BGE TEC

BGE TECHNOLOGY GmbH

Scoping the possibility of ILW disposal in boreholes

Technical Note – BGE Technology GmbH

Tilman Fischer, Joachim Engelhardt, Toivo Wanne

October 9th 2020

1 DISPOSAL OF ILW DRUMS IN BOREHOLES

For the disposal of intermediate level waste (ILW) in Norway an intermediate depth repository in type of a mine has been considered and looked at in more detail so far. Another option is to dispose the drums in boreholes, which is briefly discussed in the following.

For the described concepts and estimations the following numbers are used:

- Drum height: 86.2 cm
- Drum diameter: 63.0 cm
- Number of drums: 8000

This number nonetheless is very uncertain. Other estimates have shown significantly smaller drum numbers. These numbers varied from not even 900 drums to 5000 drums. Still, the calculations can easily be changed and adapted to other values.

As first approach, two different basic ideas are discussed. First the disposal in relatively small boreholes, in which the drums are stacked above each other. This option shows similarities to the deep borehole disposal concept for the high-level waste (HLW). The second option is the disposal of the drums in shafts. In this case, the shaft is shallower than the borehole, but only operated from the surface. In addition, the drums are located next to each other, as well as above each other. A figure to point out the shaft, or underground silo, concept can be found below.

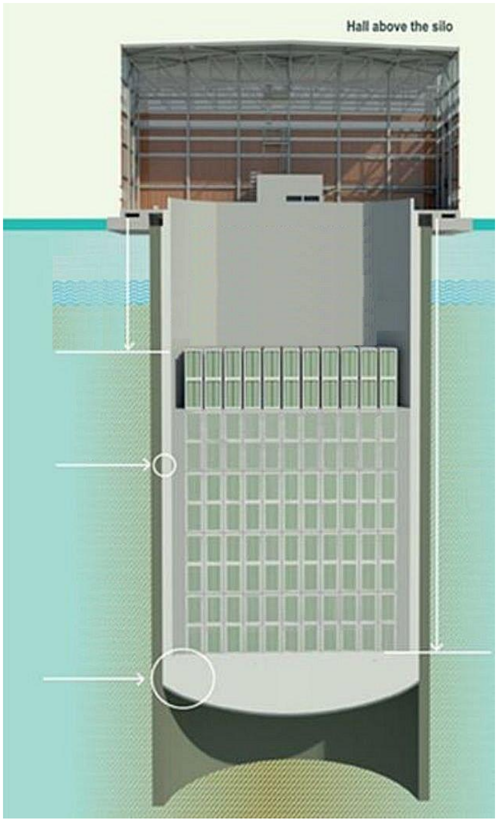

Figure 1 – Shaft/silo disposal concept. [Figure from the "Krško NPP Radioactive Waste and Spent Fuel Disposal Program", version 1.3, 2019].

1.1. Small diameter borehole option

The term small diameter borehole is describing a concept or option that considers all ILW drums stacked above each other and not next to each other. Therefore, the borehole diameter can be kept relatively small and is determined by the diameter of the drums. Even for this concept, there are two options. One options considers the drums to be stacked without overpacks, while the second option considers to put four drums on top of each other into one overpack.

1.1.1 Borehole disposal without overpacks

The first option requires a smaller borehole compared to the second option. Still, there are also negative aspects in this concept. The drums itself do not feature a strong mechanical stability and the lower drums are most likely to be squeezed and damaged as more drums are put on top. Also, the disposal process is taking longer since every drum needs to be lowered into the borehole individually. The emplacement in general is a topic to look at in more detail. In the Asse II repository (former mine) in Germany drums similar to the ones considered in this case have been lowered down via wirelines. Figure 2 shows a picture of the emplacement of one of these drums.

Figure 2 - Waste emplacement of drums in the Asse II repository, Germany (photo: BGE).

Even though there are options with proven practicability, handling of the drums is most likely to be the most challenging part of the operation. The drums do not have any grabbing device. In Figure 2 some sort of emplacement hook is attached to the drum. According to this picture there are solutions for this problem, but the suitability for the emplacement in boreholes needs to be checked. Another option is the use of a claw arm to grab the whole drum. This would require more space and the positive aspect of a small diameter of the borehole would be eliminated.

Another topic to discuss is the trajectory of the borehole. Compared to the deep borehole disposal, in this case a vertical borehole seems more rational. Vertical wells can be drilled faster, cheaper and do not require any special drilling devices, even though directional drilling methods are used in almost every operation these days. Taking horizontal wells into account will complicate the operation without leading to any big advantages. In these shallow boreholes it is already a challenge to bring the trajectory of the borehole into a horizontal direction. If it can be achieved, the curvature is most likely to be too small to secure a smooth emplacement process of the drums into the desired emplacement zone. An option to look into in more detail is to drill the borehole slightly deviated from the beginning as it is displayed in Figure 3. This option has the benefit, that several wells can be drilled from one drill site – given the geologic condition is uniformly beneficial in the entire site. The wells will then be placed circular and due to the outwards directed borehole tilt, the wells will not interfere with each other.

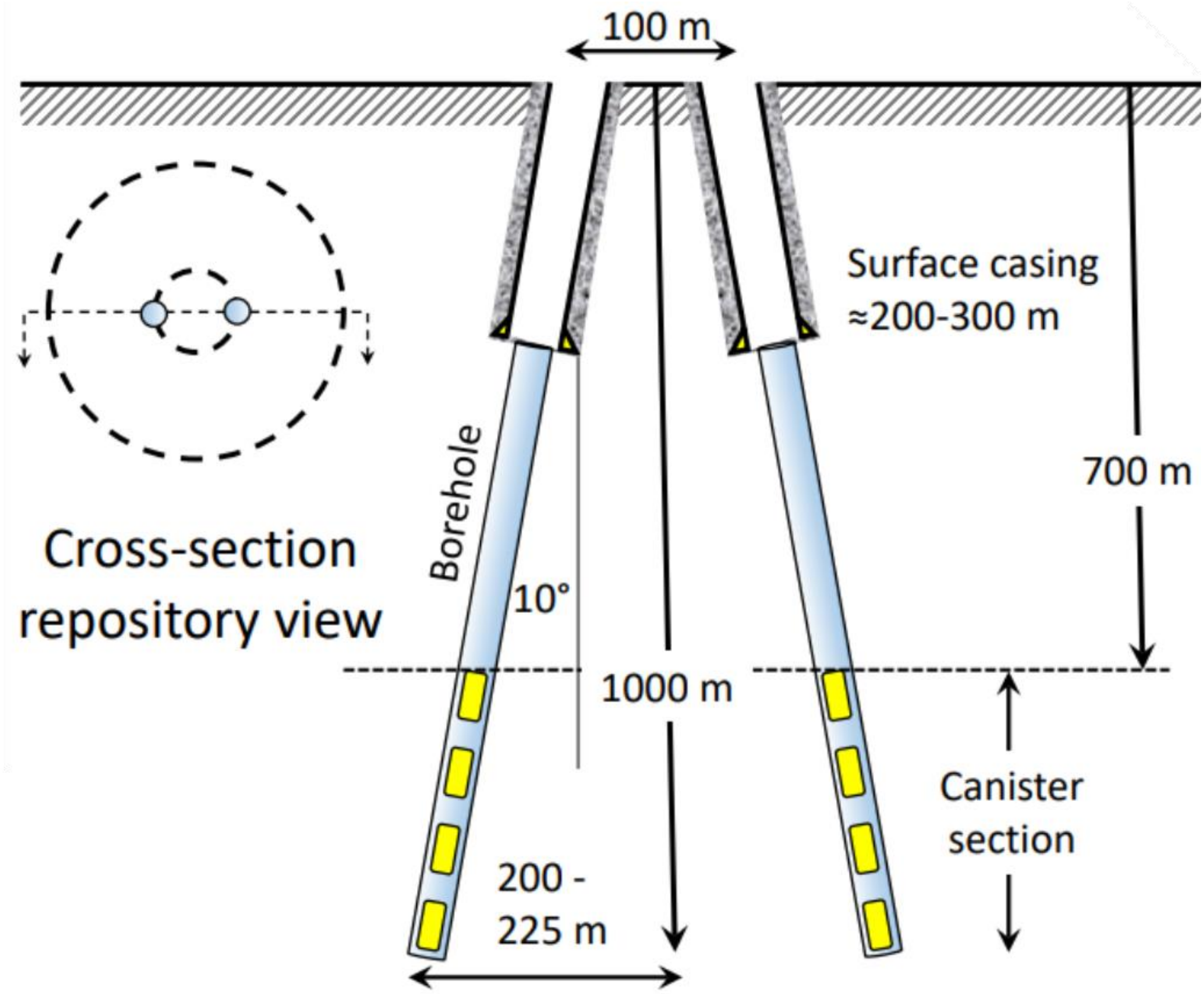

Figure 3 – Tilted borehole option (the values are only examples and are not fixed) [University of Stavanger, 2020].

One aspect, which needs to be kept in mind is the emplacement of the drum in tilted boreholes. Here the drums are most likely to slide on the borehole wall during the emplacement operation. This can damage the drums and weaken the mechanical strength of the drums or even destroy the metal sheath.

To include the numbers and show the extent of the operations similar calculations as for the deep borehole disposal concept have been carried out. In the first step the total required disposal length for all of the 8000 drums has been calculated. For this purpose, two options have been considered. First, no buffer zone between the drums and second, a small buffer zone of 0.2 m. As mentioned before, the mechanical instability of the drums and the weight put on the lowest drums need to be kept in mind.

1. Disposal length (no buffer) = 8000 x 0.862 m = 6.9 km
2. Disposal length (buffer of 0.2 m per drum) = 8000 x (0.862 m + 0.20 m) = 8.53 km

Compared to the deep borehole disposal, the boreholes can be significantly shallower. Taking into account the considerations for the intermediate depth repository as presented in the COO3 cost estimation report, a sealing zone of 100 meters should be sufficient. The diameter of the drums of 63 cm require final inner casing diameter of at least 65 cm, probably 67 cm to be on the safe side. Therefore, a final borehole diameter of about 68…70 cm is required, depending on the wall thickness. Up to a depth of 500 meters a borehole of this diameter seems easily feasible to construct. These assumptions result in a disposal length of 400 meters per borehole. Combining all the information, a total number of 22 to 25 boreholes are required to dispose all the ILW waste drums.

1.1.2 Borehole disposal with overpacks

The second option of using a small diameter borehole is including the use of overpacks, in which the waste drums are packed and then disposed in the borehole. Figure 4 shows the dimensions of these packages. Also, the final casing dimension are shown in this illustration. As in the option without the overpacks, a borehole depth of 500 meters is considered for the disposal.

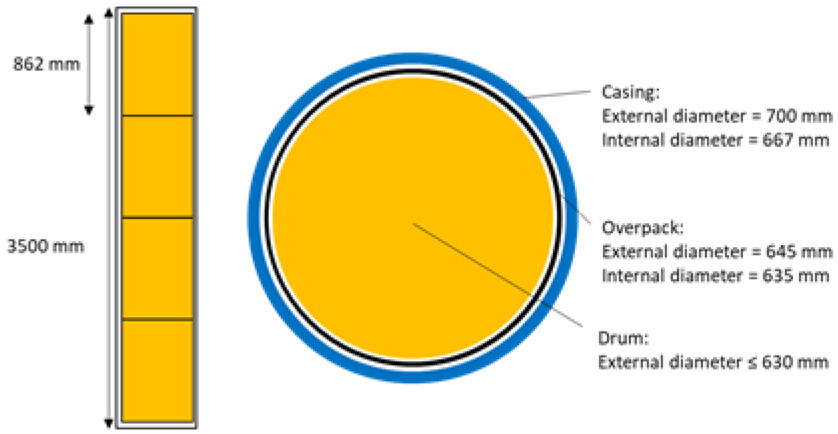

Figure 4 – Illustration of the overpacks.

As displayed each of the overpacks holds four ILW waste drums. This means, a total of 2000 overpacks is required for the disposal of all the ILW drums. Carrying out similar calculations as above roughly 100 overpacks and therefore 400 drums fit into one borehole. This results in 20 boreholes required for the disposal of all the drums. In this calculation, small sections are included as a buffer zone.

1.2. Comparison of two borehole disposal options

A brief comparison between these two options shows more positive aspects of the option including overpacks. The time required for the disposal will be reduced significantly. Also, the overpacks are likely to provide additional mechanical strength. On the other hand, both options are relatively time consuming and costly, since at least twenty boreholes to a depth of 500 meters are required.

For a rough conservative cost estimate, 2 million euro per borehole is assumed. A borehole of this depth and diameter will probably take about half a year construction time. This results in approximately 40 to 50 million euro and 10 years construction time if one well is constructed after another. To reduce the time, several wells can be drilled simultaneously. This would require more rigs, but the total costs would not change significantly. In terms of drilling and construction, the two borehole options do not differ a lot, but when it comes to the operational time the difference becomes obvious. Table 1 shows a rough estimation of the time required to dispose all of the 8 000 canisters, either one by one or four of them at a time in overpacks.

Table 1 – Disposal time calculation.

	Unit	**Disposing canisters one by one**	**Disposing canisters in overpacks**
Number of canisters/overpacks		8 000	2 000
Lowering speed	m/s	0.51	
Respooling speed	m/s	1.00	
Tripping speed	m/s	0.15	
Borehole depth	m	500	
Slow tripping length	m	100	
Duration per roundtrip	s h	3554.9 0.987	
Loading time	h	0.25	
Total time per canister/overpack	h	1.24	
Total disposal time	h d	9899.78 412.49	2474.95 103.12

As seen in the table the time required to dispose all the canisters is four times as fast if they are disposed one by one compared to the disposal in overpacks. The calculations do not include any time for the movement of the emplacement facility from one borehole to the next. The mentioned values can only be used to give a rough idea about the required time. Another reason to develop the approach including the overpacks in more detail is the fact that the overpacks can be designed in a way, that they will run smoothly into the borehole, for example by shaping the overpacks slightly conical. In addition, a handling or grabbing attachment can be included in the design as well. This will also allow to reduce the diameter of the borehole to the same value as for the disposal of drums without overpack.

2 SHAFT DISPOSAL CONCEPT

A slightly different option is the disposal of the drums in large diameter boreholes, also known as shafts. In this option the drums are located next to each other and stacked in layer with a buffer zone constructed out of concrete or a similar material in between. The basic concept is shown in Figure 1 as well as in a more schematic way in Figure 5. This approach is not unlike silo disposal of waste drums, for which there is a lot of experience worldwide.

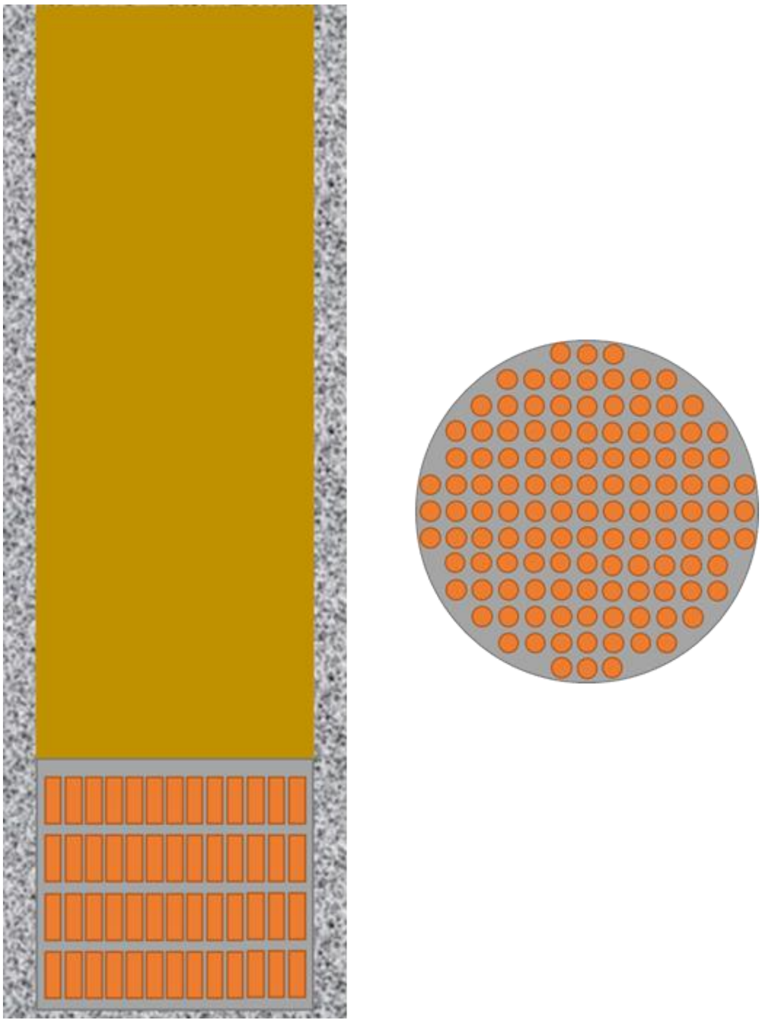

Figure 5 – Schematic view of the shaft disposal concept.

Depending on the diameter of the shaft the number of drums per layer varies and therefore the number of layers will vary as well. The size of the shaft will once again depend on the geology. Another aspect which has an impact on the size is the availability of machines to construct the shaft. In almost every underground mine, shaft boring machines are used to construct the shaft to enter and exit the mine, as well as the ventilation shafts. But also for tunnel construction, shaft boring machines are used. Another option to construct the shaft is the drilling and blasting method which is also widely applied and for which a lot experience is available. Drilling a pilot hole and then enlarging this to the wanted size can be also a possible way to construct the shaft.

Figure 6 – Shaft boring machines (SBM); hole expansion wellhead; shaft boring extension machine (SBE) (from left to right) [Herrenknecht, 2020].

The size of the shafts depends on the needs for the operation. For a first approach two shafts constructed in Germany are used to provide a basic idea. The shaft of the ASSE II repository and the shaft of the Konrad repository. The diameter of the ASSE shaft is 8.00 meters, while the Konrad shaft is 9.50 meters. With the same approach as it has been used in the borehole disposal report[1] the circles in a circle method has been applied here as well. As shown in Figure 7 a maximum of 132 drums could be fitted into an 8-meter shaft, while a 9.5-meter diameter shaft has space enough for 189 drums per layer. Placing drums this close to each other can be relatively challenging. Therefore, a more conservative approach would be to estimate a maximum of 100 drums per layer in a shaft with a diameter of 8.0 meters and 150 in a 9.50-meter shaft.

[1] Fischer, Engelhardt, Wanne. 2020. Borehole Disposal Concept. Norwegian National Facility. NND. Technical Report. BGE Technology. Germany. September 2020.d

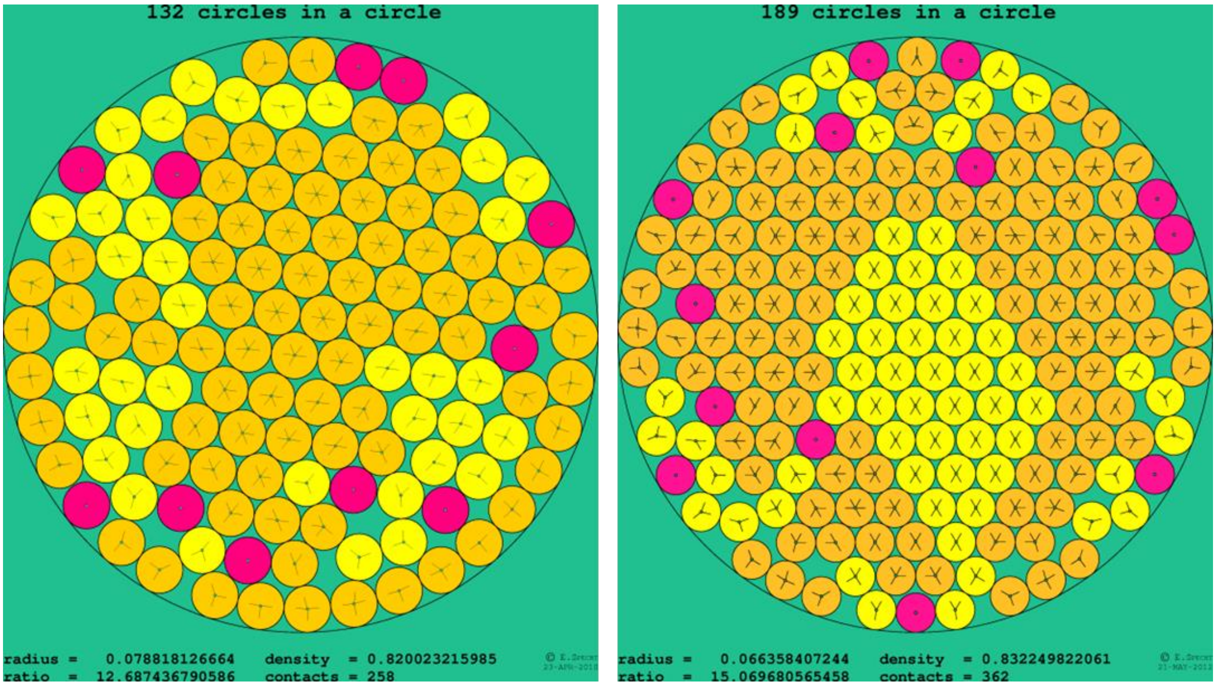

Figure 7 – Maximum number of drums per layer based on the circles in a circle principle (left: 8-meter shaft; right: 9.5-meter shaft) [http://hydra.nat.uni-magdeburg.de/packing/cci/cci.html#overview, 2020].

The number of drums per layer will impact the total number of layers. With full utilization of the area of the shafts (132 drums per layer for 8-meter shaft; 189 drums per layer for 9.5-meter one) the number of layers would be 61 respectively 43. Including a buffer zone between the layers of one meter, the total required disposal length would be 114 meters for the smaller diameter and 80 meters for the larger diameter shaft. With the more conservative approach, a disposal lengths of 150 meters and 100 meters are required. A summary of the calculations can be found below.

Table 2 – Calculations related to the shaft disposal operation.

	unit	**8-meter shaft**		**9.5-meter shaft**	
Shaft diameter	[m]	8.00		9.50	
Diameter ratio		12.70		15.08	
		maximum	conservative	maximum	conservative
Number of drums per layer		132	100	189	150
Number of layers		61	80	43	54
Disposal length	[m]	113.58	148.96	80.07	100.55

Once again an analogue to the intermediate depth mined repository can be made. This includes a sealing and backfilling zone of 100 meters, which is the geological barrier in the mined ILW disposal concept. Accordingly, a total depth of the shaft of 200 to 300 meter could be sufficient. With current shaft construction technologies this is easily possible. This concept has a lot of similarities to the disposal concepts in silos, where already experience is available, which will be useful to carry out this operation.

Shafts, which have been sunk within the past decades, provide some information about the time required for such an operation. In this technical note, only some shaft sinking times from China are included as shown below. Based on this a rough idea for the construction time of the shaft can be given.

Mine	Sinking Contractor	Finished Diameter (m)	Shaft Depth (m)	Start Date	Completion Date	Average Monthly Advance (m)	Max Monthly Advance (m)
Yangquhe Mine – Vent Shaft	China Coal No. 1 Construction Co.	6.0	943	Nov. 2009	Sept. 2010	118.0	222.8
Yongmei Shunhe Mine – Aux. Shaft	China Coal No. 5 Construction Co.	9.5	769	Oct. 2009	Aug. 2010	76.9	244.0
Cixi Mine – #1 Aux. Shaft	China Coal No. 5 Construction Co.	8.0	1,340	July 2011	Aug. 2013	98.0	137.0
Nalinhe Mine – #2 Shaft	China Coal No. 3 Construction Co.	10.5	588	Mar. 2011	Jan. 2012	65.0	120.0
N0. 2 Shaft – Qinling Zhongnanshan Tunnel	CCCC Tunnel Engineering Bureau	11.2	661	Apr. 2007	Mar. 2008	58.3	80.0
Huize Mining – #3 Shaft	JCHX Company	6.5	1,526	Feb. 2014	-	-	182.0

Figure 8 – Shaft sinking times in China [https://magazine.cim.org/en/the-evolution-of-shaft-sinking/evolution-of-shaft-sinking-part-seven-en/, 2020].

According to the average times in Figure 8 the completion of a shaft, with a depth of 300 meter and a diameter of 8 meter will take about half a year. Still, this value needs to be handled with care and it is most likely, that the construction time will be greater in the hard crystalline formations.

Additionally, there are some other beneficial point to be mentioned regarding the shaft disposal concept. Compared to the borehole disposal concept, only one facility is required. One shaft is enough to fit all the ILW. This means less surface area for the operation. Due to the wide shaft and lower depth compared to the borehole disposal concept for ILW, the handling will be easier. In terms of costs, building one shaft is most likely to be more cost effective than drilling 25 boreholes or even more[2]. Another positive aspect is the reduced structural loads in the drums. Since there are less layers of drums on top of each other, less weight and stress will be put onto the lower drums, which is beneficial to the durability of the drums.

3 CONCLUSION

Based on this first analysis, the disposal of the ILW drums in Norway seems most promising in shafts to a depth of up to 300 meters. Comparing the construction times of the shaft concept and the borehole concept, the shaft is most likely to be constructed much faster. Since the shaft provides more room, loading and emplacing the drums is probably faster than in the borehole concept, where the space is limited. Still, a more detailed evaluation of the construction and emplacement time is needed to underline this first assumption. Another point, which is needed to be looked at in more detail is the costing of the different alternatives. While for borehole drilling and construction, information is available, reliable values for the shaft sinking costs are barely publicly available.

[2] Costing of the shaft ILW disposal option was not looked at in more detailed in the work.