Amendment to NOROG Report "Guidance on calculating blowout rates and duration for use in environmental risk analyses" (rev. 2021)

Recommendations on blowout scenario modelling for environmental risk analysis of exploration wells

Kari Apnesetth Gjerde and Thomas Nilsen, Equinor
June, 2021

Norsk olje&gass

The Norwegian Oil and Gas Association is an employer and industry association for oil companies and supplier firms engaged in the activities on the Norwegian Continental Shelf. The Norwegian Oil and Gas Association is affiliated with the Confederation of Norwegian Business and Industry, NHO.

P.O. Box 8065, 4068 Stavanger. www.norskoljeoggass.no

TABLE OF CONTENTS

1 SUMMARY 3
2 INTRODUCTION 3
2.1 Background 3
2.2 Objectives 3
2.3 Document structure 3
3 ON APPLICATION OF THE GUIDANCE AMENDMENT 3
4 PENETRATION DEPTHS IN FLOW MODELLING 4
5 FLOW PATHS 5
6 RESTRICTED FLOW 6
7 DURATION ANALYSIS 6

REFERENCES 7

APPENDIX A - JUSTIFICATION FOR RECOMMENDATIONS ON PENETRATION DEPTHS 8
APPENDIX B - JUSTIFICATION FOR RECOMMENDATIONS ON FLOW PATHS 9
APPENDIX C - JUSTIFICATION FOR RECOMMENDATIONS ON RESTRICTED FLOW 11

1 SUMMARY

The NOROG report "Guidance on calculating blowout rates and duration for use in environmental risk analyses" provides overall principles and guidance for calculation and treatment of uncertainty for blowout scenario analyses (BSA). Although the report is commonly recognised among operating companies and BSA vendors, there has still been considerable variation among the analyses submitted to the authorities by exploration drilling projects on modelling granularity, modelling approach and treatment of uncertainty, including scenario probabilities used and justification of such figures.

With the intention to contribute to a more harmonised industry practice, this amendment to the mentioned report presents recommendations regarding analysis details related to flow restrictions, flow paths, and reservoir penetration depths used in flow modelling. In addition, some recommendations regarding how to account for the use of a capping stack in blowout duration analysis is included.

2 INTRODUCTION

2.1 Background

The NOROG report "Guidance on calculating blowout rates and duration for use in environmental risk analyses" /1/ provides overall principles and guidance for calculation and treatment of uncertainty for blowout scenario analyses (BSA). Although the report is commonly recognised among operating companies and BSA vendors, there has still been considerable variation among the analyses submitted to the authorities by exploration drilling projects on modelling granularity, modelling approach and treatment of uncertainty, including scenario probabilities used and justification of such figures. The need for additional standardisation has become clear through discussion between authorities and operating companies, operating companies and BSA vendors and discussion internally in operating companies.

2.2 Objectives

The objective of this this amendment to the NOROG report /1/ is to contribute to a more harmonised industry practice in exploration well BSAs applying a level of detail and degree of conservatism in line with the principles provided in the main report.

2.3 Document structure

This amendment consists of a main part including the recommendations given in Sections 4-7 and a set of appendices. The main part provides direct BSA modelling recommendations. Justification underpinning these recommendations is provided in the appendices along with advice on when and how modelling adjustments deviating from the recommendations in Section 4-7 could or should be used. Note that the section and appendix numbering structure of the amendment does not correspond with the structure in the NOROG main report /1/.

3 ON APPLICATION OF THE GUIDANCE AMENDMENT

This document is an amendment to the NOROG report /1/ which was first issued in Norwegian in 2004 /2/, revised in 2007, and revised and translated to English in 2014. The amendment provides more detailed modelling recommendations, based on the principles and more general recommendations given in the main report.

Particular attention is drawn to two important principles in the main report:

- In the analysis uncertainty may be dealt with either by:
  - more detailed modelling and detailed representation of uncertainties in terms of probabilities, and/or
  - making simplifications to the conservative side in selection of scenarios or probability values.
- Modelling choices and numeric values used should be justified by sound and relevant arguments, if not supported by facts.

Whether the recommendations provided in Sections 4-7 are valid for a given well and how adjustments can be made if required is described in Appendix A-C.

The recommendations given in Sections 4-7 apply to modelling of both subsea and topside flow.

4 PENETRATION DEPTHS IN FLOW MODELLING

Two alternative models are recommended for modelling of penetration depths, with two and three depths, respectively. When applying the recommended penetration depth probabilities, the two models will produce approximately the same mean flow rates.

Two-depth model:

1. Top penetration: Drilled 5 m into the reservoir
2. Full exposure: Drilled to target total depth

Three depth model:

1. Top penetration: Drilled 5 m into the reservoir
2. Drilling ahead: Drilled 50 % of the reservoir section (measured depth) from the top of the reservoir to the target total depth
3. Full exposure: Drilled to target total depth

The depths involved in the two models are illustrated in Figure 1.

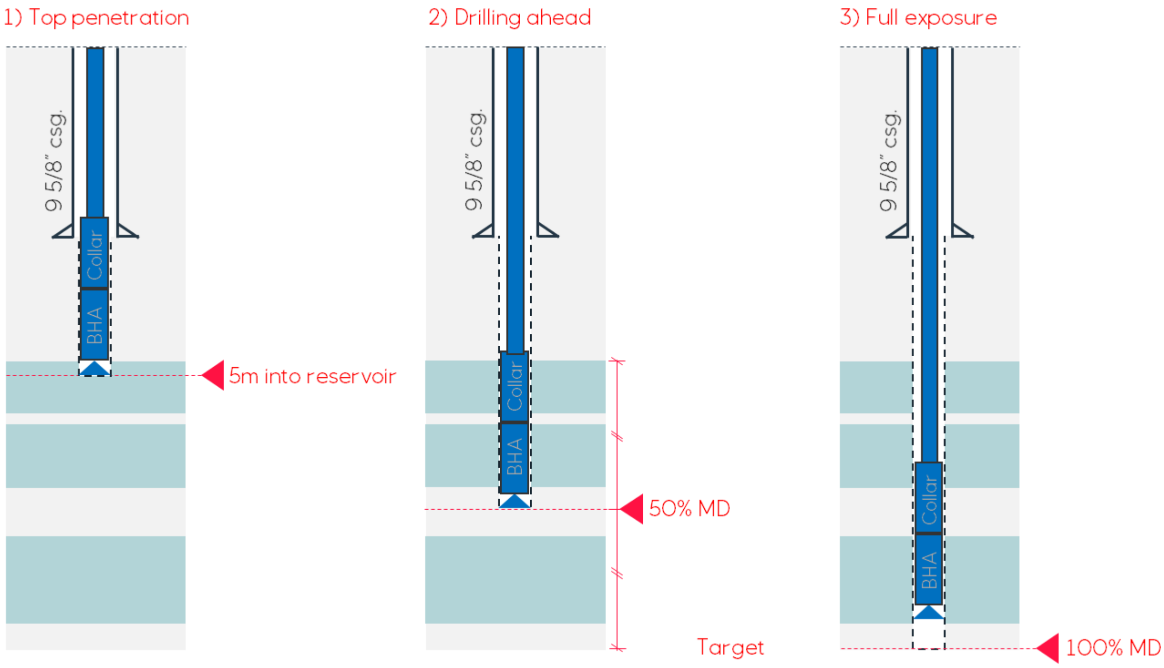

Figure 1: Illustration of 3 penetration depths used in depth modelling

Recommended penetration depth probabilities related to the two models are provided in Table 3.1.

Table 3.1: Recommended depth probabilities for the two penetration depth models

Penetration depth	Penetration depth probabilities (%)	
	Two-depth model	Three-depth model
1) Top penetration	40 %	30 %
2) Drilling ahead	0	40 %
3) Full exposure	60 %	30 %

If there is strong evidence that a gas cap will be present in the case of an oil discovery, this may be included in the flow model for all penetration depths considered. Oil coning effects should be sufficiently accounted for in the model.

Analysis efforts can be reduced by using the two-depth model. For multilayer reservoirs, the three-depth model may be favourable. In a case of complex reservoir zone geometry and/or properties, modelling different from the two above alternatives may be necessary. In such cases, the above alternatives should be used as a starting point for extended modelling. Refer to Appendix A for further guidance.

5 FLOW PATHS

For all penetration depths, two alternatives to flow path modelling are recommended:

1. Three flow path modelling approach (through drill string, annulus or open hole)
2. Consider flow through annulus only.

If the three flow path modelling approach is used, the following flow paths with associated probabilities should be used:

- Flow through drill string: 10 %
- Flow through annulus between drill string and casing: 80 %
- Flow through an open hole: 10 %

Representation of all flow paths by annular flow at 100 % probability will give approximately the same mean flow rates and is considered a fully applicable alternative sufficiently accounting for the three flow path modelling approach.

In the modelling of flow through the drill pipe, no flow restrictions in the drilling bit or the BHA (bottom hole assembly) should be accounted for.

In the modelling of annular flow, the drill pipe should be modelled without a BHA and the end of the pipe should be positioned 10 meters above drilled depth.

6 RESTRICTED FLOW

If restricted flow is accounted for, the following probability distribution is recommended for all penetration depths:

- Restricted flow: 40 %
- Unrestricted flow: 60 %

Restricted flow is recommended modelled by maximum 95 % reduction of the flow path cross section and represented by a disc placed at the well outlet with a circular hole with diameter less than well inner diameter and minimum 5 % of the flow path cross section area.

Regardless of casing design, the following disc hole diameters are recommended as a simplified standardised representation of 95 % cross section reduction:

- Flow through drill pipe: 1”
- Flow through annulus: 1.5”
- Flow through an open hole: 2”

7 DURATION ANALYSIS

Reference is made to Section 4.4 in the NOROG report /1/ and in particular, Equation 3.1:

$$T = \min(T_{Active}, T_{Bridge}, T_{Relief}, T_{Cease}),$$

where T_{Active}, T_{Bridge}, T_{Relief} and T_{Cease} represent the time until the flow stops when the following mechanisms are considered in isolation:

- Active measures from the rig
- Bridging
- Drilling relief well(s)
- Natural cessation.

Refer to /1/ for further explanation of the mechanisms. The NOROG report applies to all types of drilling and well operations. Note that, due to the state of underground information, natural cessation is normally not recommended included as a stopping mechanism in analysis of exploration drilling.

During later years, blowout contingency in the form of installation of a capping stack is established in the industry and is recommended accounted for when establishing the duration probability distribution. This can be done by using the following modification of the above equation:

$$T = \min(T_{Active}, T_{Bridge}, T_{Relief}, T_{Stack}), \quad (7.1)$$

where T_{Stack} represents the time until the flow stops when considering the use of a capping stack in isolation.

Establishing a probability distribution of T_{Stack} should be well-specific and based on understanding of the complexity, failure mechanisms and limitations involved in installation of a capping stack on a blowing well. The analysis should include, but not be limited to include, consideration of:

- Technical limitations of applying a capping stack
- Operational challenges – there are a number of potential failure mechanisms that could occur during stack installation and well shut-in, that imply a probability of significantly lower than one even if operating within technical limits and area of application
- Mobilisation time
- Factors forcing offset installation
- Factors influencing duration related to vertical and offset installation.

REFERENCES

/1/ NOROG: Guidance on calculating blowout rates and duration for use in environmental risk analyses, 2014
/2/ OLF: Retningslinjer for beregning av utblåsningsrater og -varighet til bruk ved analyse av miljørisiko, 2004 (In Norwegian)
/3/ Lloyd's Register Consulting, "Blowout and well release frequencies based on SINTEF Offshore Blowout Database 2019", Report no: 19101001-8/2020/R3, 2020
/4/ SINTEF Offshore Blowout Database
/5/ Add Energy: Establishment of methods to include choking effects during blowouts - For environmental risk assessments (Report for Statoil), April 23rd, 2014

APPENDIX A - JUSTIFICATION FOR RECOMMENDATIONS ON PENETRATION DEPTHS

Section 4 recommends 2 alternative penetration depth models, consisting of two and three depths, respectively. Both models are based on common industry practices.

Historical blowout data from exploration wells representative for today's industry practice are scarce and considered a poor basis for establishing a probability distribution over the model penetration depths. Kick data, although not fully representing blowout scenarios has been considered to provide a better basis.

A study of 21 exploration well kicks in NOROG member company wells after 2003 has been performed. Most of the wells were NCS wells and a few wells outside Norway but with comparable technical and subsurface conditions. The depth distribution of these kicks was 33 / 43 / 24 %, representing the 5 m / 50% / 100% depth categories, rounded off to the 30 / 40 / 30 % distribution recommended in Section 4, in line with the principles of simplification to the conservative side in /1/. Note that kicks sorted under the 50% Drilling ahead scenario are incidents that were not triggered by depth-related factors and could have occurred at any depth. 50% MD penetration is used as an average depth of such occurrences. Note also that the data also included one kick taken in the intermediate section. In typical NCS exploration wells blowout scenarios resulting from intermediate section kicks will be rather similar to the 5 m scenario in the reservoir section, since the flow will be governed by limited reservoir exposure more than hole diameter, and are thus not included in the model as a separate category.

The probabilities 40 / 60 % recommended in Section 4 for the two-depth model 5 m /10 % are derived from comparative studies in a selection of example wells in Equinor and will produce the same probability-weighted rates as the tree-depth model.

The three-depth model is recommended in general. It will provide a more differentiated result, especially for multi-layer reservoirs, but also require more simulations than the two-depth model. The two-depth model is also sufficient, especially for thin reservoirs and reservoirs with simple geometry and uniform properties or wells with low flow potential and low environmental risk.

In general, the probabilities are recommended used as presented in Section 4. However, if suggested by significant well-specific aspects, the probabilities may be adjusted based on judgements in a multidisciplinary group of experts. The reasons for adjusting should be strong and supported by sound justification comprehendible to professionals not part of the expert team or well project.

For complex wells or reservoirs, a well specific model with more than 3 depths may be tailored. This could be relevant e.g. for wells with several pay zones and more than one pressure regime. If such models are developed, they should be based on the three-depth model and supported with justification providing a sound reasoning for the adjustments made.

Relevant incidents in the SINTEF Offshore Blowout Database /4/ have been reviewed as part of the development of the depth models. The review presented in Table A-1 included blowouts in 25 exploration and 8 development wells from 1980-2020. Refer also to some related comments below the table.

Table A-1: Historical blowout distribution by degree of reservoir penetration based on data from SINTEF Offshore Blowout Database /4/

Exposure time			**Since 1980**	**Last 30 years**	**Last 20 years**	**Last 10 years**	**Trend adjusted average**
Number of incident wells	**Total (Exp./Dev.)**		33 (25/8)	21 (16/5)	11 (9/2)	1 (1/-)	-
Incident fraction distribution	**Intermediate section**		0,40 (0,36/0,50)	0,52 (0,44/0,80)	0,64 (0,56/1,00)	-	0,39 (0,34/0,77)
	Reservoir section	**5 m into reservoir**	0,03 (0,04/-)	0,05 (0,06/-)	- (-/-)	-	0,02 (0,02/-)
		50 % of reservoir drilled	0,33 (0,44/-)	0,19 (0,25/-)	0,18 (0,22/-)	-	0,18 (0,23/-)
		100 % of reservoir drilled	0,24 (0,16/0,50)	0,24 (0,25/0,20)	0,18 (0,22/-)	1,00 (1,00/-)	0,41 (0,41/0,23)

The data includes exploration wells e.g. in US GoM, where the uncertainty related to the depth of the reservoir top is often higher and there is often more uncertainty related to the reservoir pore pressure. This is believed to produce relative high frequencies related to the intermediate section. As opposed to exploration wells, development often has a design where the intermediate section extends into the reservoir zone. This is also believed to drive this frequency.

As can be observed, the distribution of reservoir penetration depths in Table A-1 variates significantly over well type and observation period. The amount of data is limited, especially for exploration wells and wells with properties similar with typical NCS conditions. Moreover, it should be taken into account, that the level of detail in incident records does not always support identification of penetration depth. All in all, the kick data study described above is considered a more updated and robust basis for establishing the penetration depth probability distribution.

APPENDIX B - JUSTIFICATION FOR RECOMMENDATIONS ON FLOW PATHS

There have been two dominating industry practices related to flow path modelling the later years:

1. Separate between flow through drill string, through annulus and through an open hole
2. Focus on flow through annulus, assuming that drill string and open hole flow will balance each other when calculating the probability-weighed flow rate, based on rather low and equal probabilities being related to these two flow paths.

The two practices have been applied for both subsea and surface flow.

Simulations performed while developing these recommendations show that the assumption supporting practice (2) is valid. When comparing the probability-weighed flow rates derived from the two practices on five wells with different characteristics, the deviation between the two practices variated within +6.9/- 4.3 % (deviation of annulus model compared to three flow path model). The small impact of the simplification, which saves considerable simulation efforts, provides a basis for recommending continued use of both the above practices, as described in Section 5.

Among the companies who have used practice (1) with three flow paths, different relative probability distributions have been applied and partly different distributions have been used at different penetration depths. In the development of these recommendations it was agreed to simplify and standardise the distribution.

Relevant historical incidents in the SINTEF Offshore Blowout Database /4/ have been reviewed with regards to flow path. Table B-1 shows data from the period 1980-2017 and includes 33 blowouts in 25 exploration wells and 8 development wells. 5 of these blowouts were registered with two flow paths. Below, the wells with two flow paths are treated as individual incidents, one for each flow path.

Table B-1: Historical blowouts from /4/ distributed on flow paths

Flow path	Number of incidents exploration drilling	Number of incidents development drilling	Total number of incidents
Inside DP/tubing	3	1	4
Annulus	11	4	15
Outer annulus	7	3	10
Outside casing	6	1	7
Open hole	1	0	1
Underground blowout	1	0	1
Sum	**29**	**9**	**38**

Underground flow is not relevant for BSA. Moreover, simulations show that the flow paths outer annulus and outside casing typically give flow rates in the same range as annulus. Thus, Table B-1 can be extended to Table B-2.

Table B-2: Re-distribution of 37 historical non underground blowouts on three recommended flow paths

Flow path	No. of incidents	Flow path group	No. of incidents	Relative frequency
Inside DP/tubing	4	Drill string	4	0,11
Annulus	15	Annulus	32	0,86
Outer annulus	10			
Outside casing	7			
Open hole	1	Open hole	1	0,03
Sum	**37**	**Sum**	**37**	**1,00**

In order to account for uncertainty and simplify to the conservative side in line with the principles of the main report, the frequencies from Table B-3 are rounded to the recommended probabilities presented in Table B-3 and in Section 5.

Table B-3: Recommended blowout flow path probabilities for practice (1) with three flow paths

Flow path	Probability
Drill string	10 %
Annulus	80 %
Open hole	10 %
Sum	**100 %**

APPENDIX C - JUSTIFICATION FOR RECOMMENDATIONS ON RESTRICTED FLOW

A blowout implies flow of reservoir fluid from the reservoir(s) to the surroundings. However, during a blowout, restrictions may be present in the well causing flow to be lower than the potential flow allowed by the flow paths described in Section 5 and App. B. Possible causes to restriction include:

- A partly closed BOP
- Elements of the well structure are deformed and reducing the flow path cross section
- Pieces of well equipment partly block the flow path
- Collapsed formation or well filling up with formation solids.

The restriction model described in Section 6 is developed based on scenarios with a partly closed BOP but may also be considered to represent restriction effects from the other, above mentioned causes.

During the process of preparing the NOROG guidance report /1/ simulations were performed by Add Energy to explore the effect of restrictions on flow rate. A main conclusion was that for a restriction representing an about 95 % reduction of the flow path cross section is necessary in order to reduce the flow rate significantly.

Three main approaches to restriction modelling in BSA are observed in the industry the later years:

1. Not taking account of potential restrictions
2. Restrictions modelled as 95 % reduction of the flow path
3. Restrictions modelled as a disc with a 1" hole placed on top of the well.

Approach (1) is a conservative approach that may be practicable for wells with low risk, but not fit for purpose for wells potentially close to risk tolerance criteria. (2) reflects the NOROG guides well, but it opens for interpretation with respect to existing variations of well design. (3) is a simple and practicable approach, but it does not necessarily correspond with 95 % cross section reduction introduced in the NOROG main report for all flow paths. Moreover, a 1"-opening would be prone to be eroded to a larger diameter over time in wells with high flow rate.

Through cross industry discussions the model described in Section 6, representing a compromise between approaches (2) and (3) was agreed. The model is based on a disc on the top of the well, but with diameters 1", 1.5" and 2", to represent flow through a drill string, annulus and open hole, respectively. For typical exploration well design on the NCS, these dimensions will be close to the 95 % closure criteria for all flow paths.

It is recommended to use this set-up also for wells deviating from the typical design, e.g. using a 9 5/8" liner instead of the traditional 9 5/8" liner or wells with flow potential in sections above the reservoir section.

It has been argued that erosion could still decrease the choking effect of a restriction over time. Modelling of erosion is however considered to introduce a, for most cases, unnecessary level of detail to the BSA. Another time-dependent effect in flow modelling, which require detailed modelling and analysis, is reduced flow over time due to reservoir depletion. Neglecting both these effects in the analysis can be argued to counter-act each other and be considered as a practicable simplification.

Among the industry parties that have applied approaches (2) and (3) above, a relative probability of 70 % has commonly been used for restricted flow for all flow paths. Based on a review of statistics and studies /3/, /4/, /5/ and discussion among professionals, it has been concluded that the basis for using this probability figure is weak. A probability of 40 % is recommended based on an overall evaluation. The data and considerations made are summarized below.

Lloyd's annual reports /3/ present statistics on historical blowouts judged to have been restricted based on interpretation of release points and flow path of relevant incidents in the SINTEF Offshore Blowout Database /4/. In the 2020 report 48 % of the incidents were considered to have restricted flow. According to /5/ this proportion has been considerably higher in earlier reports. Table C-1 presents the distribution of incidents in exploration and development wells on restricted vs full flow and flow paths.

Table C-1: Distribution of blowouts between full and restricted flow and flow paths. Development drilling in parentheses), ref. /3/.

Flow path	**Restricted**	**Full**	**Distribution**
Inside drill pipe	(1)		4 %
Annulus	8 (1)	2	44 %
Open hole	1		4 %
Outer annulus		3 (3)	24 %
Outside casing	1	5	24 %
Sum	**10 (2)**	**10 (3)**	

In Lloyd's categorisation of blowouts as full or restricted thorough considerations are not made with respect to the degree of restriction/choking. As discussed above, a significant reduction of the flow rate will not take place unless choking at a level corresponding to about 95 % reduction of the flow path cross section area occurs. Hence, there are reasons to assume that a significant proportion of the choked incidents do not comply with the NOROG definition of restricted flow. The report does not discuss the effect of a restriction over the duration of the blowouts.

In /5/ Add Energy presents figures from review of their own incident database. They report that in total 55 % of the incidents were considered restricted. 35 of the 55 % were restricted by a partly closed BOP. The data contain incidents on different well and operation categories and the report does not discuss whether the restricted flow occurrences with regards to 95 % choking.