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Extended abstract

Assessing the impacts of scale residues from offshore oil and gas decommissioning on marine organisms

Tom Cresswell[A,C], *Sue Brown*[A], *Henri Wong*[A] *and Simon Apte*[B]

[A]ANSTO, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia.
[B]CSIRO Land and Water, New Illawarra Road, Lucas Heights, NSW 2234, Australia.
[C]Corresponding author. Email: Tom.Cresswell@ansto.gov.au

Abstract. Successful decommissioning of offshore oil and gas infrastructure requires an effective and safe approach to assessing and managing chemical and radiological residues. Scale frequently accumulates on the interior surfaces of pipes and other structures and may persist long after extraction operations have ceased. Scale materials can contain a range of metal contaminants (including mercury), as well as naturally occurring radioactive materials. In newer or more accessible infrastructure, the scale is routinely removed, and becomes a waste product. The persistent nature of scale contaminants can result in a radiological dose to the organisms living on, or near an intact pipeline. Eventually, infrastructure corrosion following *in situ* decommissioning (abandonment) could lead to metal and radionuclide contaminants being accessible to the surrounding seafloor environment, where bioaccumulation and subsequent ecotoxicological effects from the chemical and radiological properties of the scale could occur. The paper describes a tiered approach to assess the ecological impacts of pipeline scale in order to assist operators with their plans for decommissioning offshore infrastructure, especially when considering ‘leave in place’ options.

Keywords: decommissioning, closure, retirement, offshore infrastructure, pipelines, scale, metals, mercury, naturally occurring radioactive materials, NORM, risk assessment, *in situ*, ecotoxicology, ecology, marine.

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Introduction

Australia’s marine Exclusive Economic Zone is one of the largest in the world, covering a total marine area of approximately 10 million km^2. Australia’s marine industries were estimated to be worth more than A$68 billion a year in 2015–2016 with the oil and gas industry being the second largest contributor at over A$23 billion a year (AIMS 2018). By the year 2026, it is estimated that over 65 offshore installations around Australia’s coast and in territorial waters will require decommissioning in some form at an estimated cost of US$39 billion (A$60 billion) over the next 30 years (Wood Mackenzie 2020).

While the current decommissioning requirement in Australia is for complete removal of all offshore infrastructure by the operator (*Offshore Petroleum and Greenhouse Gas Storage Act 2006*, available at https://www.legislation.gov.au/Details/C2017C00051), there is an opportunity for *in situ* decommissioning (e.g. leave in place) under certain circumstances and where it is deemed to be environmentally acceptable. Several academic reviews of offshore oil and gas decommissioning practices have been published in recent years (Fam *et al.* 2018; Fowler *et al.* 2018; Bull and Love 2019; Sommer *et al.* 2019), and most consider partial removal options can deliver better environmental outcomes than complete removal for platforms (e.g. Fowler *et al.* 2018). While some of these reviews list contaminants associated with decommissioned infrastructure as environmental and ecological considerations for decommissioning (e.g. Sommer *et al.* 2019), such contaminants are often constrained to the disturbance of drill cuttings located on the seafloor or the degradation of materials including metal anodes or primary infrastructure components. There is rarely any recognition of contaminants associated with subsea pipelines that may contain metals (e.g. mercury) and naturally occurring radioactive materials (NORM) in the form of precipitated scale on pipeline internals (Fig. 1). By 2060, the predicted NORM inventory for Australia’s decommissioned offshore assets is estimated to be between 223 and 1674 tonnes (McKay *et al.* 2020). Similar estimates for metals within residues (i.e. not associated with primary infrastructure components) are unavailable. Such contaminants, if left in place with associated infrastructure, may pose a risk to surrounding marine organisms and to human consumers of marine organisms.

Wood Mackenzie (2020) highlights the lack of knowledge of environmental impacts from offshore decommissioning as one

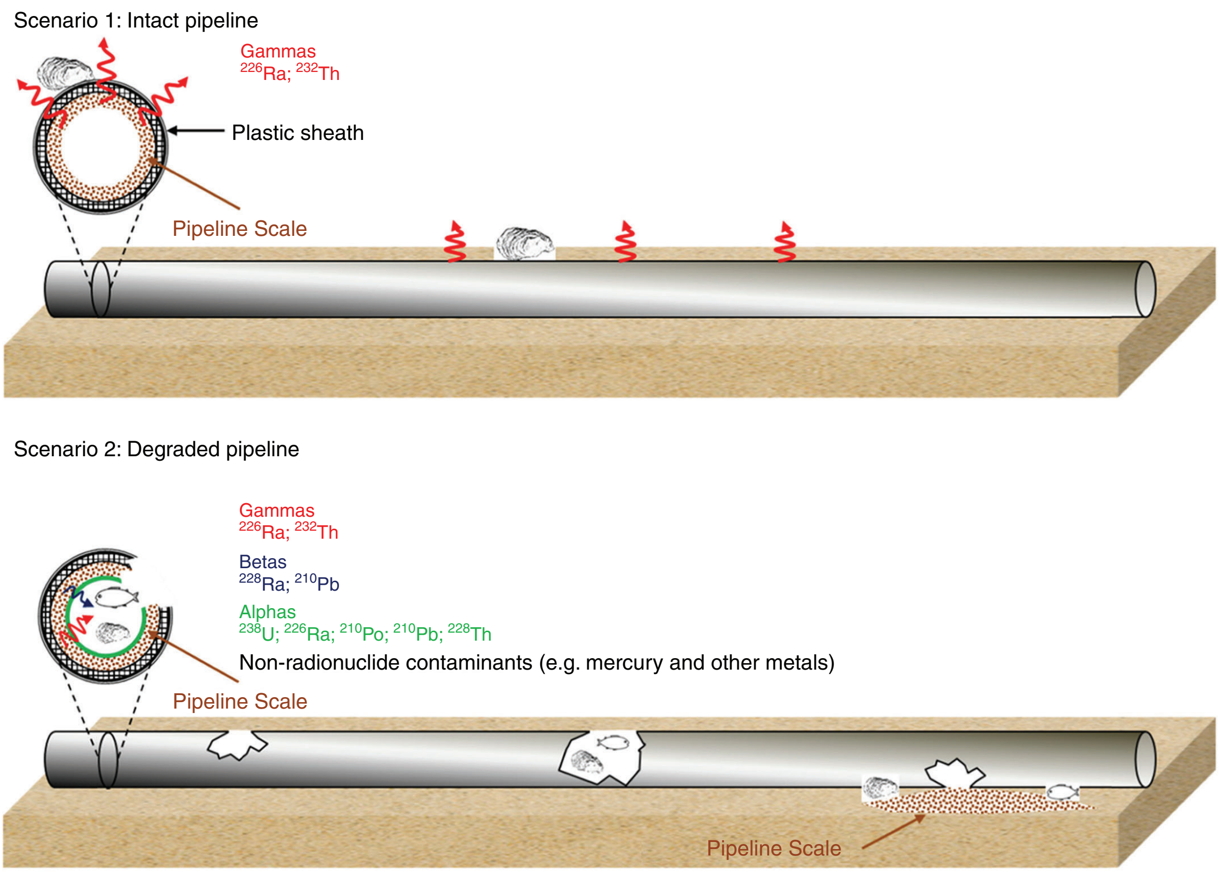

Fig. 1. Conceptual model of subsea pipeline scale inorganic contaminant exposure scenarios to marine organisms. Scenario 1 represents a sealed operational/shortly after decommissioning pipeline where sessile organisms may be exposed to gamma radiation from scale. Scenario 2 represents a degraded pipeline (following 'leave *in situ*' decommissioning) where organisms may colonise/seek refuge in pipe internals. Contaminant exposure may include exposure to gamma and beta radiation (external dosimetry) and exposure to alpha radiation and metal contaminants via dissolution/direct ingestion.

of the key issues surrounding Australia's upcoming decommissioning exercise. Furthermore, the *Australian Environment Protection* (*Sea Dumping*) *Act 1981* (https://www.legislation.gov.au/Details/C2016C00778) specifies that 'Before granting a permit for dumping or artificial reef placement…a provision that the applicant will, at his or her own expense, undertake such research and monitoring…relating to the consequences of the release into the marine environment through the proposed dumping operation or artificial reef placement of any contaminants (Section 19:9a)'. This paper describes a tiered approach to assess the ecological impacts of pipeline scale in order to assist operators with their plans for decommissioning, especially when considering *in situ* abandonment options.

Methods

We have developed the following approach to qualifying and quantifying inorganic and radiological contaminants and the potential for risk to marine ecosystems. The approach is separated into four tiers: (1) characterisation of the inorganic and radiological contaminants; (2) solubility/leach testing in seawater and dilute acid; (3) radiological dose modelling for model marine organisms; and (4) direct organism bioaccumulation assessments in the laboratory. In order to perform the above assessments, it is necessary to recover scale material (~200 g) from subsea pipelines. This could occur via either the sampling of pigging dust at the pig receiver and/or via recovery of a section of pipe from the seafloor to an onshore facility, where internal scale is removed and sent to our laboratory. Both sample types are hereafter referred to as scale. At each assessment tier, concentrations of metal/loid contaminants are compared to environmental quality guidelines such as the Australia and New Zealand Guidelines for Fresh & Marine Water Quality (ANZG 2018). If concentrations of individual contaminants exceed either sediment or water quality guidelines, the next tier of assessment is conducted. For NORM contaminants, there are no specific environmental quality guidelines and therefore a biota radiological dose assessment is undertaken (Tier 3).

Tier 1: scale characterisation

A subsample of received scale is pulverised (<50 μm) before a borate fusion is undertaken. The sample is then analysed via X-ray diffraction to determine the major crystalline matrix and X-ray fluorescence to determine the major elemental

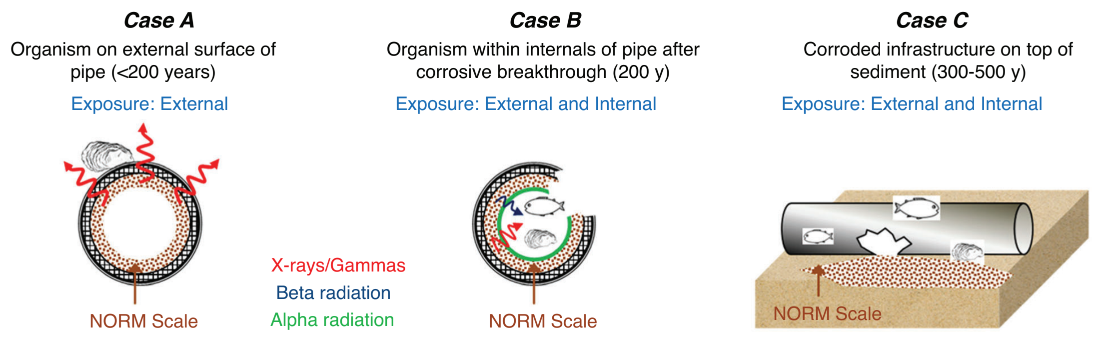

Fig. 2. Conceptual model of the cases used to estimate radiological doses to marine biota using the ERICA Assessment Tool.

composition. Another pulverised subsample is decomposed via a sodium peroxide fusion digest before being analysed via inductively coupled plasma mass spectrometry (ICP-MS) for trace elemental composition. A third pulverised subsample undergoes high efficiency steam distillation and the evolved methylmercury is captured, the compounds decomposed by pyrolysis to Hg^0 and analysed by an atomic fluorescence detector to determine methylmercury percentage of the total mercury.

Tier 2: solubility testing

A subsample of the received scale is screened (<2.4 mm) and leached in seawater in the laboratory at the ambient water temperature of the seabed from where the pipeline is located. The method has been modified from the Australian Standard Leaching Procedure (ASLP; AS4439.3). Samples are leached in duplicate at a loading of 1:100 (solid to seawater ratio) in bottles rolled at 6 rpm in an incubator. Seawater leachates are conducted over two periods (18 ± 2 h and 1 month) to determine dissolution kinetics. At the end of the specified periods, leachates are filtered (<0.45 μm) and analysed for seawater soluble inorganic and radiological constituents.

A second subsample of screened scale is leached in dilute acid to target exchangeable forms of contaminants. This leach provides an over estimation of the concentration of contaminants that may be solubilised in the gut of a marine organism after ingestion. Samples are exposed to 1 M hydrochloric acid for 60 min before being filtered and analysed for dilute-acid extractable inorganic and radiological constituents.

Tier 3: biota dose modelling

The concentrations of radionuclides from scale characterisation (i.e. bulk radionuclides) and from seawater solubility testing are used to estimate the potential radiological impacts to marine biota from exposure to scale radionuclides using the ERICA Assessment Tool. Three case scenarios are modelled (Fig. 2): (A) intact pipeline where organisms exist on the external surface of a pipe (e.g. pipe operation and immediately following decommissioning); (B) organisms within internals of pipeline after corrosive breakthrough; and (C) corroded pipelines on top of sediments.

Basic radiological dose assessments are conducted with a standard set of model organisms that represent key taxa within the benthic marine ecosystem, accounting for attenuation due to pipeline materials for gamma radiation. Results from dose modelling are compared against derived consideration reference levels for marine biota in table 1 of ARPANSA (2015). The ARPANSA table summarises some information on effects to wildlife at different dose rates in the environment that can guide discussions on environmental reference levels.

Tier 4: organism bioaccumulation assessments

If dilute-acid extractable concentrations of metals contained within scales exceed sediment quality guideline values (ANZG 2018), it is important to understand the bioavailability of those contaminants. Equally, if the concentration of dissolved metals from seawater leachate tests (1 month leach period) exceeds the 95% or 99% species protection levels of the default water quality guideline values (ANZG 2018), bioavailability assessments should be undertaken. Dietary bioaccumulation tests consist of treatment groups of representative marine organisms, which are fed scale-containing pellets for 28 days (one food pellet per day at approximately 5% of body weight per day) followed by a 24 h depuration period where no food is provided, following a standard protocol for dietary bioaccumulation tests (ASTM 2010). The tissue metal and NORM concentrations of the treatment group are determined analytically and compared to those of control groups of organisms (same diet with no scale). This provides a conservative estimation of contaminant bioavailability from scale and will greatly aid in the determination of the ecological fate of scale-associated contaminants in the marine environment.

Summary and conclusion

The process described in this paper allows for a more informed decision making process to be undertaken regarding the decommissioning of subsea petroleum pipelines. This approach has the potential to create large cost savings for industry, while demonstrating best-practice environmental protection of the marine ecosystem. It is important to note the following limitations wherein the approach:

- Currently does not include analysis of organic contaminants, although the approach could easily be extended.
- Is unable to simulate leaching of radionuclides at excessive (>120 m) depths.

- Is not able to determine total leachable elements from seawater solubility tests – this requires repeat (exhaustive) leach testing.
- Does not provide information on the biological effects of accumulated contaminants to marine organisms.

Conflicts of interest

All authors confirm there are no conflicts of interest.

Declaration of funding

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The authors

Dr Tom Cresswell holds a BSc (Hons) in Ocean Science (2003) and an MSc in Applied Marine Science (2005), both from the University of Plymouth, UK. Tom was awarded his PhD in Applied Sciences (Environmental Toxicology and Chemistry) from RMIT University in 2013. Tom is currently a senior research scientist in the Environment Research Theme at Australian Nuclear Science and Technology Organisation (ANSTO), where he has worked since 2012 on the development and use of nuclear techniques in ecotoxicology. He currently serves on the Board of Science and Technology Australia (STA) as the Chemical Sciences Cluster Representative (2.5 years) and on the Board of the Society of Environmental Toxicology and Chemistry (SETAC) Australasia as the Vice President (5 years). Tom was previously the Secretary of the South Pacific Environmental Radioactivity Association (SPERA), which he held for 4 years until October 2020.

Dr Sue Brown graduated from the University of Technology, Sydney with a Bachelor of Applied Science (Applied Chemistry), Honours and then completed a PhD at the University of Western Sydney (2001). Sue is a senior radiochemist at the Australian Nuclear Science and Technology Organisation (ANSTO) in the Minerals business unit, where she has worked for 36 years. Sue is the leader of the Radiochemistry Group that provides radioanalytical expertise and support to projects that will increase the competitiveness and environmental sustainability of operations in the uranium mining sector and mineral processing industries affected by naturally occurring radioactivity (NORM). Sue has extensive knowledge and understanding of radioactivity and the radioanalytical techniques used for the measurement of NORM, particularly in the deportment of radioactivity in a wide range of mineral processing circuits. Sue is a member of the Royal Australian Chemical Institute.

Henri Wong holds a BSc in Chemistry (1989) from University of Wollongong. Henri is currently the elemental facility manager in the Isotope Tracing and Natural System platform at Australian Nuclear Science and Technology Organisation (ANSTO). He started working at ANSTO in 1989, commencing in the low level radiochemistry laboratory measuring environmental radionuclides before moving into the trace elemental analysis laboratory using inductively coupled plasma - atomic emission spectroscopy (ICP-AES) and ICP-MS.

Dr Simon Apte holds a BSc (Hons) in Environmental Science (1980) and a PhD in Environmental Analytical Chemistry (1985) from the University of Southampton, UK. He is a senior principal research scientist at the Centre for Environmental Contaminants Research, CSIRO Land and Water, Lucas Heights, Australia. He is a fellow of the Royal Australian Chemical Institute (RACI). Simon was awarded the RACI's Environment Medal in 2010. His research team specialises in the determination of trace elements in aquatic systems and understanding the links between their chemical forms and their potential impacts on aquatic ecosystems.