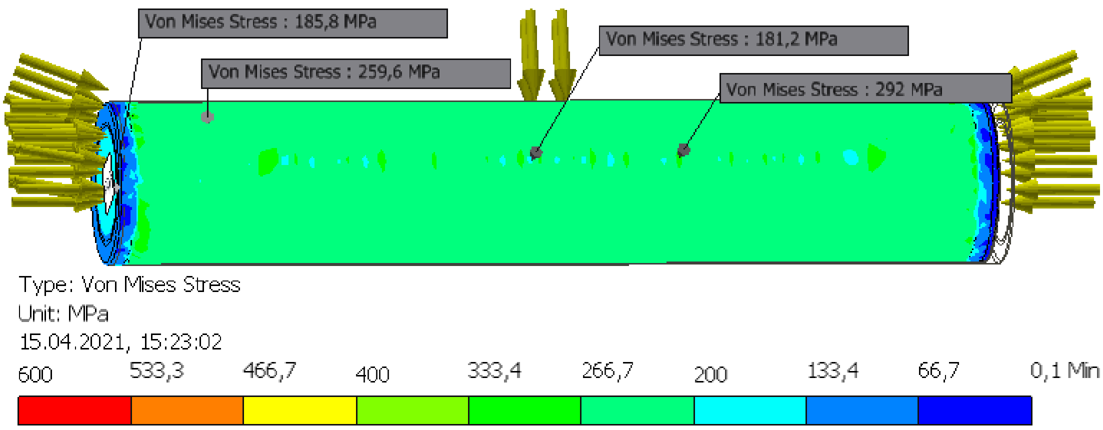


Figure 25. Full length overpack with out of centre drums with a top gap and concrete filled, stacked with 25 overpacks on top, exposed to 5.2 MPa stress.

3 Shielding Assessments

The shielding ability of the overpack with respect to envisaged ILW radioactivity levels was assessed using VRdose, based on the combined overpack and drum wall thicknesses, and based on a contact dose of 2 mSv/h outside the waste drums. The results are presented below.

Description of process of modelling overpack with drums in VRdose.

Note that all results are using the Ambient Dose Equivalent – H*(10) quantity.

The ambient dose equivalent *H*(10)* is defined as the dose equivalent that would be produced by an aligned and expanded radiation field corresponding to the real radiation field in the ICRU sphere at a depth 10 mm, on the radius vector opposing the direction of radiation incidence. This quantity is used for area monitoring. Further explanation of how *H*(10)* and other radiological quantities are calculated in VRdose can be found in [1] and [2].

Drums

1. Created cylinder shield with height = 862mm and radius = 315mm, material = iron, wall thickness = 1mm to represent a drum.
2. Created a CSG (Volume) source with height = 860mm and radius = 314mm to represent the waste inside the drum.
3. Put the source inside the shield. (Filled drum)
4. Put a dosimeter on the outer drum wall.
5. Added Co-60 isotope to the source.
6. Adjusted source activity to make the dosimeter show 2 mSv/h. The result found was 0.6895 GBq.

Overpack

1. Created overpack from cylinder shields with material = iron.
    a. Bottom is made up of massive cylinder shield with height = 60mm and radius = 323mm (VRdose currently doesn't support more than 3 decimals. The value should ideally be 645mm / 2 = 322.5mm).
    b. Top is equal to bottom
    c. Overpack walls is created from cylinder shield with height = 3540mm (3660mm – 120mm), radius = 323mm and wall thickness = 5mm.

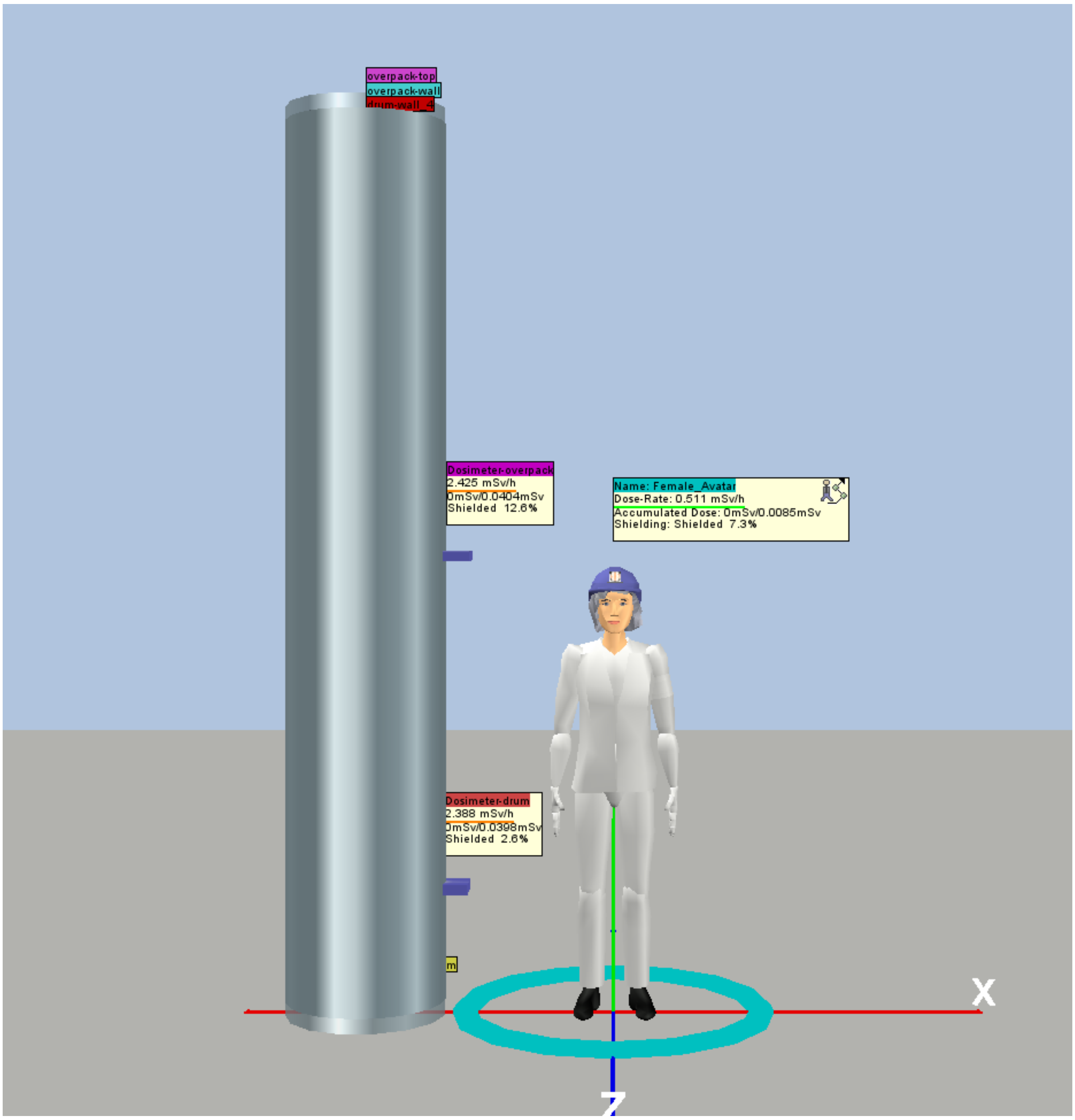
Place drums inside overpack

1. 4 copies of the filled drum are created.
2. Drum #1 is placed at the bottom of the overpack.
3. Drum #2 is placed at the top of drum #1 with a gap of 11mm.
4. Drum #3 is placed at the top of drum #2 with a gap of 11mm.
5. Drum #4 is placed at the top of drum #3 with a gap of 11mm.

Results Co-60

1. Dosimeter placed directly on outer wall of overpack: 2.425mSv/h.
2. Manikin with dosimeter at chest height placed 1m away from the overpack: 0.511mSv/h.

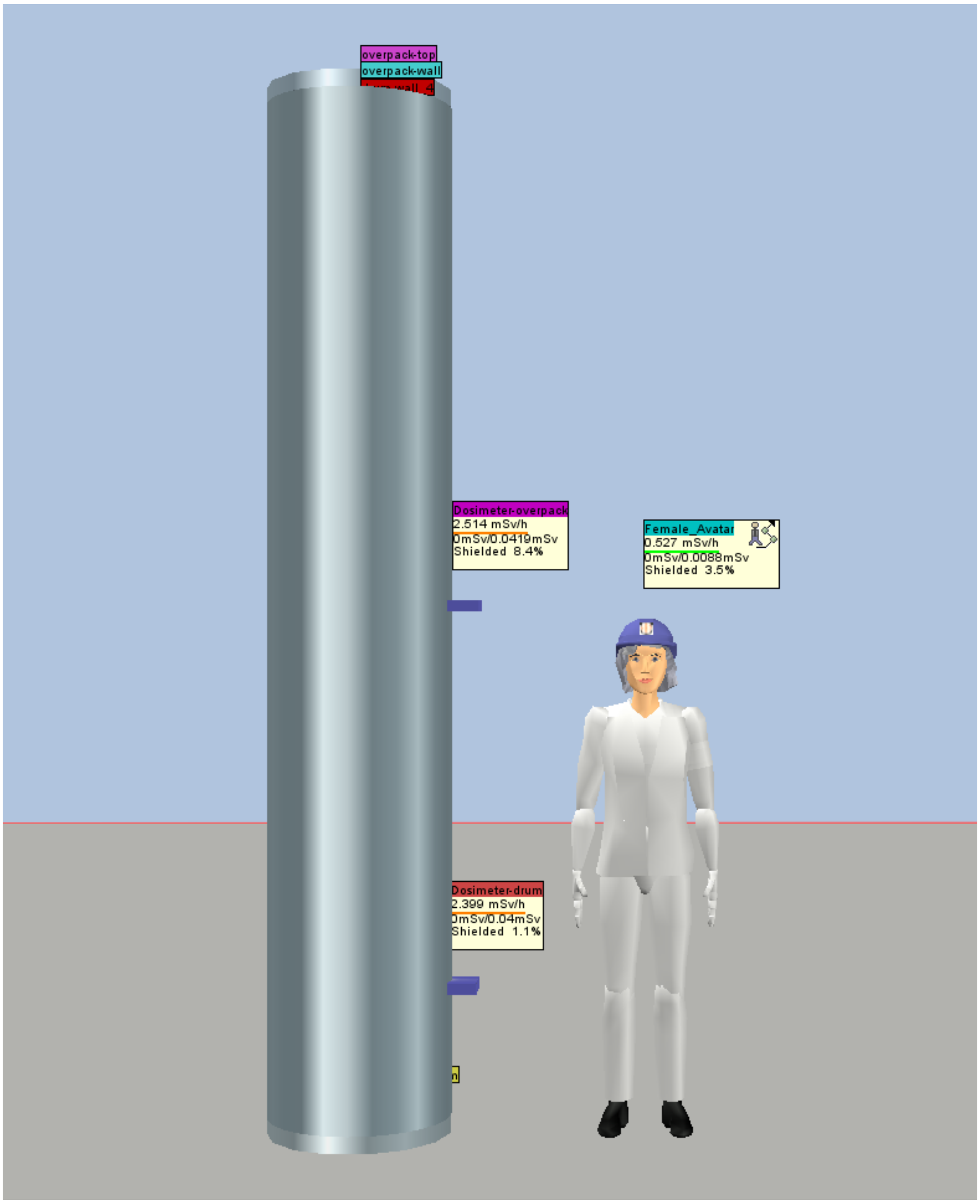
Effective



Results Cs-137

Same procedure as described for Co-60 but using isotope Cs-137.

1. Adjusted source activity to make the dosimeter show 2 mSv/h on outer drum wall. The result found was 2.612 GBq.
2. Dosimeter placed directly on outer wall of overpack: 2.514mSv/h.
3. Manikin with dosimeter at chest height placed 1m away from the overpack: 0.527mSv/h.



Adding concrete liner to the drums

A concrete liner with thickness of 5 cm was added to the drums. This was modelled in VRdose using a cylinder shield with height = 860mm, outer radius = 314mm, inner radius = 264mm and material = concrete.

The radius of the sources was changed to 264mm.

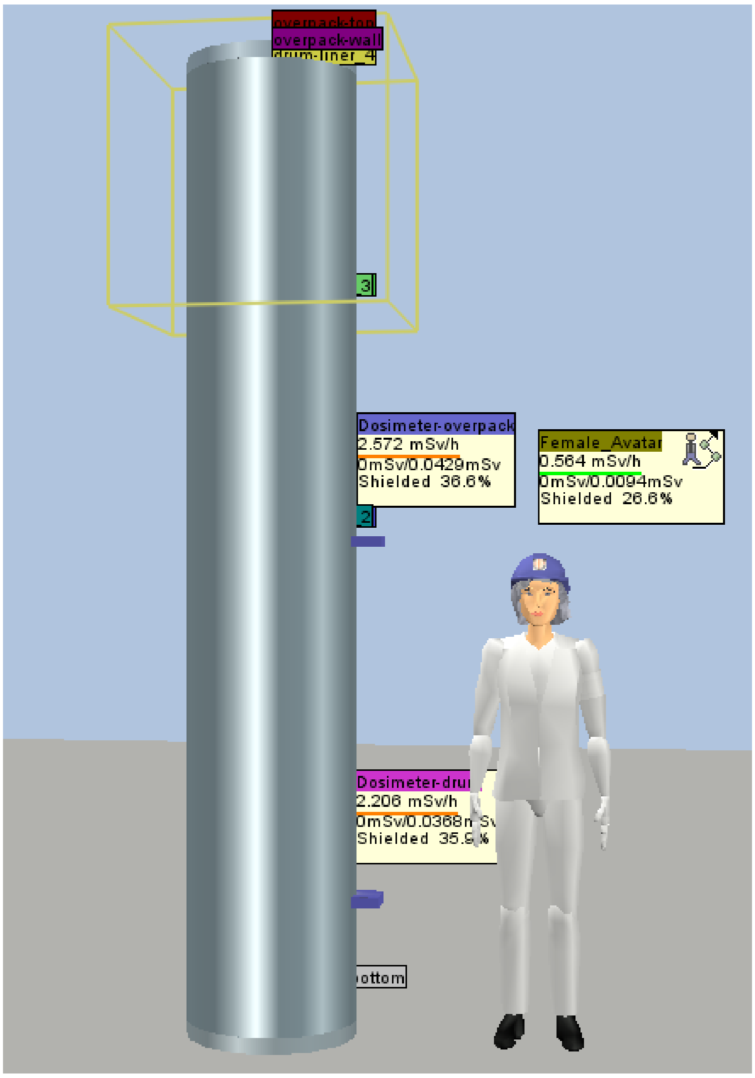
Results Co-60

First the activity was adjusted to make the dosimeter on the outer drum wall show 2mSv/h.

The result found was 0.9735GBq.

The result on the outer wall of the overpack was 2.572mSv/h.

The result for the manikin dosimeter was 0.564mSv/h.



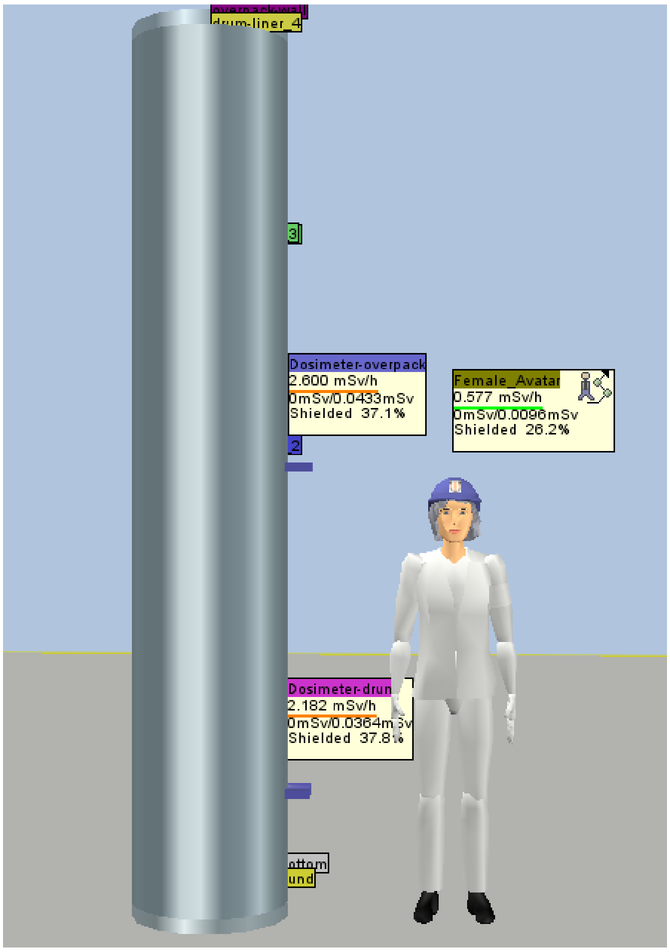
Results Cs-137

First the activity was adjusted to make the dosimeter on the outer drum wall show 2mSv/h.

The result found was 3.797GBq.

The result on the outer wall of the overpack was 2.6mSv/h.

The result for the manikin dosimeter was 0.577mSv/h.



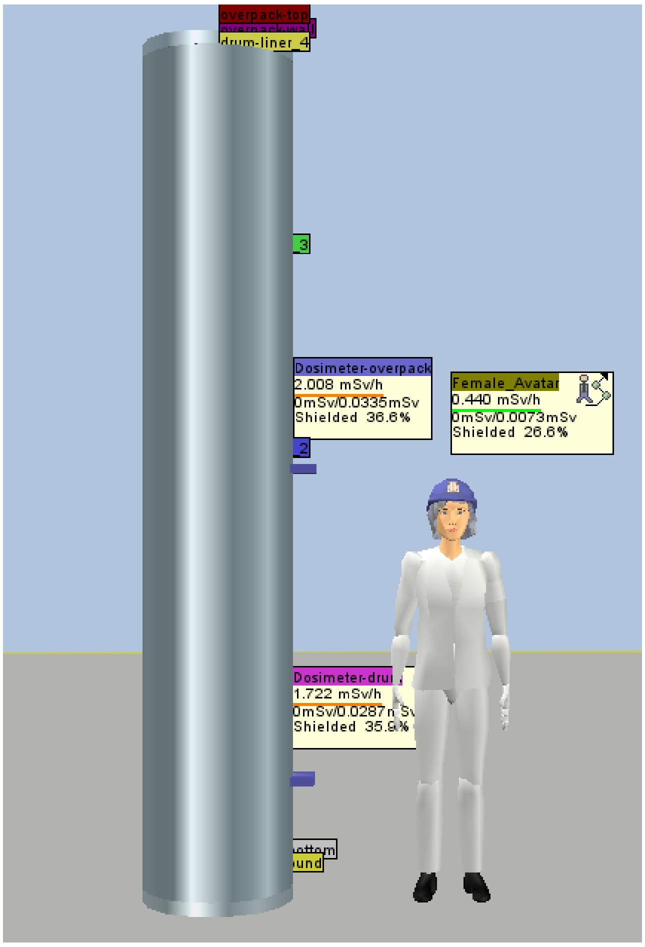
Adjusting activity to make dosimeter on overpack wall show 2mSv/h

Here the activity of the sources was adjusted down to make the dosimeter on the overpack wall show ca. 2mSv/h.

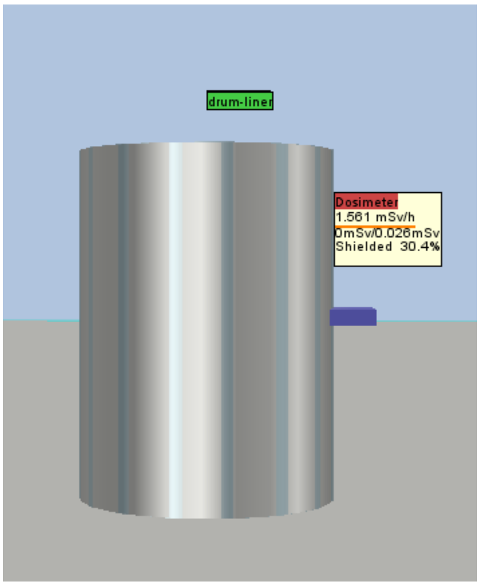
Result Co-60

The activity of each source was adjusted down by trial and error to 0.76GBq.

The result of the dosimeter placed directly on outer wall of overpack: 2.008mSv/h.



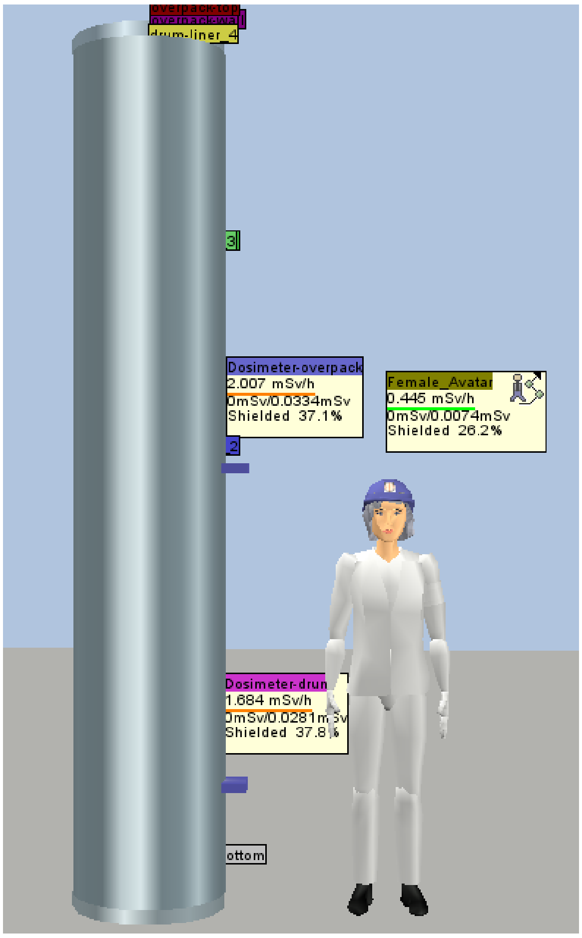
The result of the dosimeter on the drum wall after the adjusted activity was: 1.561mSv/h.



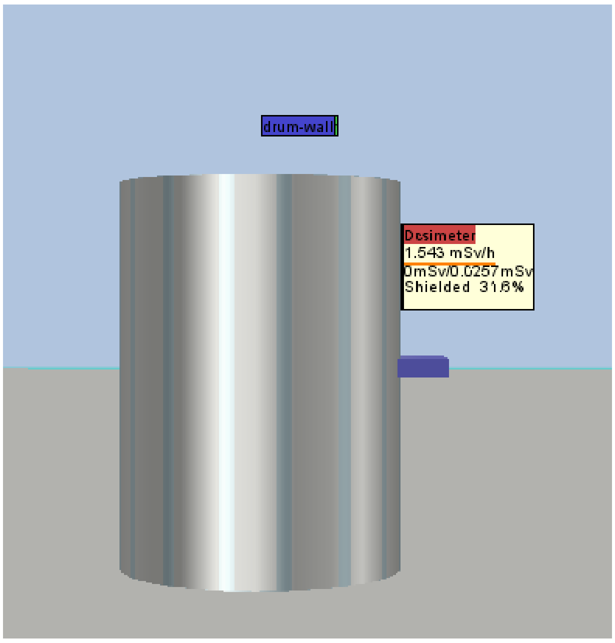
Result Cs-137

The activity of each source was adjusted down by trial and error to 2.93GBq.

The result of the dosimeter placed directly on outer wall of overpack: 2.007mSv/h.



The result of the dosimeter on the drum wall after the adjusted activity was: 1.543mSv/h.



Worst case scenario

Here, worst case scenarios of the variants with isotope Co-60, drum with concrete liner were created. Instead of using volume sources inside the drums, a point source with the same activity was placed inside each drum as close to the dosimeter on the overpack wall as possible. In the two lower drums the point source was placed in the top.

Result with Co60 activity of sources set to 0.9735GBq (this is the activity for drums with liner producing a 2mSv/h dose on the **overpack** wall): H*(10) = 54.917 mSv/h.
Dose on the surface of the drum **measured as close to the source position as possible** is 33.9 mSv/h.

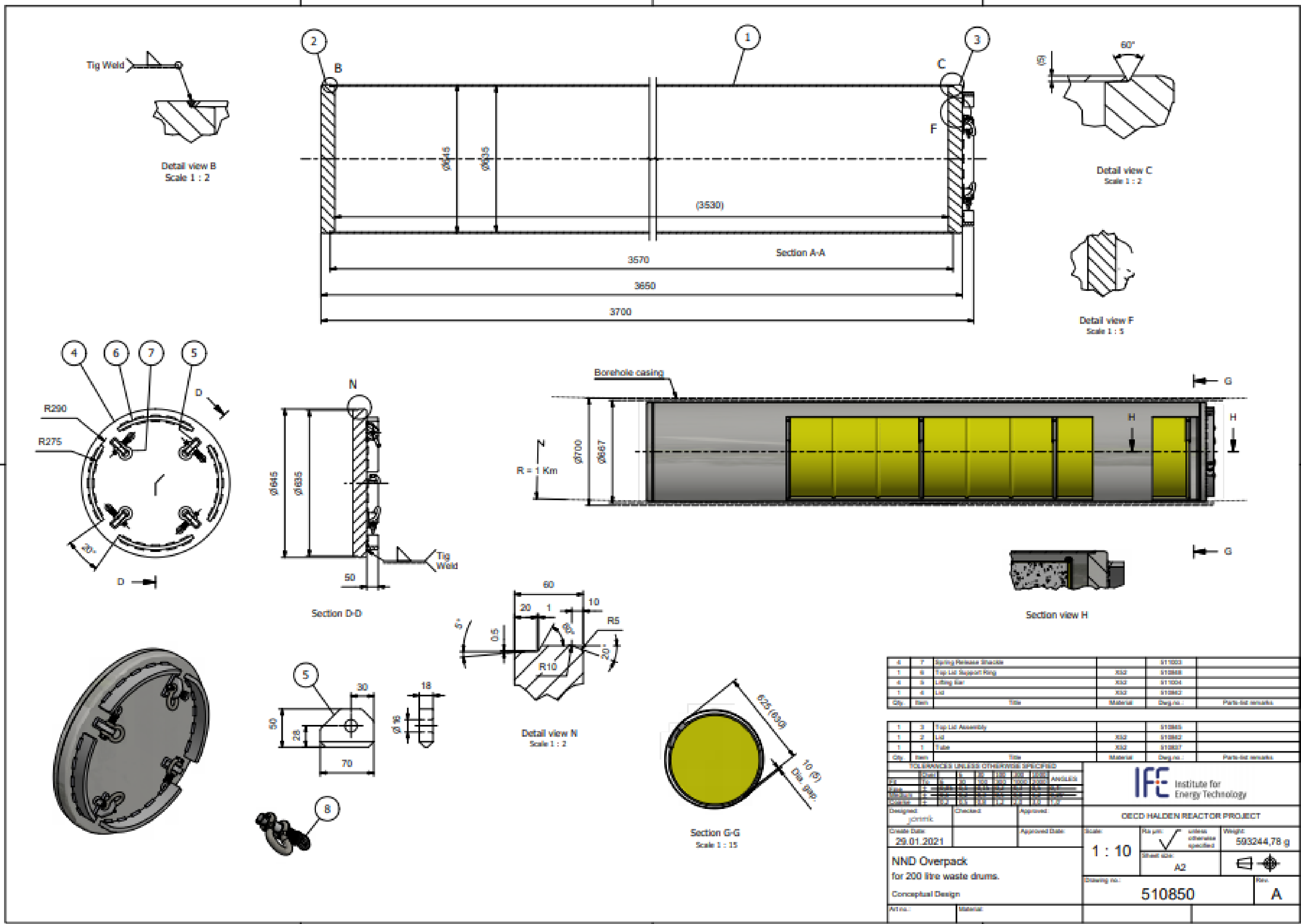
Result with Co60 activity of sources set to 0.76GBq (this is the activity for drums with liner producing a 2mSv/h dose on the **drum** wall – middle of the drum): H*(10) = 42.873 mSv/h.
Dose on the surface of the drum **measured as close to the source position as possible** is 26.465 mSv/h.

References

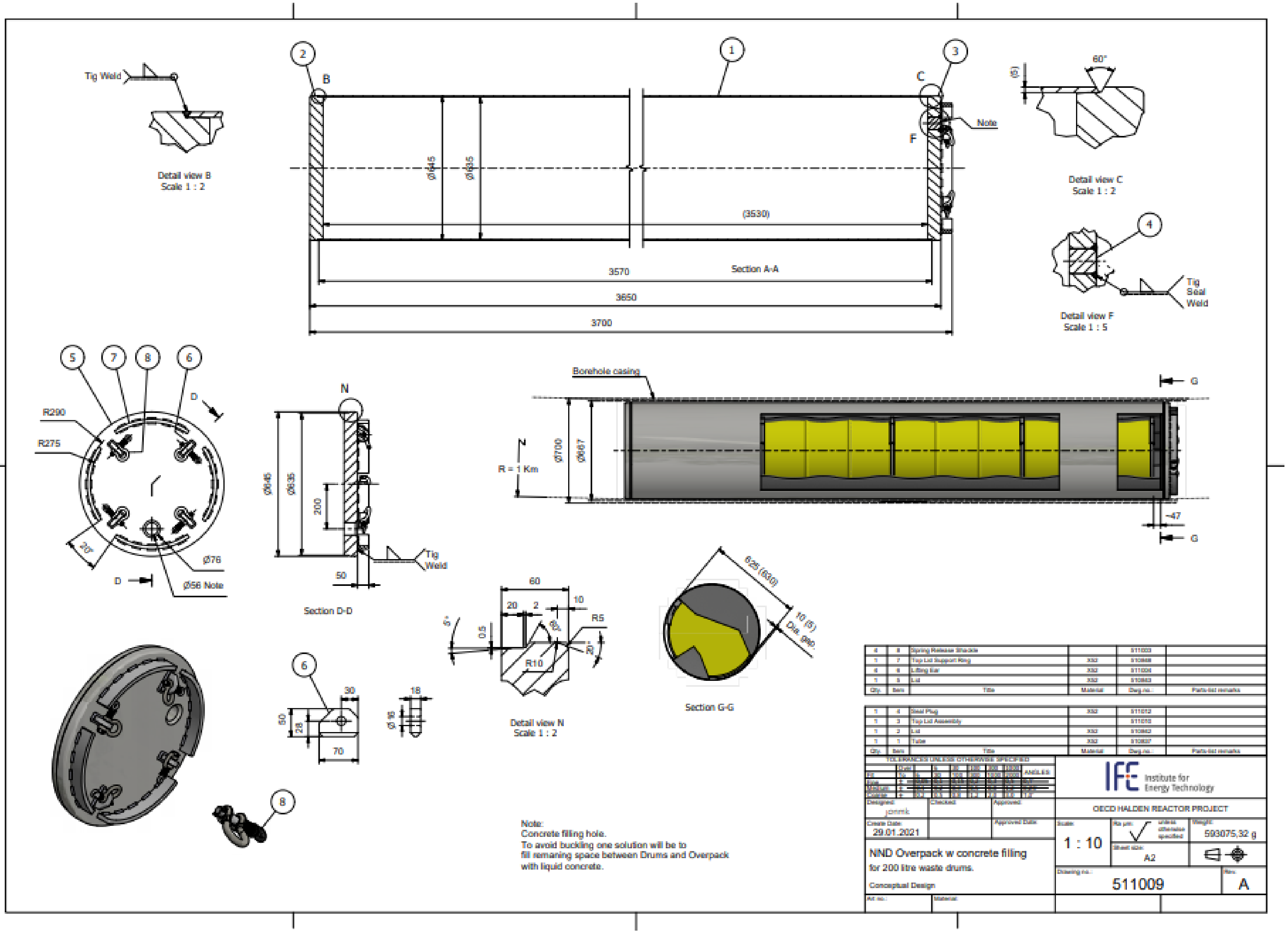
[1] Szőke*, I. "New Computational Model for Areal and Personal Monitoring in Nuclear Environments" HWR-1030, 2012-03-26.*

[2] Szőke, I., Louka, M.N., Bryntesen, T.-R., Bratteli, J., Edvardsen, S.T., Rø Eitrheim, K.K., and Bodor, K. "Real-time 3D radiation risk assessment supporting simulation of work in nuclear environments", Journal of Radiological Protection, 34 (2), 2014.

Appendix A


Tig Weld
Detail view B
Scale 1 : 2
B
C
F
(3530)
Section A-A
3570
3650
3700
Detail view C
Scale 1 : 2
60°
Detail view F
Scale 1 : 5
R290
R275
D
Section D-D
N
Ø645
Ø635
50
Tig
Weld
Borehole casing
R = 1 Km
Ø700
Ø667
G
H
Section view H
60
20
10
R5
R10
Detail view N
Scale 1 : 2
30
18
50
28
70
Section G-G
Scale 1 : 15
Spring Release Shackle
Top Lid Support Ring
Lifting Bar
Lid
Top Lid Assembly
Lid
Tube
Qty.
Item
Title
Material
Dwg.no.:
Parts-list remarks
TOLERANCES UNLESS OTHERWISE SPECIFIED
Institute for
Energy Technology
OECD HALDEN REACTOR PROJECT
Designed
Checked
Approved
Create Date:
29.01.2021
Approved Date:
Scale:
1 : 10
Weight:
593244,78 g
Sheet size:
A2
NND Overpack
for 200 litre waste drums.
Conceptual Design
Drawing no.:
510850
Rev.
A
Art.no.:
Material:

Appendix B


Tig Weld
Detail view B
Scale 1 : 2
B
C
F
Note
Ø645
Ø635
(3530)
3570
Section A-A
3650
3700
60°
(5)
Detail view C
Scale 1 : 2
Tig
Seal
Weld
Detail view F
Scale 1 : 5
R290
R275
D
20°
Ø76
Ø56 Note
N
200
50
Section D-D
Borehole casing
R = 1 Km
Ø700
Ø667
G
~47
60
20
2
10
R5
5°
0.5
60°
20°
R10
Detail view N
Scale 1 : 2
625 (630)
10 (5)
Dia. gap
Section G-G
30
18
50
28
70
Ø 16
Note:
Concrete filling hole.
To avoid buckling one solution will be to
fill remaining space between Drums and Overpack
with liquid concrete.
Spring Release Shackle
Top Lid Support Ring
Lifting Bar
Lid
Seal Plug
Top Lid Assembly
Lid
Tube
Qty.
Item
Title
Material
Dwg.no.
Parts-list remarks
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGLES
Institute for
Energy Technology
OECD HALDEN REACTOR PROJECT
Designed:
Checked:
Approved:
Create Date:
29.01.2021
Approved Date:
Scale:
1 : 10
Sheet size:
A2
Weight:
593075,32 g
NND Overpack w concrete filling
for 200 litre waste drums.
Conceptual Design
Drawing no.:
511009
Rev.
A
Art. no.:
Material:

Effective

Tittel: Overpack for disposal of 200 liter drums in boreholes v2

Dokumentklasse: **Research Report**

Signaturer:

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