International Pipeline Conference 2018

# An Update to the Recommended UKOPA External Interference Failure Frequency Prediction Model & Pipeline Damage Distributions

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UKOPA

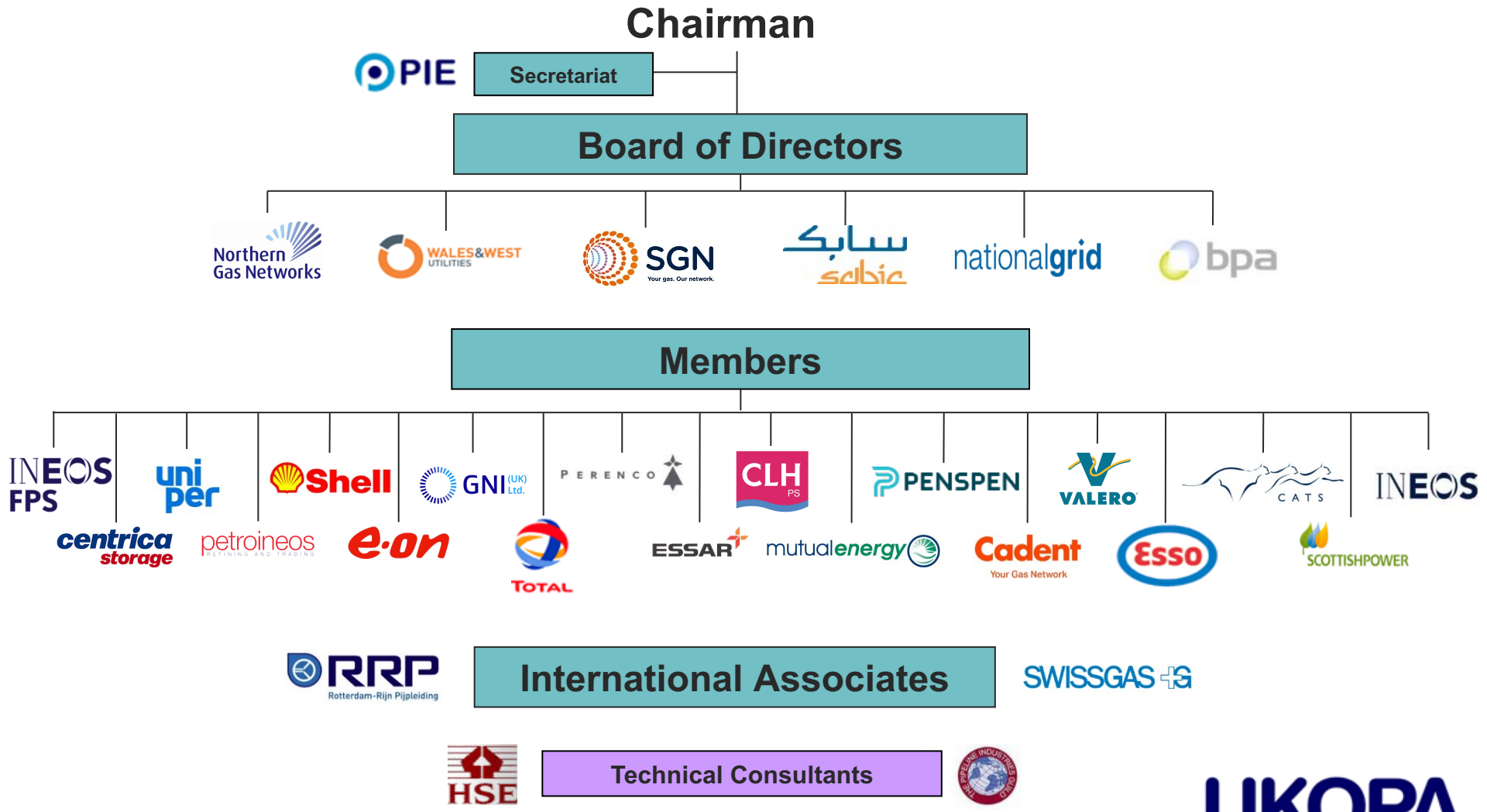
# Presentation Overview

- What is UKOPA?
- UKOPA Database
- Why Predict External Interference Failure Frequency?
- Current UKOPA Recommended Methodology
  - FARWG Review Projects
- Updated Model Recommendations
  - Dent Force
  - Distributions
- Updated Damage Distribution Parameters
- Prediction Comparison
- Summary & Conclusions

# What is UKOPA?

- The United Kingdom Onshore Pipeline Operators Association
  - Founded in 1996 to represent the views & interests of UK hazardous pipeline operators
    - **Recognised** and **authoritative** view of UK Pipeline Operators on **strategic** issues relating **to quantitative risk assessment, safety management, operations and integrity management** of pipelines.
    - Effectively **influence** the development and implementation **of pipeline related legislation** and standards for the **mutual benefit** of all stakeholders
    - Promote **good practice** in the pipeline industry.
  - Currently 27 members
    - > 21,845 km network with ≈1,000,000 km years operating experience
  - Overall strategy set by Board and discussed at main meetings
    - Workload  driven by 5 working groups
    - Chaired & attended by volunteers from member companies
    - Secretarial support from PIE
    - Technical support from consultants (currently PIE and DNV GL)
    - Some technical work outsourced

# UKOPA Organisation



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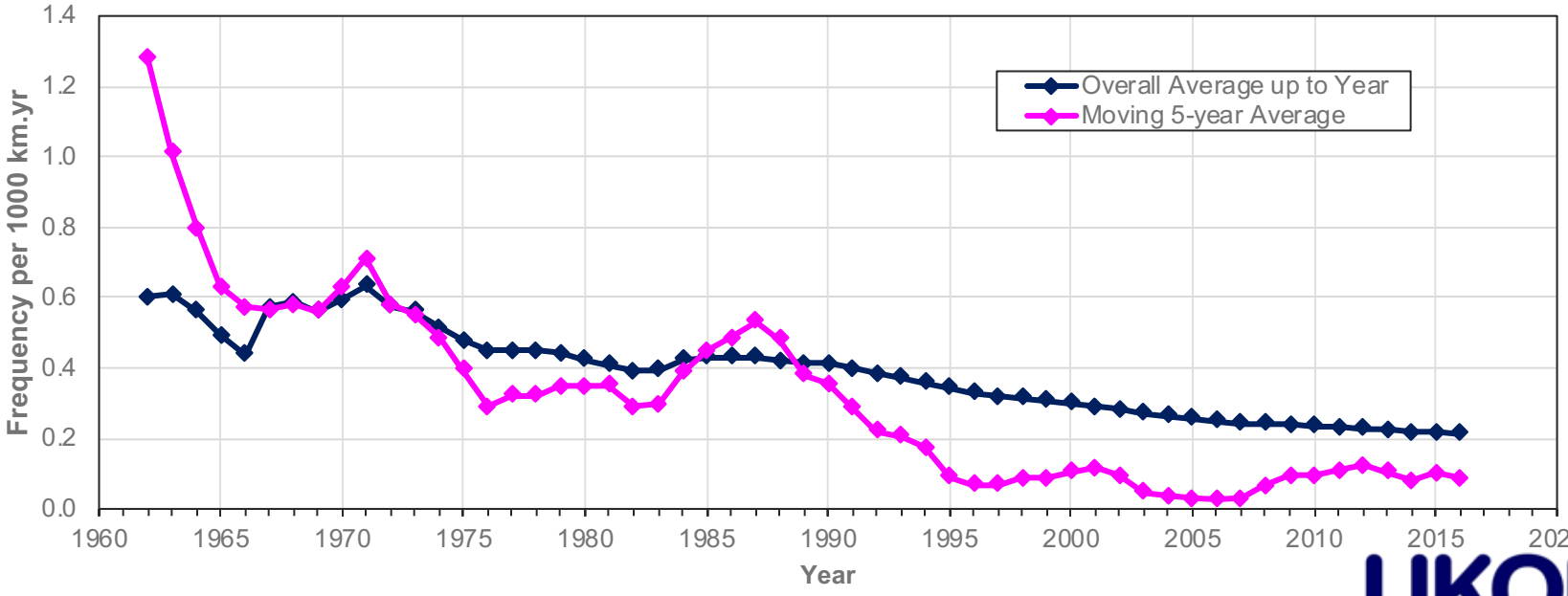
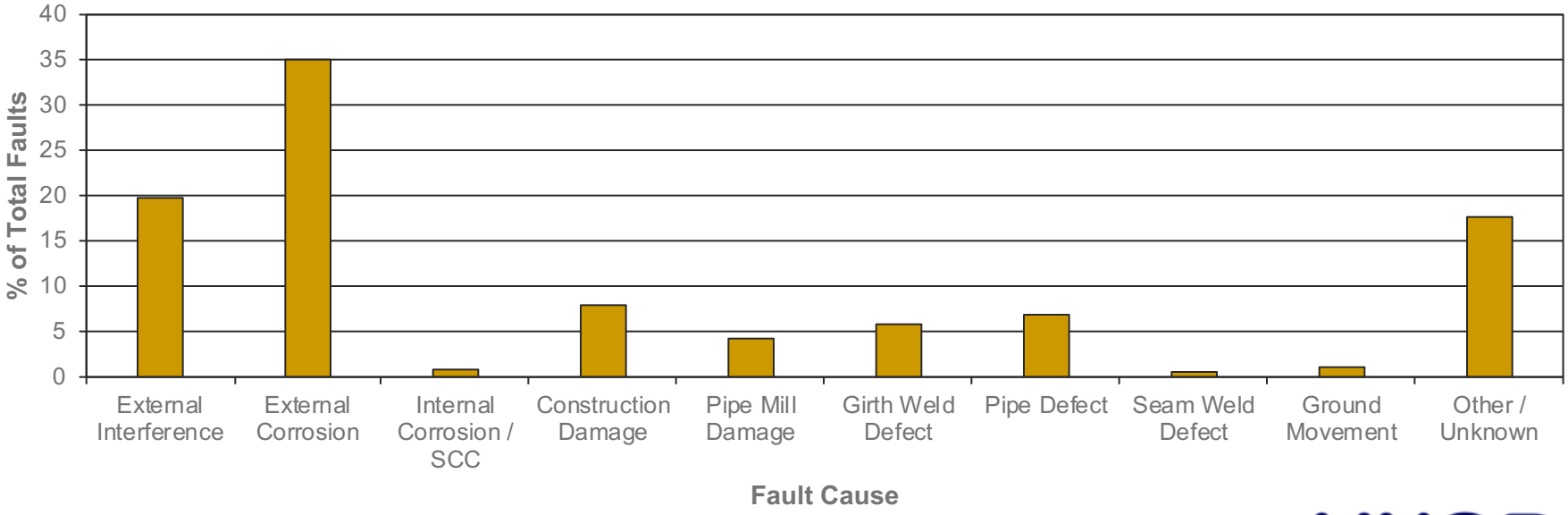
# UKOPA Database – Product Loss Data

- Data from 11 MAHP Operators
  - Natural Gas, Ethylene, Spiked Crude & LPG pipelines but not Gasoline & Stable Crude
  - Exposure = 927,351 km years (1952 – 2016)
  - 197 product loss incidents (1962 – 2016)
    - Product loss frequency = 0.212 x $10^{-3}$ per km year



# UKOPA Database – Fault Data

- UKOPA Database also records faults
  - Damage that did not cause failure with defect dimensions confirmed by field dig
    - 3756 faults (up to end 2016)
      - 5967 associated individual defects



# Why Predict External Interference Failure Frequency?

- Things occasionally go wrong…

# Why Predict External Interference Failure Frequency?

- Only 43 external interference loss of containment incidents in the database

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- Only 43 external interference loss of containment incidents in the database

| Diameter [inches] | Exposure [km.yr] | External Interference Incidents | Frequency [per 1000 km.yr] |
|---|---|---|---|
| 0 - 4 | 44,243 | 5 | 0.113 |
| 5 - 10 | 186,294 | 22 | 0.118 |
| 12 - 16 | 155,228 | 9 | 0.058 |
| 18 - 22 | 136,557 | 3 | 0.022 |
| 24 - 28 | 147,156 | 3 | 0.020 |
| 30 - 34 | 43,826 | 1 | 0.023 |
| 36 - 48 | 208,648 | **0** | 0.000 |
| **TOTAL** | **921,995** | **43** | **0.047** |

| Wall Thickness [mm] | Exposure [km.yr] | External Interference Incidents | Frequency [per 1000 km.yr] |
|---|---|---|---|
| <5 mm | 58,933 | 13 | 0.221 |
| 6 - 10 mm | 433,332 | 26 | 0.060 |
| 11 - 15 mm | 352,906 | 4 | 0.011 |
| >15 mm | 76,300 | **0** | 0.000 |
| **TOTAL** | **921,995** | **43** | **0.047** |

- Not enough historical failures to derive a pipeline specific failure frequency
  - No failures from any cause for diameters ≥ 36” or wall thickness > 15 mm

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# Current UKOPA Prediction Model Recommendations

- Probabilistic defect distribution parameters derived from UKOPA database
  - Gouge Length, Gouge Depth & Dent Depth
- Characteristic values for pipeline parameters
- ‘Hit’ rate calculated from UKOPA database
- Standard failure equations
  - EPRG Dent-Gouge model (API 579 / ASME FFS-1) & NG-18 (flow stress dependent)
- Presented at IPC2008
- Methodology embedded in the FFREQ program
  - Part of DNV GL Pipesafe software (JIP Members only)
    - Or PIE, Penspen and other models

- Updated defect distribution parameters presented at IPC2012 (1962-2009)

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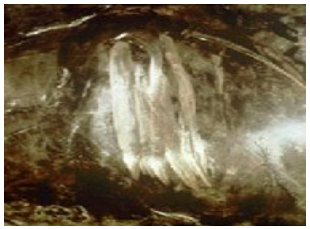
- Updated defect distribution parameters presented at IPC2012 (1962-2009)

| Weibull Parameters | Gouge Length | Gouge Depth | Dent Depth |
|---|---|---|---|
| Shape (α) | 0.573 | 0.674 | 1.018 |
| Scale (β) mm | 125.4 | 0.916 | 9.382 |



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# FARWG Review Projects

- UKOPA Fault & Risk Working Group
  - Committed to updating distribution parameters every 5 years
    - Previous update included data to end 2009…
  - Aware of areas where prediction methodology could be improved
    - National Grid COOLTRANS $CO_2$ pipeline research project

- 2 projects kicked off in 2017
  - Review current recommended prediction methodology
    - Pipeline Integrity Engineers (PIE)
  - Update distribution fit analysis for 2010 – 2016 data
    - Highgrade Associates (HGA)

# Prediction Methodology Review

- PDAM2
  - Latest edition of JIP review of ‘best’ methods for defect assessment
- NG COOLTRANS
  - AFFECT – development of prediction model for thick-walled $CO_2$ pipelines
- EPRG new dent-gouge model
  - Not yet available for formal review
    - Model may require parameters on dent shape
    - Only dent depth recorded in UKOPA database

- Key areas of prediction methodology reviewed
  - Limit-state Models
  - Spring-back & Re-rounding of Dents
  - Leak-Break Boundary
  - **Dent Force**
  - **Distributions**

# Dent Force

- Original assumption that external interference damage is independent of pipeline and depends only on excavator
  - Reasonably credible for gouges but less so for dents
- Dent depth will also depend on pipeline resistance to denting
  - Pipe geometry, material properties, internal pressure, backfill properties
- Create a distribution of force applied during external interference events instead of dent depth
  - Dent depth records
  - Pipeline design and operating parameters
  - Model relating dent depth and force applied

- EPRG semi-empirical relationship recommended

$$F_{dent} = 0.49\sqrt{P_r}H_P^{0.42} \qquad P_r = \sqrt{\sigma_Y L t}\left(t + \frac{0.7PD}{\sigma_U}\right)$$

  - Most important thing is to use same model in both directions

# Distributions

- UKOPA previously published distribution parameters for
  - Gouge length, gouge depth and dent depth
  - Weibull distributions used for historical reasons
- ISRU at Newcastle University reviewed UKOPA defect data for COOLTRANS project
  - ‘Plain’ gouges are a statistically separate population from gouges in dents
  - Lognormal a better fit for some distributions
- 5 distributions recommended
  - ‘Plain’ Gouge Length & Depth
  - ‘Gouge in Dent’ Gouge Length and Depth
  - Dent Force

# Summary of UKOPA Prediction Methodology Recommendations



- Limit State Models
  - Remain NG-18 and EPRG Dent-gouge
- Spring-back and Re-rounding of Dents
  - Should be accounted for
    - Use simple EPRG correlation
- Leak-break boundary
  - Defined by 3 term flow stress dependent Folias factor
- Dent force should be used instead of dent depth
  - Simple EPRG model to convert dent depth to force and back
- 5 damage distributions
  - Lognormal or Weibull

# Updated Damage Distribution Parameters

- Data reviewed by Highgrade Associates
  - Data filtered, defects classified & distributions fitted using MLE method in @Risk

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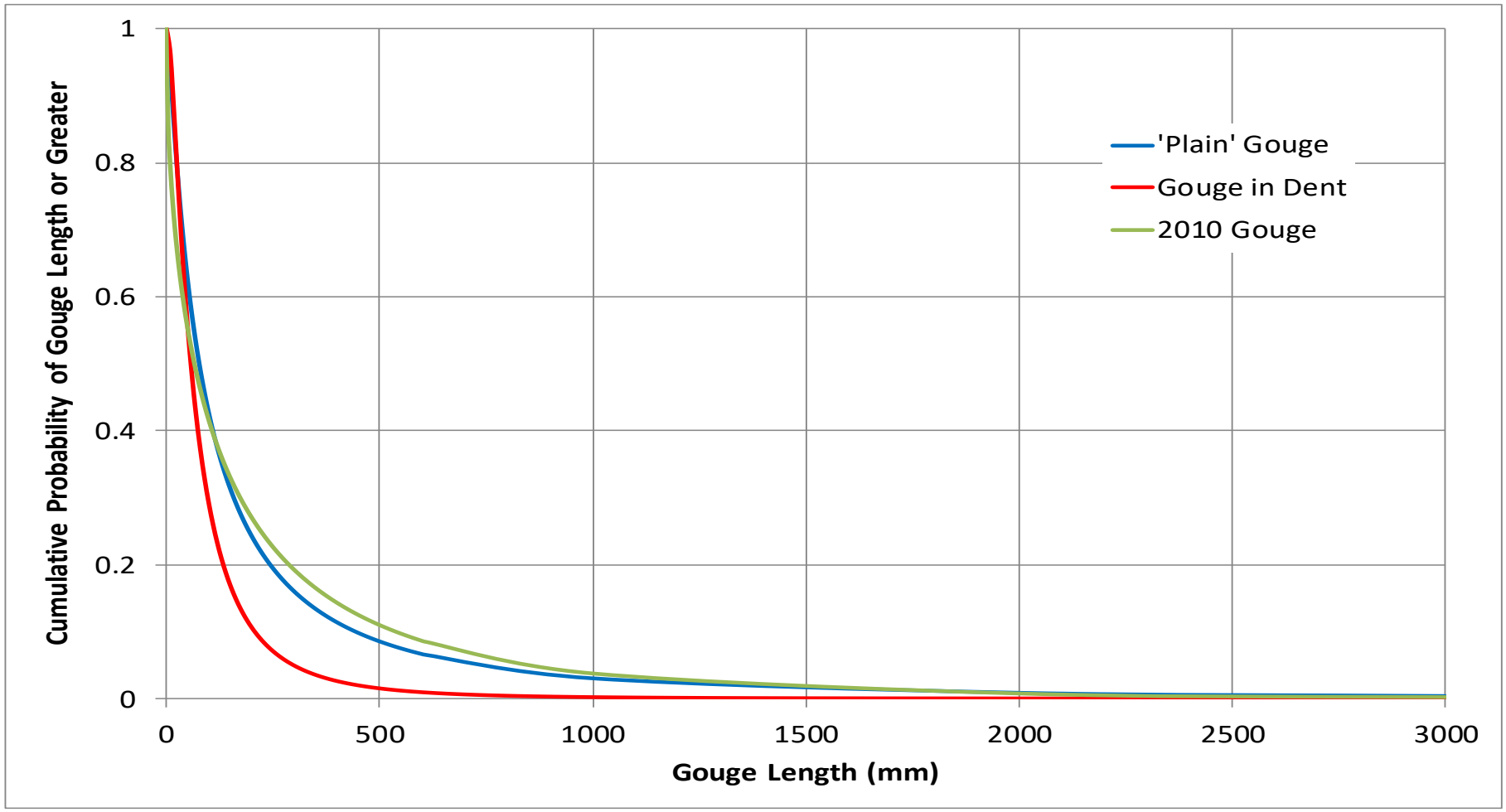
| Description | Number of Records |
|---|---|
| 'Plain' Dents | 50 |
| Dents associated with Gouges | 80 |
| **Total Dents** | **130** |
| 'Plain' Gouges | 551 |
| Gouges in Dents | 131 |
| **Total Gouges** | **686** |
| **Total External Interference Defects** | **808** |

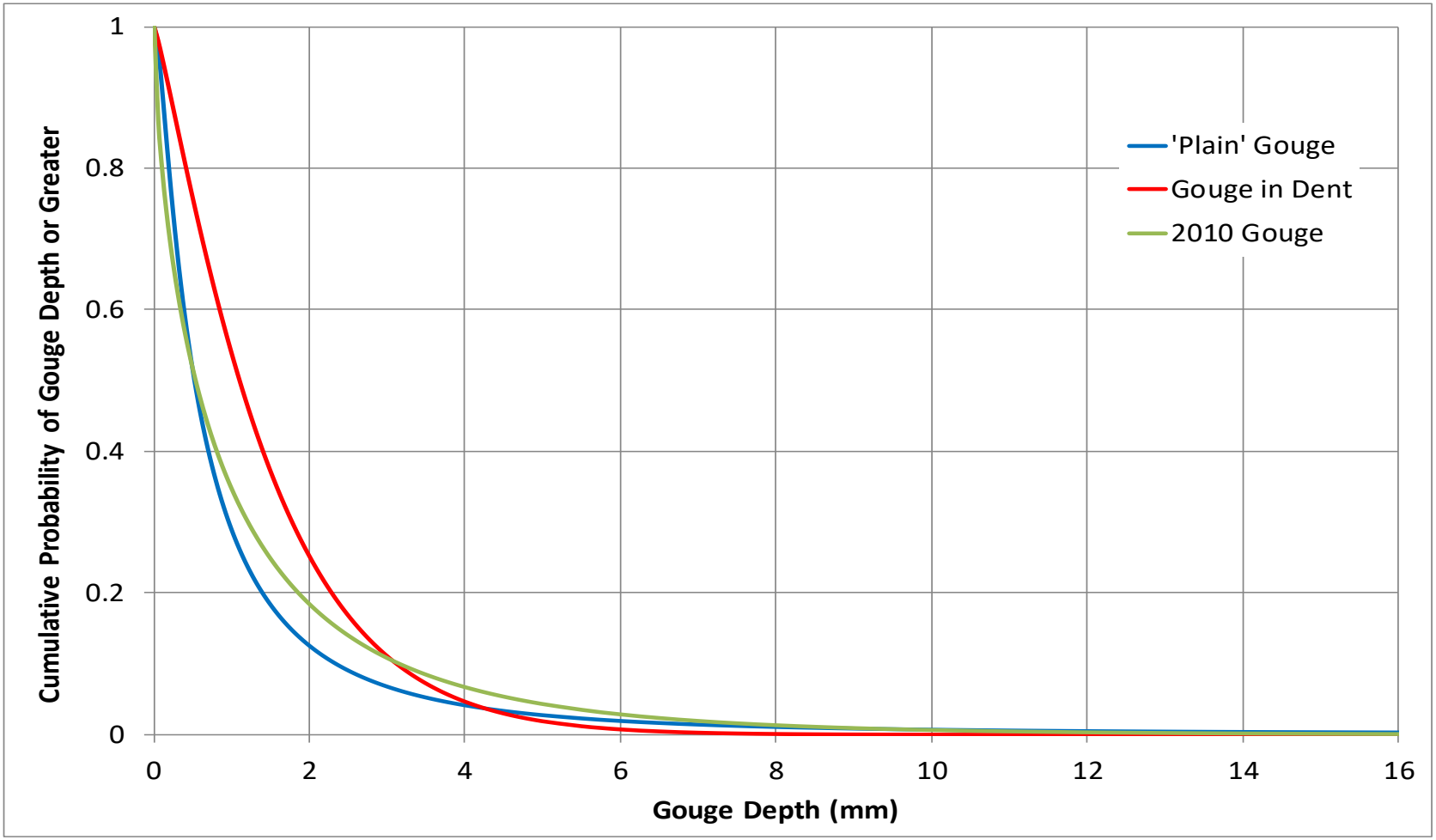
# Updated Distribution Parameters

| Fault Type | Fault Parameter | Distribution Type | Distribution Parameters | |
|---|---|---|---|---|
| 'Plain' Gouge | Length (mm) | Lognormal | μ | σ |
| | | | 4.351 | 1.360 |
| | Depth (mm) | Lognormal | μ | σ |
| | | | -0.645 | 1.161 |
| 'Gouge in Dent' | Length (mm) | Lognormal | μ | σ |
| | | | 4.059 | 0.996 |
| | Depth (mm) | Weibull | α | β (mm) |
| | | | 1.15 | 1.51 |
| Dent | Force (kN) | Lognormal | μ | σ |
| | | | 3.969 | 0.516 |

# Gouge Length



# Gouge Depth


Cumulative Probability of Gouge Depth or Greater
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
Gouge Depth (mm)
'Plain' Gouge
Gouge in Dent
2010 Gouge

# Frequency of External Interference

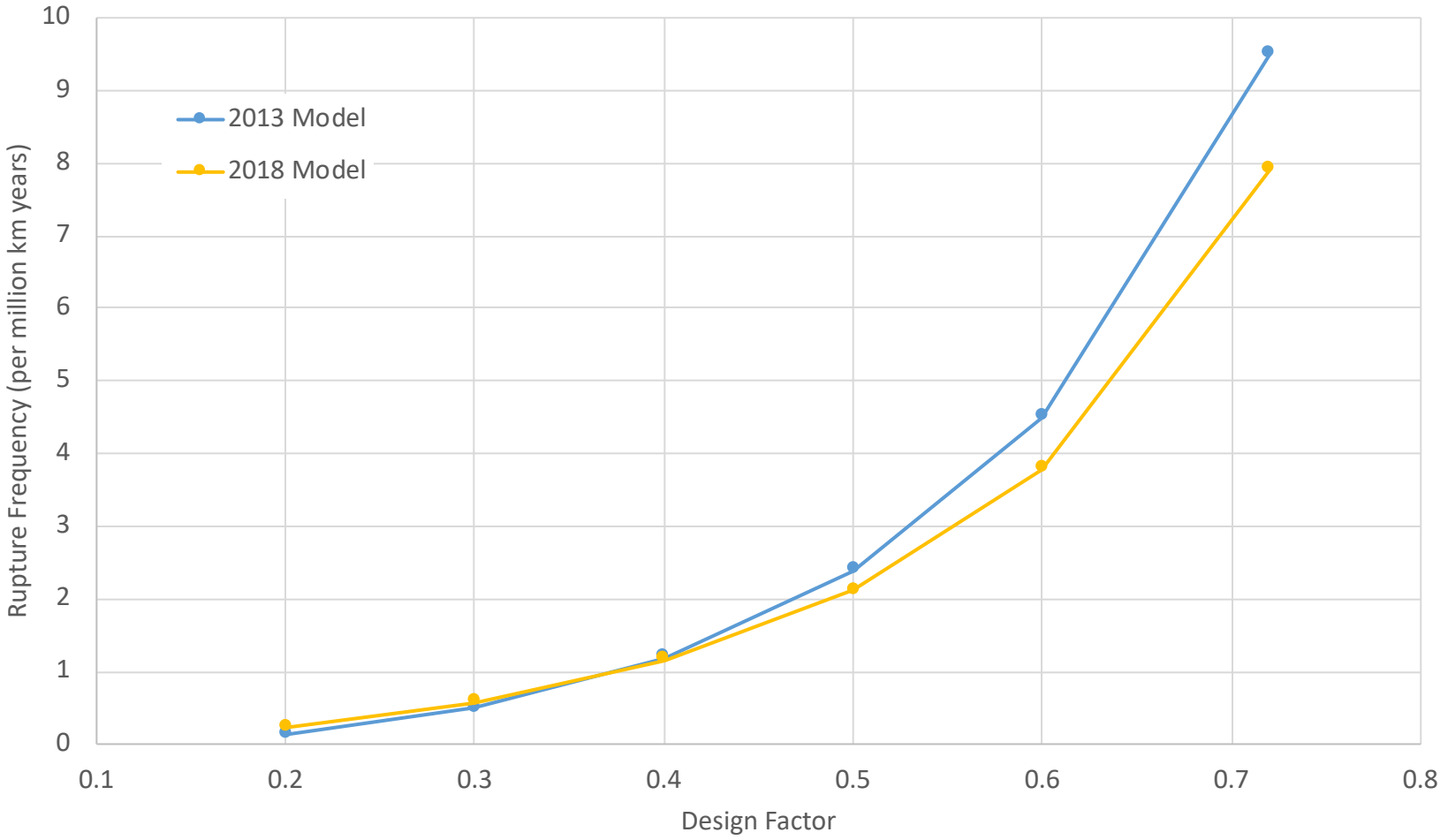
- 1962 to 2016
  - Total individual defects with non-zero depth = 728
  - Total operating exposure = 927,351 km years
- This gives ‘hit rate’ corresponding to average depth of cover of incidents in database
  - Normalised to nominal 1.1 m depth of cover
- Frequency of external interference in UK Rural area

  = 1.091 per thousand km years
  - R area ≈ Class 2 (B31.8 / CSA Z662)

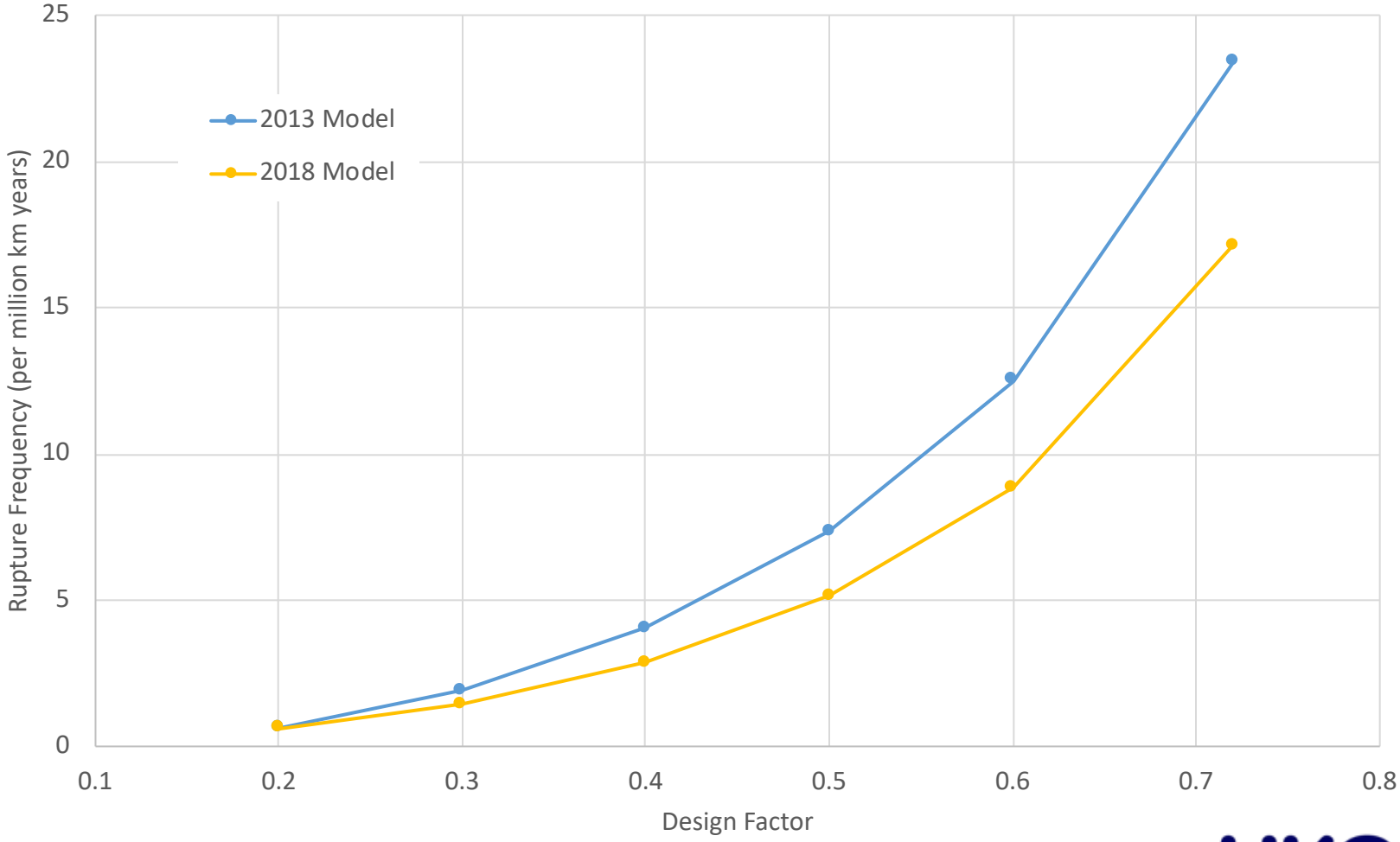
# Prediction Comparison

- Calculations for a standard range of pipeline diameters, grades, wall thicknesses and design factors
  - Various models from FFREQ (mid-1990s) to 2018 update
- Rupture predictions presented for 3 sets of pipeline cases using 2013 and 2018 models
  - 914 mm diameter, X65, 11.91 mm wall thickness
  - 609 mm diameter, X60, 9.52 mm wall thickness
  - 323.9 mm diameter, X52, 6.35 mm wall thickness
- Only change due to distribution parameters and ‘hit rate’

# 914 mm, X65, 11.91 mm



# 609 mm, X60, 9.52 mm



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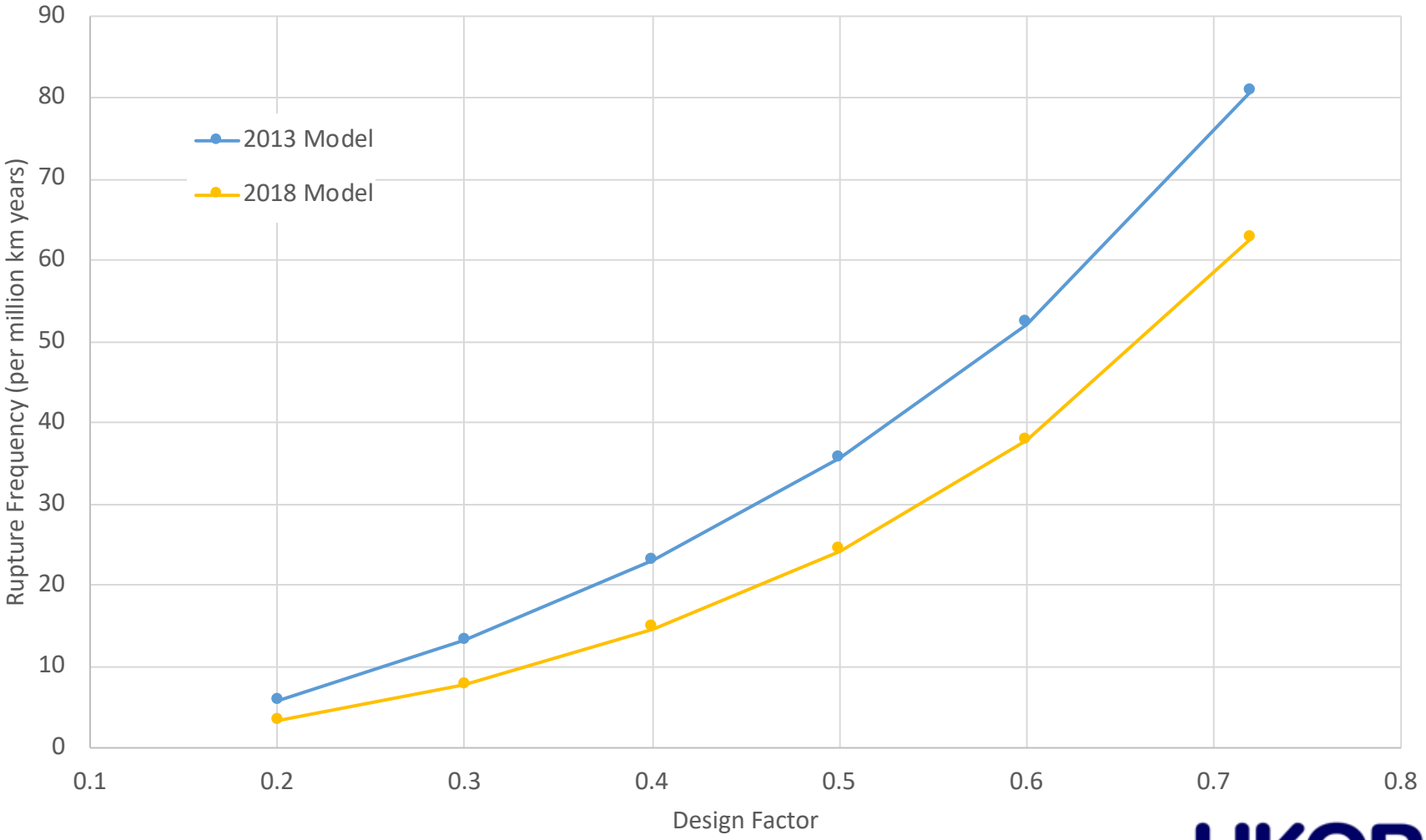
# 323.9 mm, X52, 6.35 mm



# Summary & Conclusions

- Significant review of key elements of methodology for predicting external interference failure frequency completed
- Parameters for 5 damage distributions produced

- Small reduction in predicted rupture failure frequency between 2013 and 2018 models
  - 6 years more data included in distributions
  - Reduction in hit rate

# Thanks


- Co-authors for all the hard work

- All members of the UKOPA Fault and Risk Working Group for contributions to the development of this work over the years
  - Especially Jane Haswell & Rod McConnell

- Special thanks for assistance and advice
  - Julian Barnett, Andrew Cosham and Bob Andrews,

# Any Questions?