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How can new P&A technologies ever demonstrate they are good enough to meet industry requirements?

Astrimar Ltd

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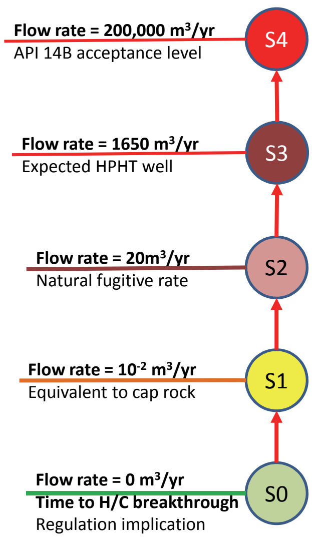
How good does a well barrier need to be?

- DCR Regulations: Prevent escape of fluids on a permanent basis
  - How long is permanent? - eternal implication
  - Prevent escape: Does this mean zero leakage?
- What if the barrier leaks?
  - Life will depend on leak acceptance criteria
  - Which acceptance criteria are appropriate?
- What is the barrier Life?
  - Prediction and/or
  - Long term monitoring



How good do new plug materials need to be?

- Regulatory acceptance required
- OGUK require evidence that the new plug material has:
  - Acceptable sealing performance ← Replace cap rock? As good as cement ?
  - Durability: 3000 years ← Remain in place and not leak for 3000 year

Durability: the ability of a physical product to remain functional, without requiring excessive maintenance or repair, over its required lifetime.

- What are the barriers to entry of new plug materials into P&A market
  - As good or better sealing performance than a good cement
  - Lower installation /deployment cost, time and resources than cement

How can new P&A technologies ever demonstrate they are good enough to meet industry requirements?

- Evidence provided through qualification of plug materials
  - OGUK (2015): Guidance on qualification of materials for the abandonment of wells

OGUK (2015) Qualification of Materials for Well P&A

- Required characteristics of barriers
  - Very low bulk permeability
  - Good interface seal
  - Remain in place
  - Resistance to down hole fluids
  - Suitable material/mechanical properties
  - Long term integrity

Example Metallic Plug Recommended Tests	OGUK Criteria
Dry mass (corrosion weight loss) after ageing	< 3%
Expansion/swelling during hardening	<1% linear expansion
Shrinkage during hardening	<1% linear shrinkage
Differential thermal expansion relative to casing	within 10^{-5} K^{-1}
Creep	<1% linear strain
Ultimate Compressive Strength before ageing	>1.4MPa
Ultimate Compressive Strength after ageing	>1.4 MPa
Tensile strength after ageing	< 50% reduction
Shear bond strength before ageing	>1Mpa
Shear bond strength after ageing	>1Mpa
Decomposition temperature	Non-melting at well Temp

- Interpret measured material characteristics
- Translate to expected performance
- Provide assurance of meeting regulatory expectations

↓

- The only realistic approach is to use Predictive models with a lot of support from qualification testing data

Materials and Plug Performance Questions

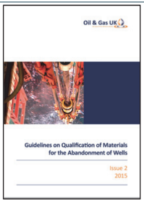
- Long term barrier performance - a major challenge
  - Metal barriers (excluding noble metals) will eventually corrode and return to more stable hydrated oxides, hydroxides and sulphides (plugs and casing)
  - Cements in contact with well fluids and formation fluids react to form more stable compounds
- Degradation rate
  - How fast ? Over decades, centuries, millennia?
- Impact of degradation on leak rate?
  - Does corrosion increase the permeability /leak rate of metal plugs?
  - How much does cement degradation affect permeability / leak rate?
- How does sudden or slowly changing stress impact plug performance?
  - If it yields, does leak rate increase?
- Need more emphasis on understanding rate of degradation and impact of ageing on barrier performance

Plug Technology Readiness Questions

- Do laboratory measurements accurately reflect field conditions?
  - Material property tests ok to achieve TRL4
  - Small scale prototype plugs ok to achieve TRL5
  - Full scale rigs and/or field trials needed to demonstrate TRLs 6 to 8
  - Long term monitoring with acceptable reliability needed to demonstrate TRL9
- Common for developers to jump to full scale TRL 6 testing before doing ground work to achieve TRLs 4 and 5

TRL	Description
1	Basic principles observed. Science research translated into applied R&D
2	Technology concept formulated. Technology reviewed - paper studies
3	R&D initiated as proof of concept. Simple experimental tests conducted
4	Materials tested and plug concept demonstration initiated
5	Prototype plug developed and tested in the laboratory
6	Full scale plug validated in a suitable full scale test facility
7	Operational plug system Integration tested in a suitable full scale test facility
8	Plug system installed and commissioned
9	Plug system operating with acceptable reliability

Data input to Predictive Models



Well and Plug Design → Workshop Trials

Material Qualification Tests → Predictive Model → Plug Performance (Leak rate and Life)

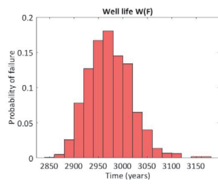
Q-FMECA

INPUTS → **MODEL** → **OUTPUTS**

Materials database: qualification test data, existing published data

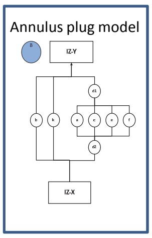
Plug and Well data
Well condition, annulus cement condition, plug design, well design

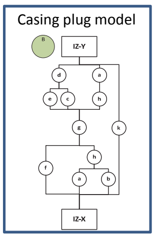
Predictive models: integrate accepted theory with experimental materials data and well specific data

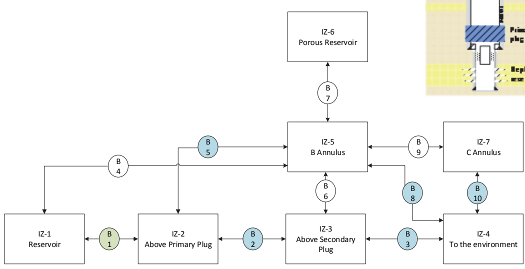


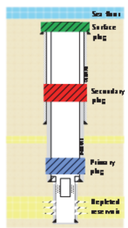
Using STEM-flow to assess Bi alloy plugs

- Astrimar supporting RECL in the qualification of bismuth alloy as part of Innovate UK funded research programme
  - Q-FMECA and identification of qualification tests
  - Develop models to predict seal performance, plug and well life
    - Annulus plugs, casing plugs
- STEM-flow tool developed by Astrimar
  - Predict barrier and well system performance
  - All barrier elements modelled
  - Materials Database





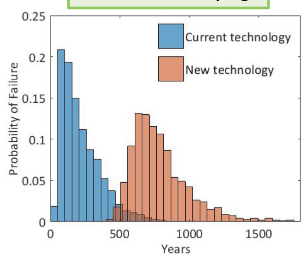




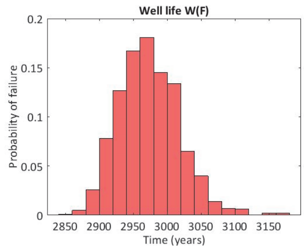
Use of STEM-flow in Bi alloy Plug Qualification

- Developed to enable forecast of plug and well leak rates, volume released and plug life
- Model parameters are based on
  - measured barrier characteristics such as those defined in OGUK guidelines
  - Specified acceptance criteria
  - Plug design
- MCS routines are used to address uncertainty in parameters
- Generates distribution of plug/well life
- Qualification test data used to reduced the uncertainty in predicted performance
- Compare new plug material performance with existing cement performance

Statistical life of plug

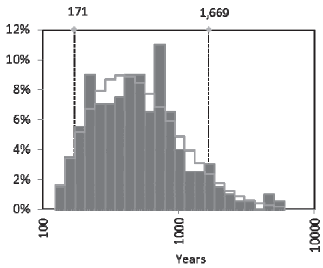


Statistical life of well

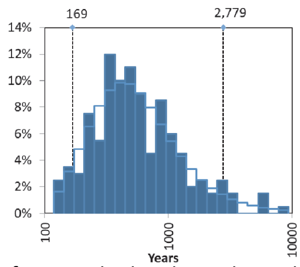


Predicted Life for Various P&A Scenarios

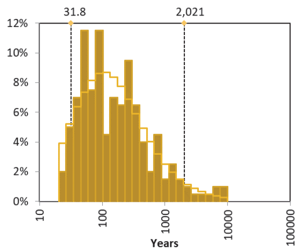
Good cement, logged annulus



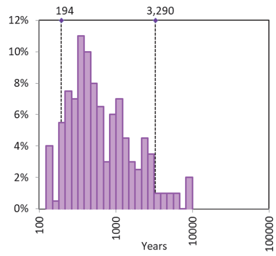
Low shrinkage cement, logged annulus



1000ft Unlogged annulus combination barrier



10 ft Bismuth plug, logged annulus



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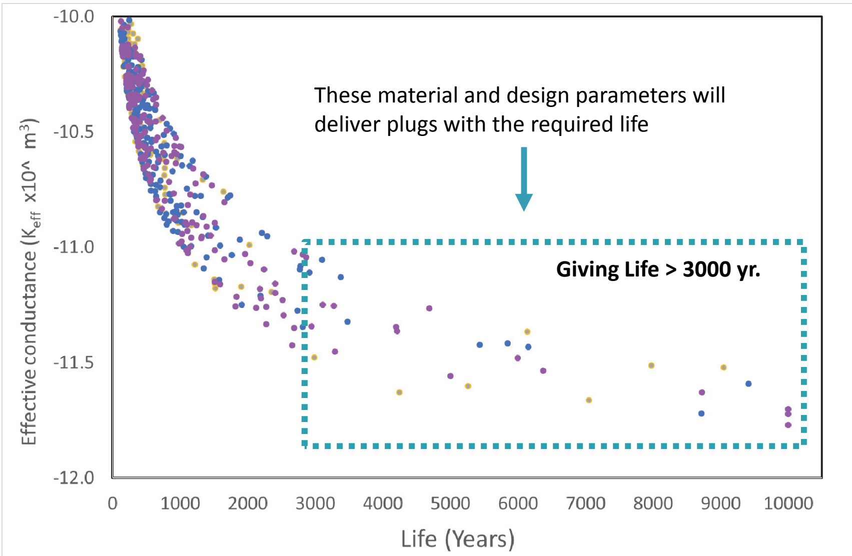
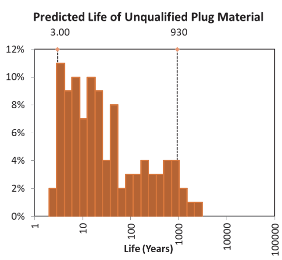


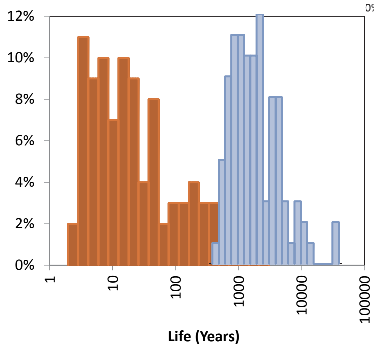
Benefits of Qualification of Structural Bismuth Alloy Annulus Plug

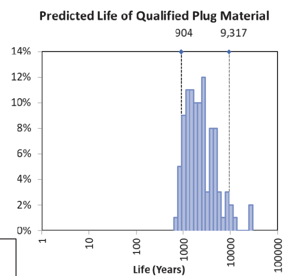


Life expectation for an unqualified Bi Alloy anulus plug Sealing against cap rock

Large uncertainty in predicted leak rate and life

Impact on Bi Alloy life uncertainty following TRL 4 extensive testing





Life expectation for a qualified Bi Alloy anulus plug sealing against caprock

Marked improvement in leak rate and life performance

Conclusions

- Performance depends on requirements
  - H/C Breakthrough, maximum leak rate or volume released
- Barrier material properties:
  - Do not directly relate to required barrier performance
  - Interface properties more important than bulk material properties
  - Modelling is required to translate measured properties to performance
- Significant life performance uncertainty around the impact of long term material degradation on bulk and annulus barrier leakage
- Without qualification data – performance uncertainties are large
- Qualification reduces performance uncertainty but may still not meet requirements
- STEM-flow is being used to determine the barrier material properties, design and well conditions that will deliver a 3000 year leak free life

Astrimar

Thank you for listening

Questions ?

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