ALLOY-BASED ALTERNATIVES FOR OIL WELL PLUGGING AND ABANDONMENT

SPE Aberdeen Well Abandonment 2019

26-27 June

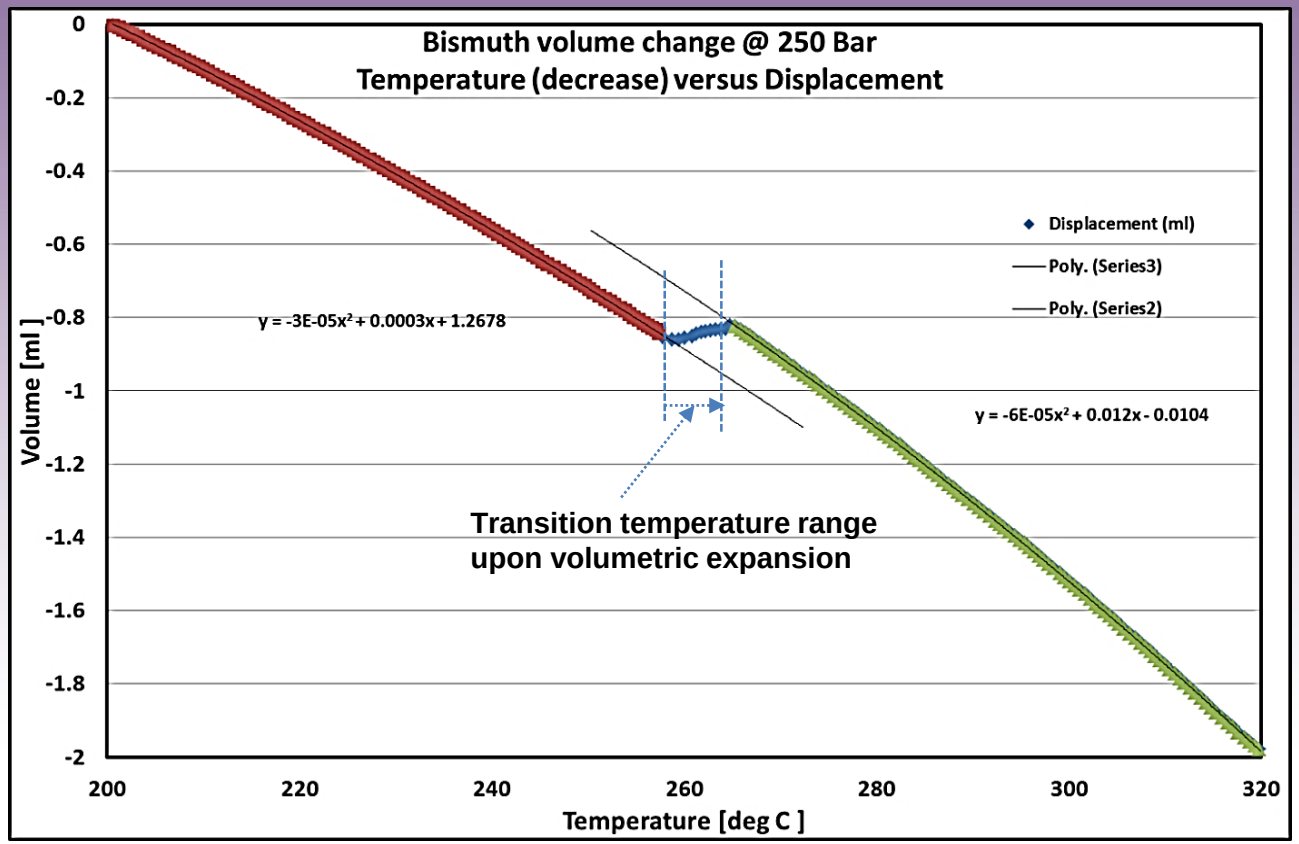
Rawwater Engineering part of the Rawwater Group

Myth busting

- 50,000 psi differential pressure seals (do not exist)
- Expanding alloys above the melting point of bismuth (do not exist)
- Bismuth plugs exist (not really true, but bismuth alloy/ steel composites do, the alloy being the matrix…)
- Bismuth plugs threaten cement (not given the global production of only 10,000 tonnes per annum)

Dunning-Kruger effect: "*The skills you need to produce a right answer are exactly the skills you need to recognize what a right answer is.*"

Understanding volumetric expansion



A World first: Proof of concept, 2010

A successful deployment and pressure test…

…but six months later there was a failure.

Why?

Cause of Failure

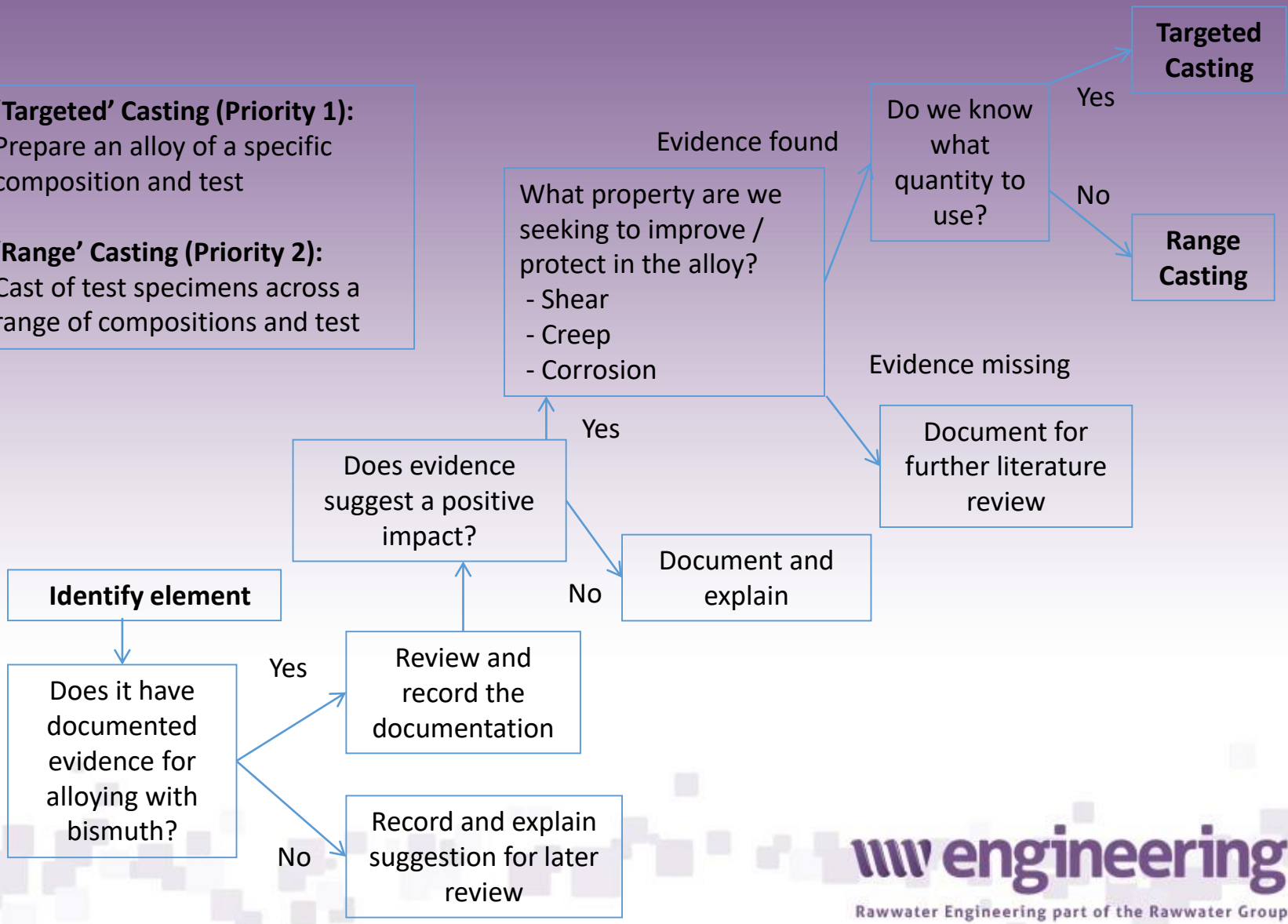
- Corrosion, but of what? The plug or the casing?
- Plug Creep, but when? At deployment or later?

It turned out to be the casing. But in the process of understanding the failure, alloy creep & deployment temperature had to be investigated, researched and understood…

Alloy development programme logic

'Targeted' Casting (Priority 1):
Prepare an alloy of a specific composition and test

'Range' Casting (Priority 2):
Cast of test specimens across a range of compositions and test



ww engineering
Rawwater Engineering part of the Rawwater Group

Materials qualification: Structural vs non-structural Alloys

‘Hardened’, before and after creep test

Bi:Sn eutectic

Plug Technology Qualification Testing

Characteristics of bismuth alloy barriers:

- Structural bismuth alloys have zero permeability
- Potentially high contact load against casing and rock: good seal
- Potential to resist high differential pressure
- Generally corrosion resistant
- Long term integrity

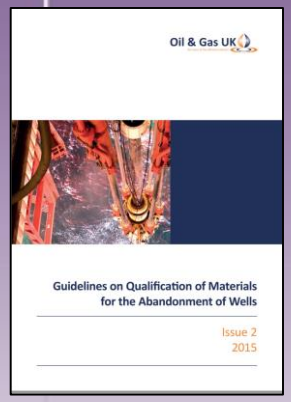
Workshop trials

- 7” plug mandrel
- Max 7.5ksi test
- Environment heaters
- Mandrel, alloy and casing thermocouples
- Multiple mandrel and casing strain gauges
- Air and pressure casting

£4,000,000 investment to date (including Nuclear and Defence)

Rawwater Engineering part of the Rawwater Group

Data Input to Predictive Models



Well and Plug Design

Material Qualification Tests

Q-FMECA

Workshop Trials

Predictive Model

INPUTS

Materials database
qualification test data, existing published data

INPUTS

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

MODEL

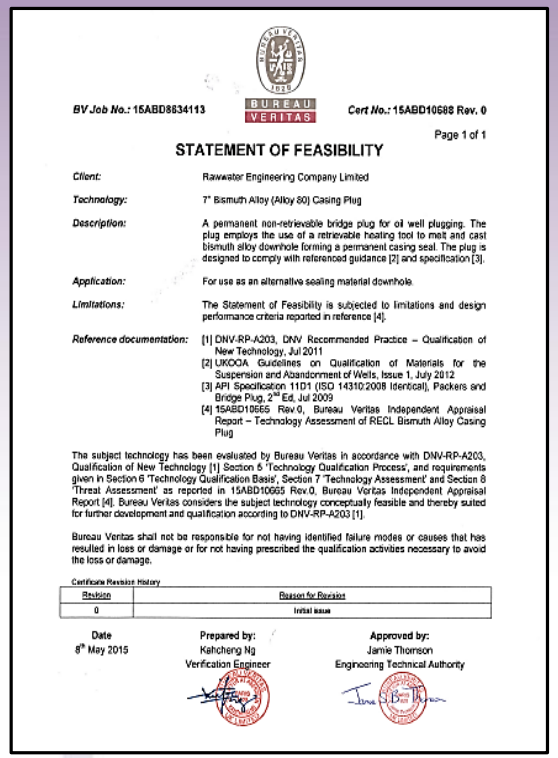
Predictive models
integrate accepted theory with material, workshop test and well specific data

Slide layout courtesy of Astrimar

ww engineering
Rawwater Engineering part of the Rawwater Group

Qualification of New Technology

1. Qualification in accordance with DNV-RP-203 (07/13)
2. Independent validation: Bureau Veritas



BV Job No.: 15ABD8834113 — Cert No.: 15ABD10688 Rev. 0

Page 1 of 1

STATEMENT OF FEASIBILITY

Client:	Rawwater Engineering Company Limited
Technology:	7" Bismuth Alloy (Alloy 80) Casing Plug
Description:	A permanent non-retrievable bridge plug for oil well plugging. The plug employs the use of a retrievable heating tool to melt and cast bismuth alloy downhole forming a permanent casing seal. The plug is designed to comply with referenced guidance [2] and specification [3].
Application:	For use as an alternative sealing material downhole.
Limitations:	The Statement of Feasibility is subjected to limitations and design performance criteria reported in reference [4].
Reference documentation:	[1] DNV-RP-A203, DNV Recommended Practice – Qualification of New Technology, Jul 2011 [2] UKOOA Guidelines on Qualification of Materials for the Suspension and Abandonment of Wells, Issue 1, July 2012 [3] API Specification 11D1 (ISO 14310:2008 Identical), Packers and Bridge Plug, 2nd Ed, Jul 2009 [4] 15ABD10665 Rev.0, Bureau Veritas Independent Appraisal Report – Technology Assessment of RECL Bismuth Alloy Casing Plug

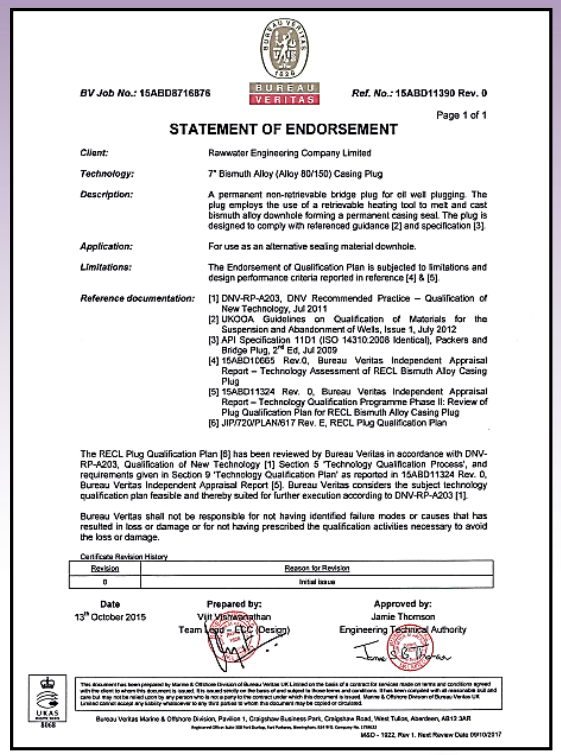
The subject technology has been evaluated by Bureau Veritas in accordance with DNV-RP-A203, Qualification of New Technology [1] Section 5 'Technology Qualification Process', and requirements given in Section 6 'Technology Qualification Basis', Section 7 'Technology Assessment' and Section 8 'Threat Assessment' as reported in 15ABD10665 Rev.0, Bureau Veritas Independent Appraisal Report [4]. Bureau Veritas considers the subject technology conceptually feasible and thereby suited for further development and qualification according to DNV-RP-A203 [1].

Bureau Veritas shall not be responsible for not having identified failure modes or causes that has resulted in loss or damage or for not having prescribed the qualification activities necessary to avoid the loss or damage.

Certificate Revision History

Revision	Reason for Revision
0	Initial issue

Date	Prepared by:	Approved by:
8th May 2015	Kahcheng Ng Verification Engineer	Jamie Thomson Engineering Technical Authority



BV Job No.: 15ABD8716876 — Ref. No.: 15ABD11390 Rev. 0

Page 1 of 1

STATEMENT OF ENDORSEMENT

Client:	Rawwater Engineering Company Limited
Technology:	7" Bismuth Alloy (Alloy 80/150) Casing Plug
Description:	A permanent non-retrievable bridge plug for oil well plugging. The plug employs the use of a retrievable heating tool to melt and cast bismuth alloy downhole forming a permanent casing seal. The plug is designed to comply with referenced guidance [2] and specification [3].
Application:	For use as an alternative sealing material downhole.
Limitations:	The Endorsement of Qualification Plan is subjected to limitations and design performance criteria reported in reference [4] & [5].
Reference documentation:	[1] DNV-RP-A203, DNV Recommended Practice – Qualification of New Technology, Jul 2011 [2] UKOOA Guidelines on Qualification of Materials for the Suspension and Abandonment of Wells, Issue 1, July 2012 [3] API Specification 11D1 (ISO 14310:2008 Identical), Packers and Bridge Plug, 2nd Ed, Jul 2009 [4] 15ABD10665 Rev.0, Bureau Veritas Independent Appraisal Report – Technology Assessment of RECL Bismuth Alloy Casing Plug [5] 15ABD11324 Rev. 0, Bureau Veritas Independent Appraisal Report – Technology Qualification Programme Phase II: Review of Plug Qualification Plan for RECL Bismuth Alloy Casing Plug [6] JIP/720/PLAN/617 Rev. E, RECL Plug Qualification Plan

The RECL Plug Qualification Plan [6] has been reviewed by Bureau Veritas in accordance with DNV-RP-A203, Qualification of New Technology [1] Section 5 'Technology Qualification Process', and requirements given in Section 9 'Technology Qualification Plan' as reported in 15ABD11324 Rev. 0, Bureau Veritas Independent Appraisal Report [5]. Bureau Veritas considers the subject technology qualification plan feasible and thereby suited for further execution according to DNV-RP-A203 [1].

Bureau Veritas shall not be responsible for not having identified failure modes or causes that has resulted in loss or damage or for not having prescribed the qualification activities necessary to avoid the loss or damage.

Certificate Revision History

Revision	Reason for Revision
0	Initial issue

Date	Prepared by:	Approved by:
13th October 2015	Vijit Vishwanathan Team Lead – ECC (Design)	Jamie Thomson Engineering Technical Authority

Bureau Veritas Marine & Offshore Division, Pavilion 1, Craigshaw Business Park, Craigshaw Road, West Tullos, Aberdeen, AB12 3AR

Next Steps

- Aberdeen office expansion
- Collaboration with deployment partner
- Deployment and monitoring of 3000 yr plug

Any Questions?

For further information, contact:
lee.billingham@rawwater.com
bob.eden@rawwater.com

ww engineering
Rawwater Engineering part of the Rawwater Group