P/F Suðuroyartunnilin

# Peer Review and Second Opinion of Risk Analyses for Suðuroyartunnilin

## Report

October 2024

HOJ Consulting GmbH
www.hoj.ch

Ballyweg 33
CH-6440 Brunnen
Switzerland

Tel+41 41 820 3376

P/F Suðuroyartunnilin

# Peer Review and Second Opinion of Risk Analyses for Suðuroyartunnilin

## Report

October 2024

| | |
|---|---|
| Report No. | H-FO-001 |
| Revision | 0 |
| Date | 11.10 2024 |
| Prepared | Niels Peter Høj |
| Checked | Joan Qi Si |
| Approved | Niels Peter Høj |

# List of Contents

# 1 Introduction

Risk analyses have been carried out by third-party consultants for the Suðuroy Tunnel. Before the project is sent to Lagtinget, the Client has requested HOJ Consulting (Niels Peter Høj) to carry out a peer review and provide a second opinion concerning the analyses and their conclusions.

The present report summarises the result of the review and contains a short description of the findings in the main report and detailed comments in appendix.

The risk analyses which have been reviewed are:

- "Sudurøytunnelen, Risikovurdering av aspekter knyttet til byggeperioden" by SINTEF, 10.11.2023.
- "Risikovurdering, Forprosjekt Suðuroyartunnilin" by Norconsult, 24.11.2023.
- Notat "Risikovurdering av langsgående ventilasjon i Sudurøytunnelen" by Sweco, 15.03.2024.

The original documents are written in Norwegian language. As agreed with the Client, the present review is written in English language. Quotes from the risk analyses are stated in Norwegian language and are roughly translated into English if required.

# 2 Summary

Three risk analyses carried out by third-party consultants during the pre-project for the Suðuroy Tunnel have been reviewed by HOJ Consulting (Niels Peter Høj). Based on this review, which is documented in the present report, the second opinion is formulated:

Compared to good practice for risk evaluations, all three reports have some deficiencies. Generally, the relevant probabilities are not combined with associated consequences, and the estimated risk is not evaluated according to well-defined acceptance criteria. Finally, the efficient risk-reducing functionality of the additional safety measures is not documented in the reports.

On the other hand, the study and the findings in the report concerning construction risk have not revealed any major issues which would contradict the statement that it is "**fully achievable** to undertake even this long tunnel with limited risk that is within what is manageable for the project".

Similarly, the review has not identified any significant issues related to the operational risk to the users, which would contradict the conclusion that it is possible to design and operate the Suðuroy Tunnel so that it is **sufficiently safe** – under the condition of the given system description, and the proposed additional safety measures.

In the later stages of design, however, it is highly recommended to investigate some further safety measures. These measures include:

- PA (public address) system with loudspeakers,
- Possibly escape shelters per 500 m and per 1000 m,
- Possibly a wider tunnel cross section of T10.5.

If these safety measures are not too expensive compared to the effect on the safety of the users, they should be implemented. The reviewer would assume that a PA system would be an efficient measure with moderate costs and would recommend this measure.

Some of the measures assumed in the system description and in the recommendations of the designer would also need to be further studied in the next project phase. These measures include:

- Possible restrictions to the traffic with heavy goods vehicles.
- Improved conditions for the rescue services

In the next phase it would also be highly recommended to establish comprehensive risk evaluations in accordance with best practice for both the construction- and the operation-phase.

# 3 Review of the risk evaluation of the construction phase

The review concerns "Sudurøytunnelen Risikovurdering av aspekter knyttet til byggeperioden", (Sudurøy Tunnel Risk evaluation of aspects related to the construction phase) ver. 01, 2023-11-10, SINTEF.

The report on construction and project risk evaluation has been reviewed and commented. The present chapter summarises the findings, whereas the appendix (chapter 6) contains detailed comments to the abovementioned main report and its appendix.

Three meetings (which were held between SINTEF, a contractor, a consultant and the Client) have served as basis for SINTEF's construction risk evaluation. The risk evaluation is based on the structure of a risk matrix and is predominantly qualitative.

The input and information received at the meetings are useful and relevant. The project has been reviewed in the meetings, and no major problems have been found, which are not reasonably possible to solve during the process of design and the construction of the tunnel.

Albeit vaguely formulated, the identified safety measures are useful and relevant for the project.

The hazard with the largest risk potential is events leading to large inflows. This should be prevented as far as possible with detailed geological surveys. In addition, good evacuation routes need to be ensured, and finally, sufficient pumping capacity shall be available - both as a measure to ensure the escape route and to prevent costly damages.

In the present review, the basic information from the meetings is not challenged and new data have not been collected. Based on the available input and information, the reviewer might support the conclusion that it is "fullt oppnåelig å gjennomføre selv denne lange tunnelen med begrenset risiko som er innenfor det som er håndterbart for prosjektet" (fully achievable to undertake even this long tunnel with limited risk that is within what is manageable for the project).

## 3.1 Risk analysis

Regarded as a risk analysis (or a risk evaluation), the report has some deficiencies – and does not fully document the conclusion stated above.

The methodology of the risk analysis and risk evaluation is insufficiently described, and it does not specify any principle of risk acceptance principles.

Many of the so-called "risk elements" are poorly described and lack the reference to any basis or reference. In many cases, the risk elements are not proper events, which can be associated with probability and consequences but appears rather as the result of a brainstorming process with some topics which must be solved during design. Similarly, the risk reducing measures lack specific description, which is necessary not only for understanding the safety measure, but

also for specifying the measure in the project and for follow-up on its implementation.

The estimation of probability and consequence of some of the risk elements seem unrealistic, and in other cases it is generally difficult to associate the risk elements with a probability.

The effect of some of the risk reducing measures are overestimated to a level which is unrealistic to achieve.

The use of a risk matrix has not been helpful to the process and its participants. It seems that this framework has led to misrepresentation of some of the risk elements.

## 3.2 Future analyses

It is recommended to continue the project and in the next phases to carry out a detailed analysis of both construction and project risk going. Further detailing is required both for description of the events, which can cause personal damage, extra costs or delays and for the probability and consequences of these events. Relevant sensitivity studies can be included. The goal of the detailed analysis should be to establish specific measures to be implemented and followed up in the design and construction of the tunnel.

# 4 Review of the risk evaluation of the operational phase

Norconsult's risk evaluation "Risikovurdering, Forprosjekt Suðuroyartunnilin" contains an estimation of probabilities for fires and accidents as well as a study of the worst-case scenario of fire and possibilities of escaping a fire aided by ventilation and rescue services. The evaluations are well referenced and generally well explained.

However, as a risk evaluation it would be expected that the probabilities of events would be linked together with the consequence of these events for establishing the risks. Subsequently, it would be a part of a risk evaluation to hold the risk up against risk evaluation criteria and evaluate further risk reducing measures. Norconsult's risk evaluation only partially documented these steps.

The Norwegian regulations are mentioned throughout the report as if the tunnel was located in Norway. Norwegian regulations may be applied for the Suðuroy Tunnel, but in that case, it should be stated specifically based on a decision by the Client or the Government of the Faroe Islands.

## 4.1 Probabilities of events

The special characteristic of the Suðuroy Tunnel is mainly that it is very long. On the other hand, the traffic in the tunnel is rather low.

Instead of a full risk evaluation, a scenario analysis has been supplemented with an estimation of event probabilities for Suðuroy Tunnel and these estimations have been compared to similar results for a so-called "reference tunnel". A method developed by TØI has been used for the estimation of probabilities. The reviewer trusts that the calculations are performed correctly in accordance with the TØI model, however, the reviewer is very sceptic towards the realism of the results of this model.

According to the comparison with the reference tunnel, the probability of events in the Suðuroy Tunnel is significantly higher than in the reference tunnel. Based on this difference, the report concludes that further risk reducing measures must be introduced. The proposed measures are generally consequence reducing measures. It is not evaluated in the report whether the proposed risk reducing measures are sufficient. An evaluation of the sufficiency will only be possible, if the comparison relates to the risk and not only to the probability of events. Hence, the reviewer recommends extending the analysis to a full evaluation of the risk.

The difference in event probabilities between the Suðuroy Tunnel and the reference tunnel is largely a result of the TØI model, which predicts decreasing accident rates (accidents per vehicle-km) at higher traffic volumes (vehicles/day). The reviewer is not convinced in the result that the probability of accidents and fires in the Suðuroy Tunnel is significantly higher than in the reference tunnel.

In spite of the criticism towards the method of calculating the probabilities, the reviewer agrees that an evaluation of further risk reducing measures can be relevant for Suðuroy Tunnel.

## 4.2 Evacuation in case of fire

The core of the report is a scenario analysis of the worst-case fire located in the middle of the tunnel. The probabilities estimated previously in the report are for any fire and thereby not applicable for this worst-case scenario.

Based on conservative basic assumptions in a worst-case scenario, 3 vehicles are determined to be caught in a standstill behind the fire (in addition to the vehicle on fire). The reviewer finds this a reasonable estimate, if it is ensured that an efficient system for communicating the need to turn around is installed.

The fire model is based on a “medium” growth in the first 10 minutes followed by a “fast” growth. This may be a reasonable model but a fire scenario, with a fast growth from the start of the fire, should be investigated as a sensitivity study. Sensitivity studies can be included in a comprehensive study in the next project phase.

For passengers escaping on foot in the direction of the smoke spread, the safety is depending on a delicate balance of use of ventilation and rescue.

The report argues that the persons can escape on foot from the fire – supported by the ventilation system and the rescue services. The reviewer can well follow the philosophy in the approach; however, it may be possible to further fine-tune and improve the procedures for increasing the safety for these persons directly exposed to the fire. The fine-tuning may make further use of cameras and means of communication for optimal operation of the ventilation system in earlier phases of the fire. The communication to the users and decisions on operation of the ventilation system should be possible before the rescue services arrive at the scene of the fire. With suitable measures, safety seems validated.

The situation at the incident site may be problematic: If vehicles and persons are stationary or escaping on foot on both sides of the fire, no safe decisions are possible. For this reason, it is important with clear instructions in the initial minutes of the fire. The detailed procedures should be established based on comprehensive studies in the next project phase.

Assistance from the rescue services may be required if it is not possible to ensure that persons on one side of the fire have evacuated. This would be a sub-scenario of the stipulated worst-case scenario, but in any case, it will be relevant to ensure a sufficiently short access time for the rescue services.

## 4.3 Required safety measures

Some important safety measures are described in the system description and indicated in the assumptions. The reviewer agrees to these safety measures, a.o.:

- Lay-bys
- Lighting, emergency lighting and continuous evacuation lighting
- Ventilation
- A control centre connected to the tunnel 24 hours a day

- Communication systems: radio for rescue services and radio communication through DAB/FM to the vehicles, variable message signs in the tunnel (at the lay-bys) and outside
- Full video coverage and AID (automatic incident detection)

In addition to these measures, Norconsult recommends the following safety measures for improving traffic safety:

- Lighting and "halls" in the tunnel to reduce the feeling of monotony
- Enforced side stripes along and between the driving lanes.

Furthermore, Norconsult recommends safety measures for fire safety:

- Improved conditions for the rescue services
- Ventilation strategies and management: low speed in the initial phase with possibility to reverse the direction at an appropriate point of time
- Shortened distance between the turning bays
- Communication systems: variable message signs in the tunnel (at the lay-bys) and outside
- Traffic lights and barriers for closing the tunnel
- Possible restrictions to the traffic with heavy goods vehicles.

The recommendation of these measures is not validated directly by the results of the risk analyses, it is not clear from the report exactly how (and how much) the measures reduce the risk. The cost efficiency of the measures is not mentioned in the report. For safety measures with low costs, a qualitative recommendation may be acceptable, and the reviewer qualitatively second the recommendations. However, the measures concerning restrictions to HGV traffic need to be further investigated in the next phases of the project.

Some safety measures have been dismissed by Norconsult with little or no validation. Norconsult specifically does not recommend the measures below. The exclusion of these measures is not based on results of the risk analysis but rather on qualitative statements:

- PA (public address) system with loudspeakers is discouraged by Norconsult. However, to the opinion of the reviewer, this system may well be efficient in the tunnel: A PA system may be useful also for conveying message to tunnel users in different phases. For example, for making the vehicles in the tunnel to stop, turn around and drive out, or to advice on the evacuation on foot.
- Escape shelters are not recommended by Norconsult, but the report state that preparations should be done for shelters each 1000 m.
  To the opinion of the reviewer the risk reducing effect of escape shelters per 500 m and per 1000 m should be further investigated in the next phase of the project. The costs of various designs of these measures should also be estimated.

The following changes are not mentioned as possible safety measures in Norconsult's report, but they might be dealt with in the next phase:

- The cross section of Suðuroy Tunnel is designed as T9.5 (i.e. with a width of 9.5 m at the base of the tunnel). A wider tunnel cross section of T10.5 could have advantages with respect to ventilation (stratifica-

tion of smoke) and give better possibilities for turning around at locations outside the lay-bys. The costs and risk reducing effect can be further investigated in the next project phase.

A parallel escape tunnel would be required for establishing proper emergency exits. This solution may well be way too expensive. However, for a documentation of the reason why this solution has not been selected, some rough indications of effect and costs should be established.

# 5 Review of the risk evaluation of longitudinal ventilation

The criticism stated in Swecos report "*Risikovurdering av langsgående ventilasjon i Sudurøytunnelen*" towards the design of the Suðuroy Tunnel could be extended to a large majority of tunnels with two-way traffic. The considerations in the report do not take into account probabilities and thereby do not constitute a risk analysis or a risk-based approach. The calculations made by Sweco are rather *scenario analyses*, which use a combination of very conservative assumptions with regards to traffic, location of fire, severity of fire, actions to close the tunnel and behaviour of the tunnel users. With the layers of conservatism, the comments towards the results of the calculations made by Norconsult seem to be too strong and should at least be moderated.

## 5.1 Basic assumptions

It is of course a goal to design the tunnel so that tunnel users can escape serious events like fire in the tunnel.

The "self-rescue principle" is mentioned in Sweco's report. In the EU Directive 2004/54/EC point (11) it is indicated:"*(11) Safety measures should enable people involved in incidents to rescue themselves, allow road users to act immediately so as to prevent more serious consequences, ensure that emergency services can act effectively and protect the environment as well as limit material damage*." This text does not require that all tunnel users shall be able to walk out of the tunnel in smoke-free conditions. A concept of escape by car or assisted by rescue services and supported by safety measures, ventilation and similar, will respect the requirement in Directive. (It may be noted that the EU Directive is addressing the trans-European network in EU. Hence, Suðuroy Tunnel is not formally subjected to the requirements in the directive).

Suðuroy Tunnel does not - in respect to escape possibilities - deviate significantly from the other tunnels in the Faroes Islands and does not deviate from hundreds of tunnels with two-way traffic in Norway (and Iceland). The only special characteristics worth to mention is the long length of the tunnel (one of the longest of its kind); on the other hand, the traffic is very low.

## 5.2 Scenario analysis

The report by Sweco does not consider probabilities, and the risk to the tunnel users is thereby not estimated. Without an estimated risk, a risk evaluation cannot be performed. In spite of this, the so-called "zero vision" is referred to citing the Norwegian Transport Plan. However, the zero vision cannot be taken as a fundamental acceptance limit of zero risk; in any activity some residual risk will remain. The zero vision is rather a process toward continuous improvement. In a risk-based approach risk evaluation criteria could be established to ensure that the risk is reduced to a suitably low level.

The alarming numbers in the results of Sweco's calculations, are not only based on an extreme operating scenario (which is not foreseen for the Suðuroy tunnel)

and an extremely severe fire development, but also other extreme assumptions. Thereby the results seem rather unrealistic or at least extreme worst cases.

The major special characteristic of Suðuroy Tunnel is its long length. It should have been illustrated how much the length influences the risk level.

## 5.3 Safety measures

It is stated in Sweco's report that the tunnel must be designed and equipped with technical installations, which can support and facilitate the tunnel users in case of emergency. This statement is fully supported by the reviewer.

The scenario analyses carried out by Sweco do not assess nor discuss which technical installations and equipment are efficiently supporting the tunnel users. However, some design variations are mentioned, for example:

- The cross section of the tunnel with width 9.5 m or 10.5 m. (The effect of this variation is not demonstrated, but Sweco recommends 10.5 m.)
- Control centre, it is questioned in the report how and where the tunnel is controlled.
- Rescue response centres. It is stated in the report, that the duration for the arrival of the rescue services may be too long. A measure may be to establish response centres at or near the tunnel portals.
- PA (loudspeaker) equipment is briefly mentioned.
- It is mentioned by Sweco that one of the most dangerous scenarios is fire in an HGV with dangerous goods. A safety measure against this scenario could be to restrict traffic of dangerous goods to times of the day with little traffic – or restrict the traffic in the opposite direction (which will make it possible to ventilate in the direction of the DG transport and create a much safer situation).
- Shelters as safe havens are mentioned as a safety measure. This could be a possibility, which recently has been applied in some tunnels in Norway and in Iceland.
- An emergency escape tunnel is also mentioned. To the judgement of the reviewer, this safety measure is unusual and expensive and has not been applied in similar tunnels in the Nordic countries.

The above safety measures ought to be further investigated. The investigation should take the starting point from a risk-based approach, where the risk reducing effect of the measures is held up against the cost of the measures.

# APPENDICES

# 6 Appendix: Detailed comments to the risk evaluation of the construction phase

The present appendix contains the detailed comments to: "Sudurøytunnelen Risikovurdering av aspekter knyttet til byggeperioden", (Sudurøy Tunnel Risk evaluation of aspects related to the construction phase) ver. 01, SINTEF. 2023.11.10.

Parts of the main report are quoted (in the original language of the report) and commented. For some more general topic, a separate section is included. For the appendix, the most important risk contributors are discussed individually.

## 6.1 Re: 1 Bakgrunn, innledning og hensikt

| Quote | Comment |
|---|---|
| Denne risikovurderingen er basert på erfaringer som er samlet basert på gjennomføringen av prosjekter på Færøyene som Vagatunnilin, Nordoya-tunnilin samt Eysturøy- og Sandoyar-tunnilin. | It is great that the construction / project risk can be based on information from persons with firsthand experience from tunnel construction in the Faroe Islands. However, by experience from one company (plus consultant and client) it cannot be excluded that the information is biased or subjective. |
| Foreliggende notat presenterer risikobildet for SuTu gjennom først en vurdering av ulike elementer under bygging som påvirker risikobildet, forventet sannsynlighet og konsekvens er vurdert ved å benytte et definert oppsett for dette. | The defined setup for the risk evaluation is discussed below. |

## 6.2 Re: 2 Kort beskrivelse av elementene som er blitt vurdert

| Quote | Comment |
|---|---|
| …generelle risiko-elementer og den andre er spesielle risiko-elementer. | It is unclear how these two types of risk elements are defined. |
| Refereansegruppen leverte gode innspill både til bygging og utforming av prosjektet, men i foreliggende notat har SINTEF valgt å se bort fra disse. | Why have these good inputs and ideas been disregarded in the report? Where is this information documented? |
| eventuelt være nødt til å gjøre signifikante kostnadskutt, kutt som vil medføre at det blir store avvik i forhold til normen | It should be clarified that the present analysis is only valid for the project as it is defined at the time of the analysis. If the project is changed, it will require an update of the analysis in order to evaluate the change. |
| | It could in general be relevant to state |

| | |
|---|---|
| | the scope of the analysis: It is done in 2023 for the purpose of the approval of the project (presumably). When more details are available during detailed design and construction, an update may be relevant / required. |
| Kategorier (geologi, utforming og design, organisasjon og entrepriseformat), // Det er vurdert om lag 30 ulike elementer innenfor generelle risikoer, og snaut 20 ulike elementer innenfor spesielle risikoer. | *(The method is discussed below, and the most important risk elements from the appendix are reviewed.)* |
| Så er det på empirisk basis gjort en vurdering av hvert slikt risikoelement | |
| der SINTEF har gitt risikoelementet en kvalitativ og kvantitativ sannsynlig | It would be relevant to validate these assessments with the group of experts |
| Hvert risikoelement er så gitt en konsekvens kvantitativt. | As above.<br>This procedure is not fully quantitative. I would propose to characterise it as semi-quantitative – or similar. |
| Som utgangspunkt for hele vurderingen ligger…<br>Med utgangspunkt i at det er begrenset med informasjon … | It would be relevant to specify exact what information was available for the analysis (drawings, geological reports etc.) both for the author of the report and for the participants in the identification process. |
| Figur 1. Konsept for evaluering av risikoelementer | The defined setup for the risk evaluation is discussed below. |
| | The matrix should be based on the currency used in the Faroe Island |
| | The matrix seems to indicate that some events can have a probability of > 1, which is mathematically impossible. Possibly “frequency” would be a better word. |
| | The interpretation of the colours red, orange, yellow, green is not explained. |

## 6.3 Method for the risk evaluation

The method (or concept) for risk evaluation is illustrated in Figur 1 of SINTEF’s report. A validation for the selected risk evaluation model is not given and the background and use of the risk matrix is also not described. Obviously, the red area represents higher risk contributions, and the green area represent very modest risk contributions. The diagram appears to have logarithmic scale on both axes (log10 on the second axis and on the first axis. Log 10 on costs and delays on the second axis but apparently log5 for the fatalities). The division between each colour represent a certain risk level (except for the fatalities, where this skewed because of the mix of the two types of logarithmic scales).

A common reference to this type of analyses would be the ITA (International Tunnelling Association) Guideline [1].

In the following some key words are given to comment on the apparent methodology. (Some of the comments may be valid for the ITA Guideline as well).

A risk matrix may be an efficient way to estimate the risk contributions of the identified hazards, and with the logarithmical division in categories, a rough risk estimation may be possible – also on a semi qualitative basis.

The method has some limitations, and it should be noted that the "elements" which are evaluated are risk contributions from identified hazards. This makes the method sensitive to the definition and formulation of the hazard. [An example: If fatalities during the construction period would be considered as one hazard and characterised as very frequent (svært ofte), with a probability of 1 (1 event per project) and a consequence of 1 fatality, the risk contribution will end in the red area. However, if the hazard would be defined per contractor, per process etc, it may be divided into perhaps 100 or 1000 sub-hazards, which would give a more favourable characterisation of these risk contributions (in the yellow area.). Hence, the method is to a high degree context dependent, and the absolute evaluation of acceptability is difficult based on the matrix.

On the other hand, the risk contributions can of course illustrate which risk contributions are clearly negligible and where the largest contributors to the risk are expected. For the largest contributors, the conclusion may rather be that further studies of this hazard are relevant. It is not easy from these evaluations to conclude what is acceptable or not acceptable.

Another application of the results could be to evaluate whether measures can reasonably be taken to reduce the risk contribution of the individual hazard. Such evaluations can be made both on a detailed subdivision of hazards and on more aggregated collective risk contributions. [In the example above, the results may indicate that some measures can be taken for reducing the fatality collective risk of 1 fatality, but it will also be possible to evaluate the individual sub-divided hazards, say fatalities by dropped objects. Both considerations can be based on the so-called ALARP principle]

*Equivalence*

With the difference types of consequence on the first axis a certain equivalence is claimed between the types of consequence.

The equivalence of 1-4 fatalities (avg. 2) with in avg. 30 MNOK increased costs indicates an equivalence for each 1 fatality with 15 MNOK or 9.5 MDKK.

The equivalence of 5-20 fatalities (avg. 10) with in avg. 300 MNOK increased costs indicates an equivalence for each 1 fatality with 30 MNOK or 19 MDKK.

This is significantly less than specified in Transportøkonomiske enhedspriser "Transportøkonomiske enhedspriser - til brug for samfundsøkonomiske analyser på transportområdet"[2] (stated in Table 2 for the year 2022).

[1] ITA/AITES Accredited Material, Guidelines for tunnelling risk management: International Tunnelling Association, Working Group No. 2, by S. D. Eskesen, P. Tengborg, J. Kamp-mann, T. H. Veicherts. Tunnelling and Underground Space Technology 19 (2004) 217–237

[2] [2] TERESA / Transportøkonomiske Enhedspriser" Specified by Danish Transportministeriet .https://www.man.dtu.dk/myndighedsbetjening/teresa-og-transportoekonomiske-enhedspriser

The Norwegian Handbook HB V712 indicates a similar figure as 32.2 MNOK for the year 2020.

| Personrelaterede uheldsomk. for 2022 | | i 2022 priser |
|---|---|---|
| Dræbt | DKK | 39,717,831 |

*Table 1 Transport economic unit prices for 2022 (in 2022 price level DKK). Accidents costs per person killed. (TERESA, Danish Transport Ministry)*

*Consistence*

If the starting point is taken in the division on the first axis for additional costs, a consistent division of personal damage would be

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| | less than 1 slight injury | 1 serious injury or 2-8 slight injuries | 1 fatality or 2-10 serious injuries | 2-17 fatalities | More than 17 fatalities |
| Avg. (fat) | - | - | 0.5 | 5 | 50 |
| Avg. (Ser. Inj.) | - | 0.3 | 3 | - | - |
| Avg. (Lt. Inj.) | 0.25 | 2.5 | - | - | - |

*Table 2 Modified division of the person-related consequences with consistence related to the log10 scale and the transport economic unit prices.*

For delays, it may seem unreasonable that an avg. 3-month delay for a construction time expected to be 8 years +/- 1-2 years is equivalent with in avg. 10 fatalities. With the modification proposed above, 3-month delay would be equivalent with in avg. 3 serious injuries.

However, the consistent division of the consequence of delay need to be determined based on an evaluation of the actual disadvantage of a delay.

## 6.4 Risk level

With the consistent division of the matrix the limits between the four colours correspond to a certain risk level (monetarised consequences / expected value in MDKK).

| | |
|---|---|
| Limit between green and yellow: | 2000 DKK/project |
| Limit between yellow and orange: | 0.19 MDKK/project |
| Limit between orange and red: | 19 MDKK/project |

Based on this, it may be concluded that any risk contribution in the green area is negligible and this “risk element” does not need any further consideration

For individual risk contributions in the yellow area, the risk reducing measures need to be very inexpensive to be cost efficient. It should be noted if the “risk elements” are correlated with other “risk elements”.

## 6.5 Re: 3 Hva forteller risikovurderingen oss?

| Quote | Comment |
|---|---|
| Risikovurderingen forteller først og fremst at det er fullt mulig å forbedre risikobildet for de aller fleste risikoelementene som SINTEF har vurdert. | That the risk picture can be improved by introduction of risk reducing measures is not surprising – and perhaps even self-evident. The relevant issue to clarify is whether the improvement must be done for a suitable construction process and an ac- |

| | |
|---|---|
| | ceptable construction- and project risk. |
| det faktisk hele 13 elementer som er funnet å være i den høyeste risikoklassen | It could be useful to discuss the background for the high-risk contribution of these elements.<br>(Is the evaluation for example based on scarce information – and with results of further investigation the risk may be reduced. Or are the risk contribution considered to be genuinely high (see also comments to the method concerning acceptability)) |
| … det ikke er noen som er røde som er knyttet til entrepriseformen | Ok, might be true.<br>What if a contractor with less experience in Faroese conditions would win the contract? |
| Situasjonen ser imidlertid noe annerledes med tanke på det rent organisatoriske og utformingen og de prosjekterte løsningene som er blitt fremlagt for prosjektet. Det skulle bety at man i prosjektet derfor må være omhyggelig med å velge gode løsninger og etablere en robust prosjektorganisasjon | It is evidently always a good idea to choose "good solutions" and establish a "robust project organisation".<br>The proposals from the risk analysis could be more specific otherwise they may have no impact. |
| Det vil kreve at man etablerer prosjektkontor både på Sudurøy og Sandøy,… | Yes, it may be a good idea to have site offices on both shores. However, the project should have one project management covering both site offices. |
| …nøye med beskrivelse og oppfølging av prosedyrer, tekniske beskrivelser, arbeidsbeskrivelser, sikre rett utstyrsvalg… | These are evidently good suggestions. However, this conclusion can be made also without a risk analysis.<br>Suggestions or preconditions as a result of the risk analysis should be formulated more specifically / concretely. |
| Ved hjelp av god jobbing med preventive tiltak så er SINTEF's oppfatning at det meste innenfor kontrakt kan håndteres og lede til en betydelig risikoreduksjon. | Ok, these preventive measures ought to be mentioned.<br>(Btw. Is this the opinion of SINTEF or the result of the risk analysis?- this should be clarified). |
| …man er grundig med utarbeidelse av kontraktstekster, tidsplaner og milepæler…klare og entydige tekster, god forståelse, transparent bilde av prosjektet med tanke på mengder, geologi og byggetid… | Nobody will contradict that a well-prepared project is advantageous for the success of the project. On the other hand, no projects will start with the goal of a sketchy planning.<br>If the risk analysis shall have any impact the proposals should be more concrete. |

## 6.6 Re: 4. Konklusjoner

| | |
|---|---|
| Den kvalitative risikoanalysen viser at det er et knippe risikoelementer som er røde og har en høy grad av risiko, | This seems rather alarming. The text in the report itself does not explain for the reader, what these critical risk elements are. |
| …men gjennom gode og vel funderte kontraktstekster, anbudsdokumenter, prosedyrer og oppfølging under bygging er det fullt oppnåelig å gjennomføre selv denne lange tunnelen med begrenset risiko som er innenfor det som er håndterbart for prosjektet. | As mentioned above, it should be stated more clearly what these measures are, and how these deviate from normal practice in tunnel projects. |
| | In order to give the reader of the analysis confidence in the suitability of the project and the measures taken, the hazards, risks and the measures against these risks should be mentioned more specifically. It should appear from the analysis than "with these specific measures the construction risk / project risk is tolerable or acceptable".<br><br>This has not been demonstrated in the present analysis. |

## 6.7 Appendix "Vedlegg 1. Risikomatrise"

39 "risk elements" have been identified.

Before risk reduction:

- 11 risk contributions are in the red area
- 18 risk contributions are in the orange area
- 10 risk contributions are in the yellow area
- 0 risk contributions are in the green area.

The majority (99.6%) of the risk contributions originate from the risk elements in the red area (see below).

After risk reduction

- 0 risk contributions are in the red area
- 6 risk contributions are in the orange area
- 14 risk contributions are in the yellow area
- 19 risk contributions are in the green area.

The majority of the risk contributions after risk reduction originate from the risk elements in the orange area.

The 11 risk contributions, initially in the red area, are specified below:

| **Risk element** | Frequency / project | Quantified consequence [MDKK] | Risk contribution [MDKK] |
|---|---|---|---|
| **Geologi** | | | |
| Kritisk lav overdekning, feil i grunnlaget, under-søkelsene misset, innlekkasje av vann og utfall på stuff | 0.03 | 2000 | 60 |
| Generelt mer oppsprukket, vannførende og dårlig stabilitet | 3 | 20 | 60 |
| **Utforming og design** | | | |
| Lange stufflengder – opp mot 10-14 km – sjeldent for B&S | 3 | 200 | 600 |
| To lavbrekk, mellom ett høybrekk vil fungere som vannlås | 3 | 2000 | 6000 |
| Ventilasjon – lang vei for transport av luft ut fra stuff – opphoping av avgasser i tunnelen | 3 | 200 | 600 |
| **Organisasjon:** | | | |
| Mangelfull geologisk oppfølging, kapasitet og faglig – manglende faglig kapasitet | 0.3 | 200 | 60 |
| Mangelfulle prosedyrer og aksjonslister | 0.3 | 200 | 60 |
| Dårlig kommunikasjon BH -Entreprenør | 3 | 200 | 600 |
| Mye arbeid og personell mange steder i tunnel, skader på personell og brann | 3 | 20 | 60 |
| Massetransport og konflikt med kjøretøy og miljø | 3 | 2000 | 6000 |
| Utstyr som svikter/feiler i kritiske øyeblikk | 0.3 | 2000 | 600 |
| ***Total** risk contribution from 11 risk elements in red area* | | | *14700* |
| ***Total** risk contribution from 18 risk elements in orange area* | | | *59.4* |
| ***Total** risk contribution from 10 risk elements in yellow (and green) areas* | | | *0.44* |
| ***Total risk contribution from 39 risk elements*** | | | *14759.84* |

The individual risk elements are discussed below with the largest contributors first. The original text is translated into English. The first two risk elements contribute 81%, the first six risk elements contribute 98% of the total risk.

1) Utforming og design: To lavbrekk, mellom ett høybrekk vil fungere som vannlås" (Design: Two low points, between one high point will act as a water trap) which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 2000 MDKK or 3 years delay or 17 (20) fatalities.

   The observation is correct; however, the risk element is not an event with a frequency, the water will continuously leak into the tunnel and be collected in the low point. It seems to be a normal design issue that the tunnel construction should have pumps in a pump sump at low points. (For the construction as well as for the completed tunnel).

   The risk reducing measure is stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Etablere midlertidig pumpesump i lavbrekk – sikre utpumping ved uønskede store innlekkasjer. Beredskapsmagasin. Strengt krav til innlekkasje, STU hadde i snitt ca. 12 liter per min per 100 m | Establish a temporary pump sump in the low break - ensure pumping out in the event of unwanted large inflows. Emergency magazine. Strict requirements for leakage, STU had on average approx. 12 liter per minute per 100 m |

The event to consider may be the large inflow. This event may be dangerous to the construction staff in the tunnel and may result in delays and extra costs. The probability reducing measure against this is stated as detailed geological surveys and probing during construction. These measures are mentioned for other risk elements. For reducing the risk of construction staff being trapped, good evacuation routes need to be ensured: Sufficient pumping capacity serves both as a measure to ensure the escape route and to prevent costly damages in the tunnel.

The design basis for the pumps is important and reference to other tunnels are important. Expert opinion from geologists should be taken into account as well.

After the safety measure, the event is estimated as "rare" (0.03 per project). Hence, the measure reduces the frequency with a factor 1000. Presumably this is an estimate of the cases where the inflow exceeds the pumping capacity, and the low point is being flooded: i.e. 0.1% of large inflows result in flooding of the low point. This may seem reasonable but depends on information from the geologist and on the design of the pumps.

The measure is also stated to reduce the consequences which may be true because the pumping capacity may give more time for evacuation and possibly result in less damages, even in the cases where the pumping capacity is exceeded. The measure states to reduce the consequences from average quantified 2000 MDKK or 50 fatalities to 200 MDKK or 10 fatalities.

The risk element is not fully described and information on the basis for the estimated frequency and consequences as well as the effect of the measure are not documented. However, the measure of a well-designed pump sump is reasonable.

2) "Organisasjon: Massetransport og konflikt med kjøretøy og miljø" (Organisation: Mass transport and conflict with vehicles and the environment) which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 2000 MDKK or 3 years delay or 17 (20) fatalities.

Evidently, mass transport is a challenge, but no details are given to this extremely high-risk contribution, and the assumptions are also not discussed. It is not clear what the event is, and it may seem as if this risk has been overstated.

The risk reducing measure is stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Det vil være opp mot 10 stk semitrailere i gang på hver side når transporten er på sitt lengste, man må sørge for best mulig utnyttelse og effekt, fast dekke eksempelvis for uttransport og massetransport som ikke er til hinder for fremdrif- | There will be up to 10 semi-trailers running on each side when the transport is at its longest, one must ensure the best possible utilization and effect, fixed cover for example for outbound transport and mass transport that |

| | |
|---|---|
| ten. Sikkerhet som i punktene over. | does not hinder progress. Safety as in the points above. |

After the measure, the frequency is reduced to "often" (0.3 times per project) and the consequence to "3" corresponding to 20 MDKK. This results in a risk contribution of 6 MDKK, and the risk reduction corresponds to 5940 MDKK, which is an enormous effect of establishing an intermediate storage in the tunnel.

To the opinion of the reviewer (NPH), the initial risk is exaggerated and also the effect of the intermediate storage is overestimated. However, the risk element seems to be more an issue of planning of the construction well, and not a risk as such. With the construction process planned by a skilled contractor, the effect of the difficulties of mass transport is included in the construction price estimate.

3) "Utforming og design Lange stufflengder – opp mot 10-14 km – sjeldent for B&S", (Design. Long tunnel construction lengths - up to 10-14 km - rare for B&S) which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 200 MDKK (or 3-month delay or 5 fatalities).

However, it is not clear in the description why and how this is a risk element, what is occurring very frequently and what is the consequence of these events. The point appears to be a matter of design more than a risk element.

The risk reducing measure is stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Grundig planlegging – logistikk – prosedyrer for kjente og ukjente situasjoner. Håndtering av vann, fordrøyning og pumpekapasitet. Det er ikke toleranse for avvik på lekkasjekrav | Thorough planning – logistics – procedures for known and unknown situations. Handling of water, drainage and pump capacity. There is no tolerance for deviations from leakage requirements |

The risk reducing measure is vaguely formulated and is difficult to recognise as an additional safety measure. Thorough planning is good for any project, and presumably this was also the initial intention – it is not clear what is the additional risk reducing measure.

It is claimed that those safety measures reduce the frequency with a factor 100, which is not plausible, and not credible. Furthermore, the consequences are reduced with a factor 10.

To the opinion of the reviewer, this risk element and the associated safety measures are not studied and/or described in sufficient detail.

4) "Utforming og design Ventilasjon – lang vei for transport av luft ut fra stuff – opphoping av avgasser i tunnelen" (Design: Ventilation – long way for transporting air out of the tunnel construction – accumulation of exhaust gases in the tunnel), which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 200 MDKK (or 3-month delay or 5 fatalities).

However, it is not clear in the description why and how this is a risk element, what is occurring very frequently and what is the consequence of these events. The point appears to be a matter of design more than a risk element.

The risk reducing measure is stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Redusere dieselbruk på biler, sjekke sprengstoff som avgir mindre gasser, elbiler, ellaster ++<br>Krever stor ventilasjonskapasitet eks.vis 2 stk 2,5 m dia ventilasjonsduker – plassbehov kan få betydning for tunneltverrsnitt | Reduce diesel use on cars, check explosives that emit less gases, electric cars, electric chargers ++<br>Requires large ventilation capacity, e.g. 2 units 2.5 m dia ventilation cloths - space requirements can have an impact on the tunnel cross-section |

The stated measures seem reasonable. If it is expensive to design the ventilation for the exhaust, measures should be taken to reduce the exhaust if possible. The measures may imply additional costs as well, but the right balance should be found in the design of the tunnel, the ventilation and the requirements for the equipment and explosives.

As result of the risk reducing measures, the frequency has been reduced to 0.3 times per project, with the comment "men så lenge det er B&S så blir det uansett sprenggasser som må håndteres" (but as long as it is B&S, there will be explosive gases that must be handled anyway), and the consequences are reduced from additional costs 200 MDKK (or 3 month delay or 5 fatalities) to additional costs 20 MDKK (or 10 days delay or 0-1 fatality). The comment is correct, but it is still difficult to see this as an event with a frequency.

This risk element includes reasonable design considerations; however, the design of the construction procedures should ensure that the probability of events with fatalities and significant costs should have a probability of less than 30% per project.

5) "Organisasjon: Dårlig kommunikasjon BH -Entreprenør" (Organization: Poor communication Builder - Contractor), which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 200 MDKK (or 3-month delay or 5 fatalities).

The risk element appears rather to be a cause of events than an event in itself: poor communication may in some cases lead to situations which after a chain of circumstances results in additional costs or accidents. However, it is not clear from the description of the risk elements what these situations are, and how they can lead to an average of 3 events - each resulting in significant consequences.

The risk reducing measure is stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Etablere og oppnå konsensus på prosedyrer og bygge tillit og respekt for hverandre på anlegget. | Establish and achieve consensus on procedures and build trust and respect for each other at the facility. |

| | |
|---|---|
| Arrangere møter/faglig tema for å bedre forstå hverandre og samarbeide/løse utfordringer i nåtid. Ha møter med fasilitator om påkrevet.<br>Etablere Referansegruppe som har fungert godt på alle 4 undersjøiske tunneler på FO (men opererer i ettertid) | Arrange meetings/professional topics to better understand each other and collaborate/solve challenges immediately. Have meetings with the facilitator if required.<br>Establish a reference group that has worked well on all 4 submarine tunnels in the Faroe Islands (but operates afterwards) |

As result of the risk reducing measures, the frequency has been reduced to extremely rare 0.0003 times per project (3 times out of 10000 similar projects), and the consequences reduced with a factor 10 to an additional cost of 20 MDKK.

The goals and recommendations are very good and can be supported by all parties in the building process. Whether this measure can reduce the frequency of events as result of poor communication with a factor 10000, and similarly the consequences with a factor 10, is doubtful. Even with the best intentions, misunderstandings and poor communications can occur, and no projects start with the baseline of "not wanting to build trust etc."

The risk element is not sufficiently described in order to evaluate whether the initial risk contribution is reasonable, the safety measures are very good and should be specified further. The described risk reducing measure cannot possibly reduce the risk contribution with a factor 100000.

6) "Organisasjon: Utstyr som svikter/feiler i kritiske øyeblikk" (Organisation: Equipment that fails at critical moments), which is estimated to occur in average 0.3 times per project, each time with a consequence of additional costs 2000 MDKK (or 3 years delay or 17 (20) fatalities).

It is not stated what type of equipment can result in such severe consequences, (no references to equipment in the appendix either) and to the opinion of the reviewer the consequences seem to be overestimated. On the other hand, it may be much more often that equipment fails in critical situations. This depends of course on the definition of "critical situations" and the type of equipment.

The risk reducing measure is stated as

| Quote in Norwegian | Quote in English |
|---|---|
| Funksjonstesting og kontroll av utstyr regelmessig | Functional testing and checking of equipment regularly |

The description of the safety measure is rather generic and belongs to any operation of equipment. It implies that the initial risk contribution is based on the assumption that the equipment is not tested and checked regularly. With this safety measure, the probability is reduced to very rarely 0.003 per project, which seems extremely low. There is always a residual probability for failure of equipment also when it has been tested. The actual project will include hundreds or thousand pieces of

equipment which are operated in up to 8 years. Even for high safety Integrity Levels (SIL), say SIL 3, which is used for example in railways, the probability of failure per hour is stated to be 10-7 per hour. With, say, 2000 – 3000 operation hours per year in 8 years, the probability of failure would be 0.002 per piece of equipment. With hundreds or thousand pieces of equipment, the aggregated frequency of failure of equipment will be much higher. The consequence, on the other hand will not be very severe except for some exception. But in order to explore this, it is necessary to go in much more detail.

With the safety measure of check and testing, the stated consequence is also reduced from the quantified consequence of in average 2000 MDKK to 3 MDKK. This is a very significant reduction, and it is not clear how this is possible. The check and test of the equipment are typically probability reducing measures. The consequence of a failure would be expected to be the same. But as commented above, the initial consequence seems to be overestimated.

To the opinion of the reviewer (NPH), the initial consequence is overestimated, and the frequency of the events is underestimated. The safety measure is very generic and belongs to normal practice. It doesn't seem plausible that the frequency can be reduced to the level indicated after safety measures. In totality the risk contribution before measures may be overestimated and the risk contribution after measures seems to be significantly underestimated. Studies in more detail seems to be required.

7) "Geologi: Kritisk lav overdekning, feil i grunnlaget, undersøkelsene misset, innlekkasje av vann og utfall på stuff" (Critically low cover, errors in the basis, the surveys missed, water leakage and ground failure in the tunnel contruction). The frequency is estimated to be in average 0.03 per project, which is rather low: only 3 out of 100 similar projects will experience this event. On the other hand, the consequences are severe and result in consequences quantified to in average 2000 MDKK/project.

Inaccuracies and mistakes in the basic information are of course severe events. It could have been relevant to specify the critical situation in more detail, but if the mistakes in the basis lead to a situation, where the tunnel is flooded and the tunnel construction will have to be given up and a new alignment of the tunnel needs to be found, then this is absolutely catastrophic. Such events are hardly heard of, and the estimation of the frequency as rare may be true.

The safety measures are stated as

| Quote in Norwegian | Quote in English |
|---|---|
| Bore oppadrettede sonderborhull Seismikk (utført i 22 of 23) vil før tunneldriving gi bedre grunnlag for beslutning av minste overdekning. Foreløpig seismikk viser lite løsmasser i fjorden – dvs. kvali- | Drill upward probe boreholes Seismic (carried out in 22 of 23) before tunnelling will provide a better basis for deciding on the minimum cover. Preliminary seismic shows little loose mass in |

| | |
|---|---|
| tetsmessige gode resultater | the fjord - i.e. good results in terms of quality |
| Gode erfaringer med tidligere prosjekter der man har hatt som minste overdekning 32 meter. | Good experience with previous projects where the minimum roof coverage was 32 metres. |
| Beredskap også med nøkkelpersoner som raskt kan bistå. | Preparedness also with key people who can quickly assist. |

The text is not completely clear, but the first point may qualify as a safety measure. The second and third point doesn't seem to be additional risk reducing measures. The third point is difficult to understand.

As result of the safety measure the frequency is reduced to extremely rare, i.e. 0.0003 per project – 3 cases out of 10000 similar projects. It is not evident from the description that the safety measure boreholes and seismic (investigations) reduce the probability of this event to practically nothing. The described hazard was "mistakes and errors", which could also be found in the investigations with boreholes and seismic. Furthermore, the risk reducing measure apparently also reduce the consequences dramatically from a quantified consequence of 2000 MDKK to 0.2 MDKK. It is difficult to understand that further investigations can reduce the consequences of the event. The investigations are typically probability reducing measures, and here it is claimed that they not only reduce the frequency of the event by a factor 100 but also the consequences by a factor 10000.

The risk element is poorly described, and it is difficult to accept the stated risk contributions.

8) "Geologi. Generelt mer oppsprukket, vannførende og dårlig stabilitet" (Geology: Generally, more cracked, water-bearing and poor stability) which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 20 MDKK.

It may be accepted that this type of event can occur rather frequently, and that it can lead to some consequences.

The risk reducing measures are stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Planlegge for tiltak, ha utstyr på anlegget, være beredt alltid, har god erfaring med dette på FO. Prosedyrer og responsplaner tilgjengelig.<br>Beredskap også med nøkkelpersoner som raskt kan bistå. | Plan for measures, have equipment at the facility, always be prepared, have good experience with this at FO. Procedures and response plans available.<br>Preparedness also with key people who can quickly assist. |

Plan for measures and preparedness plans are recommendable, but they are not specified to any degree detail here. It is not clear if this will have any impact. Good experience is not a safety measure but rather an assumption or a precondition.

Based on the stated safety measures, the frequency is reduced to extremely rare (0.0003/project). It is not plausible that a plan for unspeci-

fied measure and preparedness will reduce the frequency with a factor 100000. For illustration it can be mentioned that a safety measure, which is reducing the probability with a factor of 10, is regarded very effective.

The estimated risk after measures seems to be underestimated, and the risk element and the safety measures are insufficiently described.

9) "Organisasjon: Mangelfull geologisk oppfølging, kapasitet og faglig – manglende faglig kapasitet" (Organisation: Insufficient geological follow-up, capacity and professional – lack of professional capacity), which is estimated to occur in average 0.3 times per project, each time with a consequence of additional costs 200 MDKK.

The risk element appears rather to be a cause of events than an event in itself: it is not clear from the description of the risk elements what these events are.

The risk reducing measures are stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Etablere/leie inn flere personer med ing.-geologisk bakgrunn, fylle opp entreprenørens skiftplan, trene opp og lære av hverandre. Må ha kapasitet og ressurser på begge sider.<br>En tilleggsutfordring er at det er tidsmessige en lang reise fra den ene stuffen til den andre, derfor må det være tilstrekkelig bemanning på begge sider, samtidig gir én stuff for lite oppfølging til at det kan være 100% stilling. | Establish/hire several people with an engineering-geological background, fill up the contractor's shift schedule, train and learn from each other. Must have capacity and resources on both sides.<br>An additional challenge is that there is a long journey from one construction site to the other, therefore there must be sufficient staffing on both sides, at the same time one site office provides too little follow-up for it to be 100% position. |

As result of the risk reducing measures, the frequency has been reduced to very rare 0.003 times per project, and the consequences reduced with a factor 10 to an additional cost of 20 MDKK.

The goals and recommendations are very good, it can of course be supported that the construction site offices shall be sufficiently staffed. Whether this measure can reduce the frequency of events as result of poor communication with a factor 100, and similarly the consequences with a factor 10, is unclear.

If it is important for preventing severe events to have a geologist on both sides, then this position should be filled, also if the workload is expected to be less than 100%. Compared with the expected risk contribution of this risk element (60 MDKK), the cost of employment of one geologist may be modest.

10) "Organisasjon: Mangelfulle prosedyrer og aksjonslister" (Organisation: Inadequate procedures and action lists), which is estimated to occur in

average 0.3 times per project, each time with a consequence of additional costs 200 MDKK.

The risk reducing measures are stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Gjennomgå med alle parter i prosjektet i fellesskap behov for prosedyrer og hvilke. BH må styre alle aktiviteter som bergsikring og injeksjon og ta ansvar for dette fra første salve. | Review the need for procedures and which ones with all parties in the project jointly. The builder must manage all activities such as rock protection and injection and take responsibility for this from the first blast. |

As result of the risk reducing measures, the frequency has been reduced with a factor 1000 to extremely rare 0.0003 times per project, and the consequences reduced with a factor 100 to an additional cost of 2 MDKK.

The similar conclusion stated for communication is valid also for this risk element:

The goals and recommendations are very good and can be supported by all parties in the building process. Whether this measure can reduce the frequency of events as result of poor communication with a factor 1000, and at the same time the consequences with a factor 100, is doubtful.

The risk element is not sufficiently described in order to evaluate whether the initial risk contribution is reasonable, the safety measures are very good and should be specified further. The described risk reducing measure cannot possibly reduce the risk contribution with a factor 100000.

11) "Organisasjon: Mye arbeid og personell mange steder i tunnel, skader på personell og brann" (Organisation: A lot of work and personnel in many places in the tunnel, injuries to personnel and fire), which is estimated to occur in average 3 times per project, each time with a consequence of additional costs 20 MDKK or 1 fatality or several injuries.

Construction sites is a rather dangerous working environment. Occupational safety is an important issue and requires systematic and meticulous follow-up. The initial risk estimation seems realistic.

The risk reducing measures are stated as:

| Quote in Norwegian | Quote in English |
|---|---|
| Personbrikker og prosedyrer for hvor enhver person er til enhver tid i tunnelen og også pågående aktiviteter. Alle i tunnelen har egen radio for kommunikasjon, mye forbedret etter EST – og ikke minst PPE. | Personal tags and procedures for where any person is at any time in the tunnel and also ongoing activities. Everyone in the tunnel has their own radio for communication, much improved after EST - and not least PPE. |

As result of the risk reducing measures, the frequency has been reduced with a factor 10000 to extremely rare 0.0003 times per project.

Based on the described risk reducing measure, the effect of the risk reduction measure seems grossly overestimated.

It could be expected that reference is made to a process where occupational safety (HSE: Health, Safety and Environment) is followed up and it could be stipulated how this is done. However, even with the perfect HSE plan and follow-up, it will be impossible to reduce the risk with a factor 10000.

*[The risk to construction workers is in general is the magnitude 1 fatality per 10000 full-time work-years. (The actual project may be more dangerous than an average construction site, on the other hand systematic work with HSE may tend to reduce the risk).*

*If the risk contribution of this risk element (0.0003/project* 20 MDKK) is fully allocated to fatalities, then it corresponds to the occupational risk of 1.5 full-time work-year. The work may take, say 8 years and involve a larger number of construction workers, so the estimated frequency after safety measure is clearly several orders of magnitude too low.]*

# 7 Appendix: Detailed comments to the risk evaluation of the operational phase

## 7.1 Re: Sammendrag

| Quote | Comment |
|---|---|
| For å vurdere risiko knyttet til brann, er det definert et dimensjonerende scenario for evakuering ved brann, som sikkerhets- og beredskapstiltakene i tunnelen med stor sannsynlighet skal kunne ivareta. | The design scenario is a severe fire event with a low probability.<br>The goal is that the rescue and safety measure with large probability shall be able to cope with this situation.<br>The resulting probability of severe consequences will thereby be very low. |
| Tunnellengde og stigningsforhold i tunnelen er imidlertid vurdert som særtrekk iht. TSF. Risikoen knyttet til tunnellengde vurderes å medføre en risikoøkning, som følge av at tunnelen er svært lang (> 10 km). Stigningsforholdet i tunnelen (5% stigning) vurderes å medføre noe økt risiko for brann. | The reviewer agrees to the statement on the special characteristics.<br>The risk increasing effect of the length could be specified in detail. |
| Følgende tiltak, utover allerede planlagte tiltak, er gjennom analysen vurdert som nødvendige for at risikoen skal kunne sies å være på et akseptabelt nivå: | The stated additional measures seem reasonable.<br>However, the measures are not directly validated by the risk analysis.<br>In addition, a cross section T10.5 could be evaluated. |
| Evakueringsrom kan bli nødvendig dersom trafikkvolumet øker vesentlig, eller at anbefalte tiltak ikke lar seg gjennomføre. | Rescue shelters will improve the safety, but the costs are relatively high.<br>The risk reduction achieved with rescue shelters and the associated additional costs should be demonstrated. |
| Når løsningen ikke inkluderer evakueringsrom er det også vurdert at PA-system ikke har en veldig stor verdi. | A PA system may be useful also for conveying the message to tunnel users and efficiently ensure that the vehicles already in the tunnel stop, turn around and drive out. |
| Årsaken til dette er at man da har etablert bergrom for senere å kunne etablere evakueringsrom for hver 1000 m | The preparation for rescue shelters is fine, but a distance of 1000 m may be in the high end for being really efficient.<br>It could be considered how much is saved in preparing for the rescue shelters now, compared to building them entirely when the need arises. |

## 7.2 Re: 1 Innledning

| Quote | Comment |
|---|---|
| 1.1 …Tidligere utførte vurderinger er utarbeidet av Sweco og Sintef [1][2][10].<br>and<br>1.4 Tidligere utført arbeid | [1], [2] and [10] have not been reviewed as part of the review by HOJ.<br>*([1] Risiko knyttet til brann ved ulike konsepter for Sudurøytunnelen, rapport, datert april 2022, Sweco.*<br>*[2] Risikoanalyse av Sudurøytunnelen, prosjektnotat, datert juni 2023, Sintef.*<br>*[10] Sikkerhet Suðuroyartunnilin, prosjektnotat, datert mai 2019, Sintef )* |
| 1.2 …I norske vegtunneler er det selvredningsprinsippet som gjelder. Det innebærer at du selv har ansvar for å redde deg ut, og du må forholde deg aktivt til situasjonen. … | The Suðuroy Tunnel is not a Norwegian tunnel. It may be decided to apply Norwegian regulation, but in that case, it should be stated specifically. |
| Tunneler har et storulykkespotensiale som ikke finnes på veg i dagen, ved at en hendelse i ett kjøretøy kan utsette svært mange andre kjøretøy for fare. | The reviewer agrees to the statement that fire in a tunnel has the potential of more severe consequences than on an open road. However, the expression “svært mange kjøretøy” (very many vehicles) can be misleading in relation to the relatively low traffic, but this is of course a question of the interpretation of words. |
| Større brannhendelser med høy branneffekt, som finner sted i lange tunneler med lang evakueringstid, utfordrer selvredningsprinsippet. Disse involverer i hovedsak tyngre kjøretøy. Brann i personbil eller i kortere vegtunneler utfordrer prinsippet i mindre grad. | When it is stated that this is a challenge for the “self-rescue principle” it should be distinguished whether the self-rescue is by foot or in the vehicle. |
| 1.3.1 Tunnelsikkerhetsforskriften… | Tunnelsikkerhetsforskriften, TSF is valid for the trans-European road network as ratified in Norway from the EU Directive 2004/54/EC. Even if TSF would be applied for the Faroe Island, the Suðuroy Tunnel is not on the trans-European road network. This part of the Norwegian regulation, TSF, may be applied for the Suðuroy Tunnel, but in that case, it should be stated specifically based on a decision by the Client or the Government of the Faroe Islands. |
| 1.3.2 N500 Vegtunneler | The comments above to TSF can be extended to N500 as well. However, it is understood that the Norwegian |

| | |
|---|---|
| | Tunnel Norm has been applied also for other tunnels in the Faroe Islands (and in Iceland). |
| 1.5 Forutsetninger … Det forutsettes at tunnelen er tilkoplet en døgnbemannet kontrollsentral. | It is assumed that the tunnel is supervised by a control centre 24 hours a day. This assumption must be followed up. |

## 7.3 Re: 2 Systembeskrivelse

| Quote | Comment |
|---|---|
| 2.3 Sikkerhetstiltak og utrustning Kontrollsentral | The assumption that the tunnel is supervised by a control centre 24 hours a day must be followed up. |
| 2.3 Sikkerhetstiltak og utrustning Kommunikasjonssystemer … I denne analysen er det lagt til grunn at tunnelen bygges uten PA-anlegg. | The PA loudspeaker system may be an important condition for ensuring timely evacuation by car in the tunnel. |
| 2.2.3 Nøtutganger | The issue of emergency exits is discussed in comments to chapter 5. |
| 2.5 Beredskap | It may be commented to relocate the response centres or to establish dedicated centres at the portal. |

## 7.4 Re: 3 Sannsynlighet for brann og ulykker

| Quote | Comment |
|---|---|
| Det er gjennomført TØI-beregninger for Suðuroyartunnilin og en referansetunnel. … Beregningene danner en del av grunnlaget for å vurdere om det er behov for ytterligere risikoreduserende tiltak utover krav som stilles i regelverket. | It is stated that the so-called *reference tunnel* is used as part of the basis for evaluation of the need for further risk reducing measure.<br>A specific section ought to explain how the risk and the necessary safety measures are evaluated . |
| For beregningene er følgende parametere lagt til grunn: … Stigning over 5 % (max stigning i tunnelen er 5 %) | The gradient is of importance, however, the text is contradicting: the maximum gradient is 5%, thereby the gradient is not over 5%. |
| 3.1.2 Referansetunnel | The purpose and basis for selecting the “reference tunnel” should be explained. The goal is presumably to calculate the maximum risk corresponding to a design according to N500.<br>It would be in accordance with N500 to build a tunnel with a gradient of 5% through the entire tunnel.<br>The share of HGVs is also not limited in N500 and a share of (for example) 10% would be allowable as well. |

| | |
|---|---|
| | In order to make it comparable (which here is nearly achieved by doubling the AADT for an approximative halved length), the risk figures should be normalised by the traffic. |
| | The probabilities of events have not been recalculated. The reviewer trusts the calculations are performed correctly in accordance with the TØI model. However, see comment below. |
| (3.1.3) Iht. TØI-beregningene øker antall branner og ulykker proporsjonalt med tunnellengden… | Some fires are subsequent events of accidents.<br>In many references, the probability of accidents is increased at the portals, and thereby the relationship between accidents (respectively fires) and length is linear in the interior of the tunnel but not proportional. |
| (3.1.3) En økning i trafikkmengden vil derimot innebære en mindre økning av antall branner og ulykker. For eksempel vil en økning av trafikkmengden på 10 % medføre i gjennomsnitt en økning av antall branner og ulykker på omtrent 5 % | The model assumes that a certain increase in traffic results in half of that increase in accidents and fires has not been seen in other risk models.<br>Generally, the reviewer is very sceptic towards this model, which implies that the risk per vehicle-km is close to infinity for the first vehicle and asymptotic going towards 0 for increasing traffic density.<br>Fire events occur for the most part independently of the interaction with the other vehicles. So particularly for these events the proposed relationship seems unreasonable.<br>If the TØI model is based on data, the model may have over stressed the extrapolations or disregarded other factors than AADT.<br><br>The relationship also gives logical problems with the probability of events as function of the daily, weekly, etc., variation of traffic. According to this model, the risk per vehicle would be extremely high during nighttime (which is not observed). |
| | The difference between the calculation parameters of the reference tunnel and the Suðuroy Tunnel are the AADT and length (see above) and the larger share of the tunnel having a 5% |

| | |
|---|---|
| | gradient in the reference tunnel.<br>The difference between the results for the reference tunnel and for the Suðuroy Tunnel is almost entirely a result of relationship discussed above. |
| (3.1.3) Basert på TØI-beregningene er det høyere sannsynlighet for brann (inkl. tilløp til brann) og ulykker i Suðuroyartunnilin enn i referansetunnelen. | Based on the comments above, the reviewer is not convinced in the result that the probability of accidents and fires in the Suðuroy Tunnel is significantly higher than in the reference tunnel.<br><br>This criticism is rather directed towards TØI than towards Norconsult, and the results contribute to decisions on the safe side. However, the conclusion is that a trustworthy risk analysis and reasonably acceptance criteria should be established. |
| 3.2 Vurdering av sannsynlighet for ulike brannstørrelser | The reviewer agrees to the method for establishing conditional probabilities of fire severities, however, the results are influenced by the estimation of probability of fire events from the TØI model and the definition of the reference tunnel discussed above. Hence, the tables in sec. 3.2 may not represent the difference in risk of the reference tunnel and Suðuroy Tunnel. |
| (3.2) Det er derfor benyttet at 60 % av hendelsene i Tabell 5 utvikles til en brann. | The text is unclear. Table 5 are conditional probabilities for fires which are developed. Table 2, 3 and 4 includes "branntilløp" and 60% of those may be considered developed fires.<br>The figures in Tabell 6 can not be completely re-established, see below. |

- Fire (incl. «brantilløp» in HGVs: 0.177 per year (ref. Tabell 2)
- Developed fires in HGVs: 60%*0.177 per year = 0.106 per year

Distribution of Developed fires in HGVs in Suðuroy Tunnel:

| Fire severity | Conditional probability (HGV) | Annual estimated probability | Return period [years] |
|---|---|---|---|
| 1 MW | 20% | 0.0212 | 47 |
| 5 MW | 31% | 0.0329 | 30 |
| 25 MW | 25% | 0.0266 | 38 |
| 50 MW | 16% | 0.0170 | 59 |
| 100 MW | 6% | 0.0064 | 157 |
| 200 MW | 2% | 0.0021 | 471 |
| **all** | **100%** | **0.1062** | |

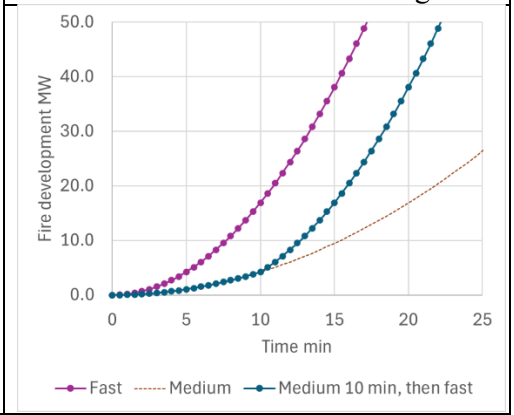
The calculation presented by Norconsult in Tabell 6 gives shorter return periods and approximately 70% higher probabilities.

## 7.5 Re: 4 Vurdering av særtrekk

| Quote | Comment |
|---|---|
| Tunnelen er 22 818 meter lang og monoton. Dette vurderes å være et særtrekk. | The reviewer agrees that length of the tunnel of 22.818 km is a special characteristic. Whether the tunnel is particularly monotone compared to other tunnels is more uncertain. |
| Atkomstiden vurderes derfor ikke å være et særtrekk for tunnelen. | Even though the access time for the emergency services (15-30 min) may not be a special characteristic, it may be a topic of further investigations. |
| (4.1.1) …vil det være viktig at trafikantene klarer å evakuere ut av tunnelen på egen hånd i eget kjøretøy. Dette er hovedprinsippet for selvredning i tunnelen | It is noted that the main principle of escape is self-rescue by the use of own vehicle.<br>Cameras, AID, lay-bys and turning niches are certainly instrumental for this principle.<br>In addition, communication can be mentioned. It is important to give the motorists a clear message about turning around, otherwise it will not happen. Radio contact, signs and possibly loudspeakers can enforce this communication.<br>Furthermore, it should be considered whether a 10.5 m wide cross section would give better chances for escape. |
| Videre vil fjernstyrte bommer og tilhørende rødt stoppblinksignal forhindre at ytterligere trafikanter kjører inn i tunnelen ved en hendelse… | Measures for closing the tunnel in case of an event are important and the recommendation from Norconsult is seconded by the reviewer. |
| Sannsynlighetsberegningene viser at personskadeulykker og ulykker med drepte eller hardt skadde vil oppstå oftere i Suðuroyartunnilin enn i referansetunnelen. | See the comments concerning the calculation of probability and comparison with the reference tunnel above. |
| Følgende tiltak er vurdert å ha en risikoreduserende effekt på hendelser og forhold hvor tunnellengde kan være av betydning: | In spite of the comments to the calculation of event probabilities and the reference-tunnel-approach, the proposed safety measures can be seconded: radio communication, ventilation, AID, ITV, evacuation light-strip. |
| 4.1.2 Stigning. Suðuroyartunnilin har stigning på 5 % ved begge tunnelportaler, henholdsvis en lengde på ca. 2 km ved hver portal. | The lengths with 5% gradient are stated as 2+2 km, whereas sec. 3.1.1 states that the lengths are 2+3 km. (Possibly this is a typo). |

| | |
|---|---|
| Suðuroyartunnelen er lang, men har moderat stigning (5%) og lengde på stigningene. | The 5% gradient is described in the table as a special characteristic, but in 4.1.2 it is called "*moderate*" (a formulation comment only). |
| Det er ca. 7 % tungtrafikk i tunnelen, dvs. en relativt liten andel tungtrafikk. | The reviewer would not characterise a 7 % HGV share as a rather normal value (a formulation comment only). |

## 7.6 Re: 5 Vurdering evakuering ved brann

| Quote | Comment |
|---|---|
| Det dimensjonerende scenariet skal ivareta en «worst case»-hendelse i tunnelen … | It shall be noted that the worst-case scenarios cannot be combined with the probabilities estimated in section 3 of the report. |
| Analysen vurderer sannsynlighet og konsekvens ved en brann i Suðuroyartunnilin kvantitativt. | The analysis does not consider the associated probabilities for the scenarios, sub-scenarios, locations, walking speeds, reaction times, etc. |
| 5.1 Metode | The method concerning toxic impact, FED calculations, walking speed, smoke spread seem in accordance with common practice. |
| (5.1.3) Ved god sikt (mer enn 10 m) er det benyttet en ganghastighet på 1,0 m/s… | The reviewer agrees that a walking speed of 1.0 m/s is conservative for smokefree conditions. |
| 5.2 Dim. scenario for evakuering i røyk<br>Basert på dette er det vurdert en branneffektutviklingskurve, som vist under, der følgende er lagt til grunn:<br>- Første 10 min.: medium brannutviklingshastighet før spredning til last<br>- Etter 10 min.: rask brannutviklingshastighet | The assumed fire development curve with medium fire development for the first 10 minutes may seems reasonable. It corresponds basically to a 5-min delay before the fast fire curve starts. However, a sensitivity analysis with a fast fire development curve from the start of the fire should be investigated.<br>  |
| (5.2.2) Gitt at kjøretøy holder skiltet fartsgrense (80 km/t) … | It may be too optimistic to assume that all vehicles can maintain 80 km/h throughout the tunnel, particularly at the steep gradient upwards. |

| | |
|---|---|
| | At lower average speeds, more vehicles will be using the tunnel at the same time. |
| … da igangsetter evakuering til fots. […] De vil da evakuere i røykfronten en stund, men vil, avhengig av gang-hastighet og ventilasjonshastighet, tas igjen av mer og mer røyk. På grunn av tunnelens lengde vil evakuerende (dersom brannen ikke skjer nær en av portalene) ikke ha mulighet til å eva-kuere helt til portal på egen hånd, fordi de enten blir utsatt for høy dose giftige røykgasser, eller blir for slit-ne/desorienterte til å ta seg frem i tun-nelen på egen hånd. | For the tunnel users attempting to escape on foot, the situation is critical. It could be investigated based on an evaluation of risk, (i.e. estimation of the probability of this situation and its consequences) whether rescue shelters would be a reasonable safety measure – or if safety can be obtained with the use of the ventilation system. |
| 5.3.1 Ved brannstart er det estimert at det er ca. 57 kjøretøy i tunnelen for dimensjonerende timestrafikk.<br>…<br>Med en stengetid på tre minutter etter en hendelse, | The reviewer agrees to the figure of 57 vehicles in the entire tunnel at the start of the fire, if the fire start in the peak hour, and all vehicles drive 80 km/h. (See discussion below) Possibly, a sensitivity study with lower speeds would be relevant. |

If the fire start in the peak hour, and all vehicles drive 80 km/h, 57 vehicles are present in the entire tunnel at the start of the fire.

Those vehicles, which have the fire behind them, will drive out without problems, leaving 14 vehicles driving towards the fire from each side. In addition, vehicles will drive into the tunnel in the 3 min before it is closed. This will be additionally 5 vehicles from each side.

During the first 2 minutes of the fire, 3 vehicles might pass the incident site and drive out.

Assuming the airflow goes in one direction with limited back-flow, the 19 vehicles on one side would not be exposed.
On the downstream side, it will be important to instruct the vehicles to turn around and drive out.

The signs are activated after 3 minutes. At this point of time 16-19 vehicles are inbound towards the fire on the downstream side. (In addition, 11-14 vehicles are outbound away from the fire on the downstream side.). On a tunnel length of 11.4 km the average distance between the vehicles is in the range 600 m to 1000 m.

Only few, say 1-2, (inbound) vehicles will be less than 1000 m from the fire

| Quote | Comment |
|---|---|
| …tre gjenværende kjøretøyene blir stående i kø i røyk nedstrøms brannen. | The report assumes 3 vehicles will be caught in a standstill behind the fire (in addition to the vehicle on fire). The reviewer finds this a reasonable |

| | |
|---|---|
| | assumption (see the discussion above), given that an efficient system for communicating the need to turn around is installed in the tunnel. Loudspeakers (PA-system) could well be an efficient measure for this purpose. A PA system can also be used to instruct the persons caught in the standstill. |
| (5.3) Med maks ganghastighet på 1 m/s er tilgjengelig tid før grenseverdien for inkapasitans er oppnådd i underkant av 40 minutter. Evakuerende har på det tidspunktet evakuert ca. 1800 m fra brannstedet. | The point when the escaping persons reach the level of incapacitation may depend on the operation of the ventilation system. However, in this scenario the distance out of the tunnel is 11 km, which will take 2 – 3 hours under smoke-free conditions. Hence, it may not be possible to demonstrate that passengers on foot can escape safely in the direction of the smoke spread to the portal. |

For passengers escaping on foot the direction of the smoke spread, the safety is depending on a delicate balance of use of ventilation and rescue.

In the beginning of the fire, the air flow should be as low as possible (say, 1.0 m/s) for maintaining stratification (smoke under the roof and relative fresh air below).

With a speed of 60 – 80 km/h the upstream part of the tunnel will be cleared for motorised traffic after 9 – 11 minutes, and after this point it may be considered to change the direction of the ventilation.

| Quote | Comment |
|---|---|
| (5.3.5) Dersom ventilasjonsretningen snur etter 30 minutter fra brannstart, viser røykspredningsberegningene at evakuerende vil være i røykfritt miljø innen 5-6 minutter etter ventilasjonsretningen har snudd. | The report discusses to reverse the ventilation after 30 min, but presumably the upstream part can be clear much earlier. |

The problematic part is the situation at the site of the fire. If vehicles and persons are stationary on both sides of the fire, and other persons are escaping on foot in both directions, no safe decisions are possible. For this reason, it is important with clear instructions in the initial minutes of the fire (by use of radio and PA system).

The rescue services may be required if it is not possible to ensure that the one side of the fire has been evacuated. This would be a sub-scenario of the stipulated worst-case scenario.

In any case, it may be relevant to ensure a short / shorter access time for the rescue services.

At present the safety seems to be a rather delicate balance of the operation of the ventilation.

Safety may be achieved or improved by control of the HGV traffic, so that less other vehicles are in the tunnel at the same time as the HGV or that traffic predominantly goes in one direction.

## 7.7 Re: 6 Risikoreduserende tiltak

| Quote | Comment |
|---|---|
| Kort oppsummert anbefales følgende tiltak, som utdypes i kap. 6.1 under: | The recommended measures stated by Norconsult are seconded by the reviewer. |
| Merk følgende – tiltakene angis som anbefalte, for at risikoen skal kunne sies å være på et akseptabelt nivå, som vurdert i denne rapporten. Det er i utgangspunktet ikke valgfritt å gjennomføre dette, og ønske om å ikke gjennomføre anbefalte tiltak vil medføre behov for ny vurdering av risiko og mulige alternative sikkerhetstiltak. | However, it is not clear from the report exactly how the measures influence the risk, and the cost efficiency of the measures is not mentioned. |
| … som nå ikke er del av anbefalingen. Dette er:<br>1) PA-anlegg med lyd og lys (N500:2022)<br>2) Evakueringsrom | 1) The basis for recommending NOT to install a PA system (loudspeakers) ought to be further explained and documented. To the opinion of the reviewer, this system may well be efficient in the tunnel: A PA system may be useful also for conveying the message to tunnel users and efficiently see to it that the vehicles already in the tunnel stop, turn around and drive out.<br>2) It may be accepted that escape shelters will not be cost efficient, but it is not really demonstrated in the report. The risk reducing effect ought to be presented and possible held up against the costs. |
| 6.2 Anbefalte risikoreduserende tiltak ved brann, Opprustning av beredskap. Dette forholdet må vurderes nærmere for å se på hvilken opprustning av dagens eksisterende beredskap det vil være behov for, for å være sikker på at beredskapen kan ivareta dette. Dette vil kreve et eget arbeid. | The reviewer agrees to the need of studying an improvement of the rescue systems. The investigations should be started shortly. The goal should be to establish a safety concept with short access times for the rescue services. Possibly with locations at or nearer the tunnel portals. |
| Vurdering av behov for restriksjoner på tungtrafikk | The reviewer agrees that safety measures could be considered, for example in terms of restrictions to traffic with dangerous goods and possible traffic control of other heavy vehicles. |

| | |
|---|---|
| System for å gi et sanntidsbilde av kjøretøytyper i tunnelen | Full camera coverage and AID (automatic incident detection) is assumed in section system description and need not be mentioned as an additional recommendation. |

## 7.8 Re: 7 Oppsummering og diskusjon

This chapter summarises the previous sections (in more detail than the summary in the beginning of the report) and does not add much more discussion. Reference is made to the comments to the individual chapters.

## 7.9 Re: 8 Konklusjon

This chapter is very similar to the summary in the beginning of the report, and the same comments can be made.

## 7.10 Re: Erfaringer fra tidligere brannhendelser i tunnel

Generally, this part is not commented. Some other events could have been relevant to mention as well.

# 8 Appendix: Detailed comments to the risk evaluation of longitudinal ventilation

## 8.1 Re: Sammendrag

| Quote | Comment |
|---|---|
| Det er tidligere utarbeidet en rapport av Sweco som vurderer ulike tunnelkonsept (trasé, utforming og sikkerhetsutrustning [A] for Landsverk […]. Dette notatet er basert på den tidligere Sweco-rapporten, samt Norconsults risikovurdering fra 2023 [B] utført for selskapet Suðuroyartunnilin P/F […]. | [A] has not been reviewed as part of the second opinion by HOJ. *[A]. Sweco: Risiko knyttet til brann ved ulike konsepter for Sudurøytunnelen, pr.nr. 10226293, rev. 01, 19.04.22* |
| Risikovurderingen legger til grunn at en større brann har oppstått og det er derfor ikke gjort vurderinger av sannsynligheten for at brannen oppstår. | With this limitation, the report is not a risk evaluation (but a scenario analysis). The term "risk" requires consideration of probability and consequence. |
| Beregningene viser at 94 (Sweco) eller 126 (Norconsult) personer vil miste evakueringsevnen i dette scenariet | This seems to be very high numbers. See comments to section 4.2.3. |
| Ut fra beregningene/vurderingene kan vi konkludere med at brannstrategien som er foreslått i Norconsult sin rapport ikke er forenelig med selvredningsprinsippet. De som evakuerer nedstrøms brannen vil bli fanget i røyk. De som evakuerer oppstrøms brannen vil ha behov for å reddes ut av tunnelen av hjelpemannskap så lenge brannen oppstår mer ca. 2,5-3 km inn i tunnelen, selv under ideelle forhold | Based on the calculations made and the conservatism included in the assessments, it seems that the conclusion that the tunnel does not give the possibility to evacuate in reasonable safety is overstated and premature. |

## 8.2 Re: 1 Innledning

| Quote | Comment |
|---|---|
| 1.3 Omfang og avgrensninger … Risikovurderingen legger til grunn at en større brann har oppstått og det er derfor ikke gjort vurderinger av sannsynligheten for at brannen oppstår. | With the limitation "no assessment of probabilities", the report is not a risk evaluation (but a scenario analysis). The term risk requires consideration of probability and consequence. |

## 8.3 Re: 2 Beskrivelse av analyseobjekt

| Quote | Comment |
|---|---|
| I Norconsults rapport står det at tunnelen planlegges med tunnelprofil T9,5 [B], mens det i Sweco sin rapport var | This may be important to clarify. The cross section T10.5 brings some advantages with respect to safety |

| | |
|---|---|
| tunnelprofil T10,5 [A]. | against accidents, fire and the possibility to turn around. |
| … Kontrollsentral… | It should be clarified where a control centre will be established. |
| Kommunikasjons-systemer…. Sweco stiller seg kritiske til at tunnelen skal bygges uten PA-anlegg. Erfaringer fra tunnelbranner viser at det er viktig med tidlig varsling til trafikantene for at de skal komme seg ut av tunnelen raskt. | The reviewer (NPH) supports the comment by Sweco. The PA loudspeaker system may be an important condition for ensuring timely evacuation by car in the tunnel. |
| Nødutganger | The issue of emergency exits is discussed in comments to chapter 4. |
| Oversikten viser at det er begrenset hva man kan regne med av innsats dersom det skulle begynne å brenne midt i en lang undersjøisk tunnel mellom Sandøy og Sudurøy | It may be commented to relocate the response centres or to establish dedicated centres at the portal. |

## 8.4 Re: 3 Selvredningsprinsippet

| Quote | Comment |
|---|---|
| Dersom det er behov for å evakuere en tunnel i forbindelse med ulykkeshendelse eller brann, er det lagt til grunn at dette skal kunne utføres av den enkelte bilfører eller passasjer.<br>….<br>Selvredningsprinsippet er i samsvar med EU-direktivet og den norske tunnelsikkerhetsforskriften, og gjelder som hovedprinsipp i alle norske vegtunneler. | The EU directive does not include a "self-rescue principle". The relevant text is stated below.<br>The EU directive says that measures should enable people involved in incident to rescue themselves, but it does not exclude that rescue services assist in the rescue. The paragraph mentions "safety measures" which can be of various nature, including the action of the rescue services, ventilation and evacuation facilities. |
| | Quote from Directive 2004/54/EC:<br>*"(11) Safety measures should enable people involved in incidents to rescue themselves, allow road users to act immediately so as to prevent more serious consequences, ensure that emergency services can act effectively and protect the environment as well as limit material damage."* |
| | It may further be noted that neither the EU directive nor the Norwegian Tunnelsikkerhetsforskriften are valid for the Suðuroy Tunnel. Even if the EU directive would be adopted for the Faroe Islands, the road link to Suðuroy is not on the trans-European network. |

| | |
|---|---|
| Avhengig av responstid og tilgjengelig utstyr, er det begrenset i hvilket omfang en kan påregne at eksterne redningsmannskaper kan komme til unnsetning ved en brannhendelse i en tunnel. | It is a postulate by Sweco that no assistance can be expected.<br>For a specific project some solutions supplementing self-rescue may be found.<br>On the other hand, if the safety is based on assisted rescue, measures must be taken to ensure that assisted rescue can take place. |
| Det verste scenarioet som kan inntreffe i en tunnel er en omfattende brann…. | The statements about the criticality of severe fires are true, however, this can be extended to any tunnel with two-way traffic. |

## 8.5 Re: 4 Risikovurdering

| Quote | Comment |
|---|---|
| Risikovurdering | The chapter does not include a risk evaluation, but a discussion of the scenarios. |

### 8.5.1 Re: 4.1 Vurdering av foreslått strategi for brannventilering

| Quote | Comment |
|---|---|
| Vi har i dette kapittelet benyttet HC-kurve for utvikling av brann | The HC fire curve is a well-accepted model for the relationship between temperature and time in a severe fire.<br>It should be noted, however, that the HC (hydrocarbon) fire curve is the model for an extreme fire in hydrocarbons or similar fire loads.<br>If a probability-based risk analysis was pursued, the likelihood of this type of fire would be very low. Most fires would be significantly less severe. |
| På grunn av trafikk i tunnelen hvor biler skyver luft foran seg vil ventilasjonshastigheten i dette tilfellet være høyere enn 1,5 m/s også i første fase av brannen. | It is possible that the traffic increases the air velocity. However, in Suðuroy Tunnel the traffic goes in both directions, and air speed will not systematically be higher than 1.5 m/s. |
| Etter at brannen starter etter 0,5 timer (1) stiger ventilasjonshastigheten ytterligere pga. oppdrift. | If a higher air velocity is disadvantageous, the mechanical ventilation can be reduced or even be disengaged. |
| | It will be important to measure the air velocity in the tunnel and adapt the operation of the ventilation to the measurements. |
| Figur 4-5 Ventilasjonshastighet 2 m/s (venstre) og 3 m/s (høyre) [M]. | It would be relevant to determine the same situation with 1.5 m/s. |
| Når ventilasjonsretningen snus ved hjelp av vifter kan vi påregne full om- | It is true that the change of direction of the air flow will fill the cross sec- |

| | |
|---|---|
| røring slik at røyken uansett ikke lenger vil ligge langs taket, men blandes inn i luftlaget under og gi et helt røykfylt tverrsnitt | tion, but the concept (as I have understood it) would be to turn on the ventilation when the tunnel users on side are in safety (i.e. at least outside the area of smoke). |
| Vi kan derfor konkludere med at det sannsynligvis ikke vil være mulig å evakuere nedstrøms i 30 minutter etter brannens oppstart. | The conclusion that it is not possible to evacuate tunnel users downstream of the fire is based on some assumptions, which may have to be discussed:<br>- It is only valid for person evacuation on foot,<br>- It is only valid for an air speed of more than 2 m/s<br>- It is only valid for an extreme fire |
| Evakuering oppstrøms | It should not be the procedure that the smoke is directed to the side, where the assisted rescue occurs. A reasonable procedure would be to clear the area, and afterwards operate the ventilation system to create good conditions for the persons on the other side. |

### 8.5.2 Re: 4.2 Vurdering av evakueringsdyktighet

| Quote | Comment |
|---|---|
| Metodikken er en forenklet endimensjonal modell som angitt i boken Tunnel Fire Dynamics [F], og er satt opp i et Excel-regneark. | The method used is “simplified” and apparently less sophisticated than the model used by Norconsult in their calculations. |
| Tabell 4-2 Scenario 1 …Medium brannvekst frem til 10 min deretter rask brannutvikling til 50 MW. … Scenario 2…Rask brannutvikling frem til 50 MW. | The heat release curve with a medium increase in the start of the fire may be a realistic model. |
| Scenario 1: Andel biler som snur i tunnel etter varsel 100%, Scenario 2: 0% | Both assumptions on the share of car turning in the tunnel are extreme. 100% is of course an upper value, but it may be more extreme to expect that 0% follow the given instruction to turn around. |
| ÅDT og % av ÅDT som simuleres | 10% of the AADT is commonly regarded as the traffic in the peak hour. (17% of AADT would generally seem to be a too high value) |
| | For an average situation of traffic at the time of a fire, the traffic would be less than assumed in the calculations. |
| 4.2.3 Beregningene for scenario 1 viser at 2,5 personer vil miste evnen til å | If the assumptions for the calculations are the same, the results ought to be |

| | |
|---|---|
| evakuere i dette scenarioet. Dette er i motsetning til Norconsult sine vurderinger som viser at alle klarer å snu og kjøre ut av tunnelen. | the same. The reader of the report is left to choose which of the models he/she believes in. |
| 4.2.3 Scenario 2. Brann i lastebil (rask brannutvikling til 50 MW) i senter av tunnelen, ventilasjon i samme retning hele tiden (dvs. den snus ikke). | This is a scenario which is not pursued in the proposed operation of the tunnel, if I understand it right. |
| 4.2.3 Scenario 2. Beregningene for scenario 2 viser at 94 personer i den tidligere versjonen av tunnelen (A: T10,5, ÅDT 1300) vil miste evnen til å evakuere, mens det for den nye versjonen (B: T9,5, ÅDT 2000) vil være 126 personer som mister evnen til å evakuere. Dette er ved rask brannvekst og at man ikke snur ventilasjonen etter en gitt tid | The numbers seem quite extreme. See discussion and calculations below. As conclusion:<br>The alarming numbers, which are also mentioned in the summary, are not only based on an extreme operating scenario, which is not foreseen for the Suðuroy tunnel, and an extremely severe fire development, but also other extreme assumptions must have been made for achieving these rather unrealistic figures. |

With the basis of AADT= 2000 veh/day, the peak hour traffic has been estimated to 200 veh/h (in Table 4.2) and a directional split of 50%/50%. With these assumptions 100 vehicles will enter the tunnel per hour. With an average of 1.5 persons/vehicle, this means that 150 persons enter the tunnel in the peak hour. With a traffic speed of 60 – 80 km/h, it will take 10 minutes to reach the centre of the tunnel (assumed seat of the fire).

Hence 150 persons*10min/60min = 25 persons will be in the tunnel at the time of the start of the fire if it occurs in peak hour. If alarm and reaction conservatively take 8 minutes, then additionally 20 persons may enter the tunnel before it is closed.

Of the total of 25 + 20 = 45 persons, some will follow the instructions to turn around and drive out.

As a rough assessment it would be maximum 20 – 30 persons caught in the fire under these circumstances, and with efficient communication, significantly less.

However, if the fire would occur at an average time of the day, the vehicles entering the tunnel would be 50%*2000veh/day/24 h = 42 vehicles or 62 persons.

This means that (25+20)*62.5/150 = 19 persons will enter the tunnel before it is closed. Some of the affected vehicles will be able to turn around and drive out, and as a rough estimate maximum 8 – 12 persons may be caught at an average hour.

| Quote | Comment |
|---|---|
| 4.2.3 Scenario 3 | The description of scenario 3 is brief, and not easy to check, but based on the observations in scenario 2, some doubt about the realism of the calculations remain. |

| | |
|---|---|
| 4.2.4 Kommentarer til beregninger og resultater // 4.2.4.1 Brannscenario …har Norconsult valgt en plassering som ligger nær en portal med ventilasjonsretning mot denne portalen. Dette vil være en mer konservativ plassering i forhold til Swecos studie… | Ideally, various different locations should be selected. |
| 4.2.4 Kommentarer til beregninger og resultater // 4.2.4.1 Brannscenario Det er derimot valgt en brann med begynnende medium brannvekst, som deretter øker til rask brannvekst etter 10 min. Den begynnende medium vekstraten begrunnes med et scenario der brannen ofte kan starte i motor eller varmgang i roterende deler (hjul/bremser/lagre/o.l.) og ikke i lasten hvor brannen forventes å vokse hurtigere | The reviewer tends to agree with Norconsult's assumption of a fire starting with a relatively lower growth. This seems to be in accordance with observations and fire-engineering models. |
| 4.2.4 Kommentarer til beregninger og resultater // 4.2.4.1 Brannscenario …I Swecos studie er det benyttet en rask brannvekstrate blant annet etter anbefaling fra [G]…. | The document [G] (*Funktionsbaserade krav och rekommendationer för brandsäkerhet I vägtunnlar (FKR-BV12)*) is a good reference. In appendix, Tabell B.4 indicates the selection of scenarios for verification of evacuation. For an HGV fire in "TC", the max. HRR is 50 MW and the growth is indicated as $\alpha = 0.047$ kW/s$^2$., which is regarded as a fast growth. |

## 8.6 Re: 5 Diskusjon

| Quote | Comment |
|---|---|
| Et av de farligste scenariene som kan oppstå i en tunnel er en stor brann i vogntog med farlig last. | It would be possible to restrict traffic of dangerous goods to times of the day with little traffic – or restrict the traffic in the opposite direction (which will make it possible to ventilate in the direction of the DG transport, and create a much safer situation) |
| Å vente på hjelp fra redningsetater kan bli fatalt ettersom det kan ta tid før redningsetatene ankommer brannstedet | If the tunnel safety is based on assisted rescue, it can be an option to establish manned fire/rescue stations at the two portals (this is of course costly and should be evaluated against other options) |
| Det er derfor ekstra viktig at selvbergingsprinsippet (se kap. 3) ivaretas slik at trafikanter kan redde seg selv. | Adherence to the principle of self-rescue is not required by international or Faroese Law, and for a specific project some other solutions may be |

| | |
|---|---|
| | found (see comments to chapter 3). |
| …må tunnelen være konstruert og utstyrt med tekniske installasjoner som vil gi hjelp og støtte til trafikantene i en nødssituasjon | It is a good idea in any case to design and equip the tunnel with technical installations supporting the tunnel users in case of emergency. |
| … man ser seg nødt til å forlate kjøretøyet for å rømme, er som regel hvis man oppholder seg tett på brannen, med redusert sikt og tilløp til en kaotisk situasjon … | This is true, but also costly. In any case the ventilation needs to be operated for facilitating an up to 500 m long evacuation on foot in the tunnel |
| Sikten reduseres ofte raskt, før den forsvinner helt [J]. I en slik situasjon er selvrednings-prinsippet adskillig bedre ivaretatt dersom man installerer redningsrom eller rømnings-tunnel. | |
| …akseptabel løsning gitt at brannvesenet redder ut trafikanter oppstrøms brannen (klarerer tunnelen), før de snur ventilasjonen slik at de som rømmer nedstrøms ikke blir tatt igjen og fanget i røyken. Dette mener Sweco strider imot selvbergingsprinsippet… | For a specific project some solutions supplementing self-rescue may be found (see above).<br>On the other hand, if the safety is based on assisted rescue, measures must be taken to ensure that assisted rescue can take place. |
| | It is noted that Sweco doesn't contradict Norconsults conclusion that the safety is acceptable given that the assisted rescue is available |
| I Norconsult-rapporten er det vurdert at alle trafikanter opptrer «perfekt» ved en brann, dvs. at de umiddelbart begynner å snu/kjøre ut av tunnelen. Erfaringer fra blant annet den 11,4 km lange Gudvangatunnelen i 2013 viser at dette ikke alltid er tilfelle | In order to support the foreseen behaviour, measures of communication can be taken, this includes messages over radio (DAB), possibly message signs in the tunnel, and loudspeakers in the tunnels has also been proven as effective. |
| (concerning experience from other tunnels) | Lærdalstunnelen in Norway and many other Norwegian tunnels also do not have emergency exits in the tunnel.<br>Other Faroese tunnels do not have emergency exits (of which the following are also sub-sea over 5 km long)<br>Eysturoyartunnilin (2020) 11.250 km<br>Sandoyartunnilin (2023) 10.785 km<br>Norðoyatunnilin (2006) 6.186 km |
| Å skulle evakuere hele distansen til nærmeste tunnelmunning vil som både beregningene viser, samt erfaring, føre til fatale konsekvenser. | Here the meaning is (presumably) evacuation by foot. If the principle is evacuation by car / vehicle or assisted, this comment on "fatal consequences" is not relevant. |
| Et scenario der en full buss…. | Scenarios with buses are in fact a challenge and a worst-case scenario |

| | |
|---|---|
| | (in this tunnel as well as in any other tunnel with two-way traffic). |
| En busslast kan bestå av eksempelvis eldre og funksjonshemmede som vil bruke lengre tid på å evakuere…. | This means that the most realistic way of evacuation is by driving the bus out of the tunnel, or by assistance transporting this group of people out.<br>Even with emergency exits at 500 m, the distance to walk (up-hill), may be challenging for disabled people. |

## 8.7 Re: 6 Konklusjon og anbefaling

This chapter is very similar to the summary in the beginning of the report, and the same comments can be made.

| Quote | Comment |
|---|---|
| Ut fra beregningene/vurderingene kan vi konkludere med at brannstrategien som er foreslått i Norconsult sin rapport ikke er forenelig med selvredningsprinsippet. De som evakuerer nedstrøms brannen vil bli fanget i røyk. De som evakuerer oppstrøms brannen vil ha behov for å reddes ut av tunnelen av hjelpemannskap så lenge brannen oppstår mer ca. 2,5-3 km inn i tunnelen, selv under ideelle forhold | The conclusion that the Suðuroy tunnel does not respect the self-rescue principle is too strong. Either the self-rescue principle is regarded as absolute, which is not in line with the original text, or the conclusion is unreasonable and not supported by the calculations. |
| Dette mener Sweco strider imot selvbergingsprinsippet siden man belager seg på fysisk redning fra nødetater for at evakuering skal være ivaretatt. | The principle of self-rescue is not an international or Faroese Law, and for a specific project some other solutions may be found. |
| … strider imot «Nullvisjonen» som sier at man skal bygge «et transportsystem som ikke fører til tap av liv eller varig skade» [C]. | [C] is *Det Kongelige Samferdselsdepartement; Nasjonal transportplan 2018-2029, Meld. St. 33 (2016-2017)* which is a plan for Norway and not necessarily guiding decisions in the Faroe Islands.<br>The Zero vision shall not be taken as a fundamental acceptance limit; in any activity some residual risk will remain.<br>The zero vision is rather a process toward continuous improvement.<br>Some other risk acceptance criteria should be established – also taking into account the probability of events and probability of circumstances of traffic at the time of an accident plus other risk reducing measures. |