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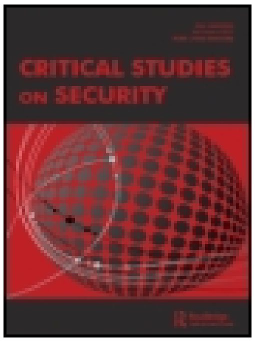

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Invention and uninvention in nuclear weapons politics

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If there is one uncontroversial point in nuclear weapons politics, it is that uninventing nuclear weapons is impossible. This article seeks to make this claim controversial by showing that it is premised on attenuated understandings of invention and the status of objects operative through familiar but problematic conceptual dualisms. The claimed impossibility of uninvention is an assertion that invention is irreversible. Drawing on 'new materialism', this article produces a different understanding of invention, reinvention and uninvention as ontologically similar practices of techno-political invention. On the basis of empirical material on the invention and re-invention of nuclear weapons, and an in-depth ethnography of laboratories inventing a portable radiation detector, both the process of invention and the 'objects' themselves (weapons and detectors) are shown to be fragile and not wholly irreversible processes of assembling diverse actors (human and non-human) and provisionally stabilising their relations. Nuclear weapons cannot be uninvented! Why not?

Keywords: invention; uninvention; new materialism; nuclear weapons; detection

If there is one uncontroversial point in nuclear weapons politics, it is that nuclear weapons cannot be uninvented. A point so seemingly self-evident that it is usually given no evidence, needs no elaboration and so powerful that wielding it against an opponent (advocates of disarmament in particular) renders their other claims naive and gives one's own an air of prudence and wisdom. The claim is so settled that scholars from all theoretical and normative positions accept and articulate it. This article seeks to make such 'facile gestures difficult' (Foucault 1988, 155) by utilising 'new materialist' thought to disrupt this assumption and its implications. The principal concern of the article is in developing an understanding of invention: something that is usually only implied when the impossibility of uninvention is invoked. It engages the process and ontological status of invention and 'objects'. It therefore begins by exploring the use of the claim that uninvention is impossible and the underlying ontological distinctions (ideas/matter, subject/object, politics/technology) it relies upon. Since the claim that uninvention is impossible is an assertion that invention is irreversible, it then uses new materialism's recasting of ontology, agency and causation to unsettle familiar assumptions about invention and objects, and engage a different understanding of 'irreversibility' than that present in disarmament politics. This makes the impossibility of uninvention an empirical question rather than an a priori assumption. To address this, the article engages empirically with the everyday practices of invention that are shown to echo

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new materialist notions of distributed agency and emergent causation in ways that further disrupt commonplace understandings of invention and may ultimately point to a different accounting of possibilities. This latter section draws both on material from the nuclear weapons literature and nuclear weapons scientists, and on in-depth ethnographic research following the invention of a related technology (a portable radiation detector for border guards to help prevent smuggling of nuclear materials). This advances three major points: that invention is ambiguous, that the process of invention (and the invented object itself) is about producing a stabilised functional unity among heterogeneous actors (including non-human actors) and that re-invention of nuclear weapons is continual and not dissimilar from invention (which challenges notions of latent or virtual proliferation). Together, this indicates that for uninvention to be impossible (rather than difficult), a remarkable achievement (irreversibility) would have to have been made, but that contemporary evidence of invention and re-invention indicates that this absolute status has not been reached. Simply put, through these moves, the article enables a different response to the claim that uninvention is impossible. Rather than accepting or evading the claim, the response can simply be: ‘that would be a remarkable achievement. How and when did that happen?’ or at least to shift the burden of proof and say ‘Why not?’

Impossibility, uninvention, uncertainty

The claim that nuclear weapons cannot be uninvented establishes the parameters of what is possible in global nuclear security politics. While the prospects and pitfalls of disarmament, the potential and significance of devaluing nuclear weapons, the stabilising or critiquing the relation of weapons and deterrence and so forth are the contested terrain of nuclear weapons debates, these never exceed – and seldom engage – the principal limit of uninventing nuclear weapons. Yet, this claim is seldom, if ever, justified with explicit elaboration of how invention is understood and why it is not possible to reverse that action. Rather, it is given force and meaning by intuitive appeal, an assertion of a universal truth that no technology can be uninvented and the translation of that assumption into claims of wisdom and prudence that embed it in wider assertions about what is possible – or not – in disarmament politics.

In 2000, Stephen M. Younger, then of the Los Alamos National Laboratory, argued:

> *Nuclear weapons cannot be uninvented*. Nor can we assume that their role in strategic deterrence will never change. Prudent thought given to the role of nuclear weapons in the twenty-first century will reap handsome dividends for the national security of the United States and for the stability of the whole world. (2000, emphasis added)

To unpack this: nuclear weapons cannot be uninvented means they are here to stay. Their ‘role’ may change, but their existence cannot. What is called for then is ‘prudent thought’ which limits the scope of possible change to differing arrays of tactical and strategic nuclear weapons in combination with conventional forces. But the certainty of existence is connected to future uncertainty:

> the future is unpredictable, but we can count on it to be dynamic … it does not appear possible with current or projected technology to assure ourselves that there are no, and never will be any, nuclear weapons in the hands of potential adversaries. (Younger 2000)

Likewise, Michael O'Hanlon argues for disarmament without 'irreversible abolition' as a prudent middle ground between uninvention and the status quo.

> Simply put, nuclear weapons will always be within reach of mankind, whatever we may do, whatever we may prefer. Even as they improve, verification methods will almost surely be incapable of fully ensuring that all existing materials are dismantled or destroyed . . . not only is permanent, irreversible abolition unwise, it is also probably impossible. (2010, 10–11)

Many critical scholars and practitioners note that the perception of legitimacy of nuclear weapons derives from the habit of thinking they cannot be uninvented and therefore cannot be abolished (Berry et al. 2010, 5). However, their response is to accept the impossibility of uninvention but to cast it as a feature of all technologies and thus declare it irrelevant since it does not mean that abolition is impossible. The International Commission on Nuclear Non-Proliferation and Disarmament argued 'of course nuclear weapons cannot be uninvented, any more than any other human invention . . . but they can be outlawed' (Evans and Kawaguchi 2009, 68). Likewise, Ward Wilson argues that the claim that nuclear weapons cannot be uninvented is 'the best and strongest argument for keeping nuclear weapons' because, unlike other 'myths' of nuclear weapons, this is 'absolutely true' and also 'absolutely irrelevant' since it is true of every human invention.

> You can't disinvent technology. With the rare exception of certain arcane techniques now lost because they were known to only a few (like the carefully guarded secret for tinting medieval stained glass a particularly spectacular shade of red), technologies never die. (2013, 105)

Similarly, Perkovitch and Acton argued that the claim that nuclear weapons 'cannot be disinvented' is used to 'deflect careful thinking rather than encourage it'. Again, an appeal to the eternal existence of inventions is made: 'No human creation can be disinvented'. For them while 'disinvention' is a distraction, 'the issue is rather whether means could exist to verify that a rejected technology . . . had been dismantled everywhere, and to minimise the risk of cheating' (2009, 17).

So on both sides, we inhabit a nuclear weapons politics in which uninvention is impossible, its impossibility is inherent in all human invention and the real political question is the possibility of *inventing* means of creating *certainty*. An impossible trap: nuclear abolition is caught between the impossibility of undoing the past and the impossibility of knowing the future with certainty. A limited political space by any definition. But why should time travel and omniscience be cast as the resources of resistance to nuclear armament? Why should critical perspectives respond to the impossibility of uninvention with 'Of course not, but . . .'?

A deeply embedded set of theoretical assumptions have created the resilience of this framing. Richard Wyn Jones (1999) argues that most security thinking and arms control practice, indeed most modern political thought, fall into one of two opposed perspectives that assert deterministic relationships between social/political relations and technology. In 'substantivist' arguments, nuclear weapons determine the politics in which they are enmeshed (establishing deterrence, etc.). In this view, autonomous processes of technology development are always with us, and uncertainty about what they will produce shortens the horizons of arms control into management not abolition (Farrell 2007). In 'instrumentalist' arguments, it is pure politics that determines that technology is a mere instrument. This has been the recourse of many critical perspectives which argue that 'nuclear weapons are implements that we manage and use as we wish' (Wilson 2013, 116) and locate the transformation of nuclear weapons politics firmly in the cultural, moral and psychological aspects of the 'genocidal mentality' of 'nuclearism' (Booth 1999).

In nuclear weapons politics, substantivist and instrumentalist positions sometimes do not characterise overall positions but rather specific points and arguments that are invoked simultaneously and selectively. For instance, Columba Peoples (2007) shows that substantivist views of nuclear weapons proliferation undergird instrumentalist arguments about missile defence technologies. What is asserted, then, is not always a universal truth of one form of determinism over the other but the underlying ontology premised upon a Cartesian dualism between ideas and matter, subjects and objects (and thence politics and technology) (Bourne 2012; Peoples 2007). This is often cast as an opposition between supposedly materialist realism and more idealist constructivism. Susan B. Martin's structural realist argument against devaluing nuclear weapons is premised on two dimensions of their 'material reality': first, that nuclear weapons exist perpetually, 'there is no way to erase nuclear weapons from the world' (2013, 176) (a substantivist claim) since knowledge about them will always exist such that a world of former-nuclear powers is a world of 'latent nuclear powers' (an instrumentalist claim) (2013, 176; Schelling 2009). Second, that effective deterrence is inherent in the weapons: 'in their essence, nuclear weapons are deterrent weapons' (more substantivism) (2013, 177). This incoherent and reductionist materialism is effectively disrupted by Nick Ritchie's (2010) critical constructivist account of how British nuclear weapons are embedded in complex heterogeneous networks that reproduce mutually reinforcing notions of the legitimacy of nuclear weapons rooted both in assumptions of necessity and western 'responsible nuclear sovereignty'. These networks are revealed to be contingent and in need of constant reproduction – yielding opportunities for devaluing. Nevertheless, the politics of devaluing nuclear weapons is described through ontological dualisms of subject/object and ideas/matter in which 'intersubjective values' are 'assigned' or 'attached' to nuclear weapons (Ritchie 2013). This article seeks to extend this sense of heterogeneity and active reproduction through engaging new materialist thought in relation to invention.

When accounts of possibility in nuclear weapons politics replay positions of whether politics or technology determines the other, or even simply operate on the basis of a Cartesian dualism of ideas and matter, they produce a very limited account of agency and action. This can be seen as an 'economy of action' (illustrated by Proffitt (2006) as the perception of the steepness of a hill depending on the energy resources available to climb it). Is transformation or maintenance of the nuclear status quo more costly in this economy? If nuclear weapons will inherently exist perpetually, then the greater burden of action falls on abolition and critical scholars must show that a substantive transformation is possible. If, however, the continued existence of nuclear weapons is open to question, then the costs (in terms of action and money) of maintenance can take on new importance. This can only be done by reclaiming materialism such that the fragility of nuclear weapons is also engaged as a property of their 'material reality'.

New materialism: from false economy to fragile emergence

New materialism is an uncomfortably unifying title increasingly used to cover approaches including Actor Network Theory (ANT), Deleuzian thought, inspirations from complexity theory and quantum physics, neo-vitalism and many others. While diverse new materialisms share affinities of emphasis that help disrupt the claims of the impossibility of uninvention and the economy of action that purports that transformation is either more costly than maintenance or that ideational and inter-subjective change must precede or drive material change. These affinities relate to ontology, agency and causation.

Ontologically new materialism rejects dualisms in favour of heterogeneous relations (assemblages). The separating and opposing of subject/object, ideas/matter and technology/politics frequently diminish the action of entities placed on one or the other side. In contrast, ANT, for instance, looks to 'the enactment of materially and discursively heterogeneous relations that produce and reshuffle all kinds of actors including objects, subjects, human beings, machines, animals, 'nature,' ideas, organisations, inequalities, scale and sizes, and geographical arrangements' (Law 2008, 141). Vincent Pouliot's use of new materialism and practice theory in relation to diplomatic practice around nuclear weapons disrupts the Cartesian separation of matter and ideas by showing that material 'objects', ideas and meanings all share an 'ontological continuity at the level of practice' such that 'ideas can be material too; and matter can take on a symbolic life of its own' (2010, 295). More widely, rather than stable objects (matter or ideas) with fixed properties, new materialism encounters 'quasi-objects'. It offers a relational ontology in which all actors and actions are viewed as composites that are provisionally stabilised, not inherently stable. Thus, for Deleuze, an assemblage is 'a multiplicity which is made up of many heterogeneous terms and which *establishes liaison*, relations between them … the assemblage's only unity is that of co-functioning' (Deleuze and Parnet 2007, 69).

Agency is distributed across the traditional dualisms of modern political thought. New materialism is an ontology not just of *many* entities but of *moving* entities. As noted by Law above, assemblages are composed of actors that include not just humans but non-humans. For Latour, 'Action is simply not a property of humans *but of an association of actants*' (1999, 182). Nuclear weapons, nuclear deterrence, nuclear detection and nuclear abolition are all emergent actions of collectives of human and non-human actants.

In these relations of active people, ideas, materials, devices, etc., causation cannot be assumed to be linear or efficient (e.g. the invention of nuclear weapons is the mere 'application' of science). Rather, new materialism often highlights the significance of self-organising, immanent and emergent forms of causation in which actions and entities are emergent properties of assembling – greater than (or different from) the sum of their parts (Connolly 2013; Coole 2013). This resists reductionism (and hence determinism), and a different politics emerges that is composed of multiple movements and trajectories of forces that become more or less stabilised but are not entirely stable or predictable.

What is (an) invention?

The impossibility of uninvention is usually asserted without specifying an understanding of invention. However, two wider concepts of invention stand out as common and coexistent, highlighted in Donald Mackenzie's (1993) work on missile guidance technology: the genius of the inventor or the linear application of scientific knowledge dependent only on trained staff and resources. For Mackenzie, attributing invention

> to a single individual or a single moment in time is quite impossible … though it can now be presented as a straightforward deduction from physics, that was not how it came into being or for many years how it seemed. (1993, 27)

Both the genius account and the application account are strongly anthropocentric: action derives from human beings. Both are also instrumentalist accounts of technology – given time, resources and the right people, technology will be created. They are each operative in the impossibility of uninventing nuclear weapons: There has been a single moment in time when nuclear weapons were invented (e.g. the discovery of nuclear fission in 1938 or the testing of the first weapon in July 1945); all subsequent inventions are really just applications of knowledge (hence, concerns of virtual or latent proliferation). In linking the two accounts, nuclear weapons politics demonstrates a strangely discriminatory anthropocentrism such that initial invention is the work of a genius (individual or group), and reinvention (stabilisation or future 'reconstitution') is merely the instrumental work of lesser engineers.

Since new materialism rethinks action and agents, it establishes a different means of thinking about invention. For Latour, 'normal anthropological usage presupposes in action a "making-be" for which it induces, by extension, a *subject* with appropriate competencies and an *object*, which thanks to the actor has now gone from potentiality to actuality' (1996, 237). In this normal usage, actors (humans) act (are the origin of creation). In contrast, Latour sees plural actants and action not as the origin of some 'ex-nihilo creation' (1996, 237) but as a mediation: action is simply 'making a difference'. Thus, the process of invention, indeed much action, is sometimes characterised by ANT theorists as a 'translation'. Translation always changes something, it is not simple transposition, not mere 'application' of scientific knowledge, but something more creative in which something different emerges. Here action, like invention, does not seem to stop, it changes, spreads, concentrates, stabilises, flows, etc. Likewise, for Gabriel Tarde, invention does not derive from individual 'genius' but is an iterative flow of forces: 'all inventions and discoveries are composites of earlier imitations … and these composites are, in their turn, destined to become new more complex composites' (as cited in Barry 2006a, 54). Importantly, these composites are not made of fundamental elements, but other composites. Atoms, molecules, human individuals and states may be fundamental in the perspective of particular disciplines, but they are not fundamental, immutable or essential in themselves (Barry 2006a).

The argument here is not merely that invention is a process, but that the 'object' that is invented is a process. Whitehead describes the 'principle of process' as 'how an actual entity *becomes* constitutes *what* that actual entity is … Its "being" is constituted by its "becoming"' (1978, 23). In this light, nuclear weapons are not merely the product of a process of invention, they *are* a process of invention. Bearing in mind that people and 'objects' act, the process of invention is what Andrew Pickering calls a 'dance of agency' between human and non-humans that is a 'dialectic of resistance and accommodation' (1995, 22). In this, dance agency is enacted by different entities at different times:

> As active, intentional beings, scientists tentatively construct some new machine. They then adopt a passive role, monitoring the performance of the machine to see whatever capture of material agency it might effect. Symmetrically, this period of human passivity is the period in which material agency actively manifests itself. Does the machine perform as intended? Has an intended capture of agency been effected? Typically the answer is no, in which case the response is another reversal of roles: human agency is once more active in a revision of modelling vectors, followed by another bout of human passivity and material performance and so on. (1995, 21–22)

Herein the object and its meaning, so often separated in nuclear politics, are unified as process. It is not just that human actors attach evolving social meanings to stable passive technological objects, but that both the object and its 'meaning' are a process in which 'a privileged trajectory is built out of an indefinite number of possibilities' (Akrich and Latour 1992, 259). Invention as verb and noun are, therefore, the same: processes associating human and non-human actants in an ordering that is built not by determinism or dominance, but by dance. What, then, might this mean for the possibility of uninvention?

Irreversibility

Arms control and ANT both utilise concepts of 'irreversibility', but they take different forms. The impossibility of uninvention means that invention is assumed to be irreversible. In contrast, in nuclear disarmament and wider arms control, practices speak of irreversibility as a political commitment often linked with establishing systems of verification and enforcement that would make 'reconstituting' nuclear weapons more difficult. Thus, the 13 steps towards nuclear disarmament agreed at the 2000 NPT Review Conference emphasise irreversibility as a principle to be applied. The concept also arises in claims that irreversible abolition is unwise (O'Hanlon 2010), or that the maintenance of capacities to reverse disarmament and 'reconstitute' weapons may serve as a useful hedging strategy (Perkovitch and Acton 2009). So the Cartesian dualism returns: inventing a technology is inherently irreversible; abolishing a technology is always politically reversible.

A recent study on irreversibility in nuclear disarmament sought a middle ground by showing that irreversibility and reversibility are matters of degree, not absolute conditions: 'All disarmament actions are, therefore, reversible. But some are more easily reversible than others' (Cliff et al. 2011, 6). However, lacking a sense of emergence or material agency, this study did not question whether the material technology and disarmament politics might also be characterised as having degrees of reversibility/irreversibility, rather 'weapons can always be produced' (Cliff, Elbahtimy, and Persbo 2011, 6).

In ANT, irreversibility is also a matter of degrees, but is an emergent property of the process of associating actants. For Callon, 'Irreversibility is (a) the extent to which it is subsequently impossible to go back to a point where the translation was only one amongst others; and (b) the extent to which it shapes and determines subsequent translations' (1991, 150). Irreversibility – in both politics and technology – is a relational matter. Certainly, the 'normalisation' of nuclear weapons in the sense of their valuing, and assumptions of legitimacy and necessity play a role here, but so does the standardisation of the action of other actants. Indeed, Callon argues 'A network which irreversibilises itself is a network that has become heavy with norms …. A network whose interfaces have all been standardised transforms its actors into docile agents and its intermediaries into stimuli which automatically evoke certain kinds of responses' (1991, 151). Irreversibility, by this measure, is the absence of politics via the automation of future action, the eradication of resistance and variation. Fortunately, this is a very difficult achievement and is 'never finally resolved: all translations, however apparently secure, are in principle reversible' (1991, 150). Since assemblages are constituted through continually shifting 'relations of movement and rest' among human and non-humans, new materialism shows that while some things may last a long time 'nothing lasts forever' (Connolly 2011, 44). Irreversibility, as defined here, is a difficult achievement for both nuclear armament and nuclear disarmament. It is also an empirical matter, not an a priori assumption.

The techno-political practice of invention and uninvention

To further disrupt the impossibility of uninvention, this article now engages empirically with practices of invention in contemporary nuclear weapons politics. This includes open source information from within the nuclear weapons assemblage that shows its fragility rather than irreversibility and information drawn from in-depth ethnographic research on the development of a portable radiation detector.

The development and deployment of portable radiation detectors have been deeply entangled with both the production of nuclear weapons and the verification of disarmament including the INF (intermediate-range nuclear forces), START (Strategic Arms Reduction Treaty) and New START treaties (DTRIP, 2011; DOE 1993). The author and colleagues conducted a multi-sited ethnography of the 'Handhold' (HANDHeld OLfactory Detector) project. Funded by the European Commission, Handhold consists of nine different institutions (universities, companies and end-users), in five European states, from a diversity of scientific backgrounds and disciplines. Out of this heterogeneity, they are inventing an integrated portable device to detect and identify CBRNE (Chemical, Biological, Radiological, Nuclear, and Explosive) substances at borders to tackle threats of – among other things – nuclear materials smuggling.

Drawing on this material, this section makes three arguments: invention is an ambiguous process (not a clear moment that has passed), it is composed of the stabilisation of a heterogeneous unity (in which agency does not disappear) and that this requires continual reinvention. Through this, an understanding of invention is developed in which the economy of action and resistance that bounds nuclear weapons politics can be re-engaged.

Invention is ambiguous

If invention is a single moment in time, and uninvention is time travel, then it is indeed impossible. Invention is never only one moment, but a politically and technologically ambiguous process. Jacques Hymans (2010) highlights this in relation to the question of when a state becomes a nuclear weapons state: the conduct of a test? (in which case, of what type and scale?) or the accumulation of a 'significant quantity' (SQ) of fissile material that Mohammed El Baradei called 'virtual nuclear weapons states'? Hymans criticises the elision of the virtual to the actual here and notes that while the test/no-test indicator has become common, enshrined in Article IX of the NPT, 'using the test as the measure of nuclear weapons stateness actually jumps the gun in most circumstances' (2010, 106). It may be preferable to assume this for pragmatic political reasons, embedded in a precautionary logic, but it does not clearly designate a moment of invention. Nor, however, is a full nuclear explosion test what ANT theorists call an 'obligatory passage point': 'Little Boy' had not been tested before it fell on Hiroshima (though something deemed sufficiently similar had); Israel has had operational nuclear weapons for 40 years without conducting a test (though there is inconclusive evidence of a test in 1979) (Hymans 2010) and much contemporary weapons development and modernisation uses laboratory and simulation-based testing.

The ambiguity of invention is not purely technical but techno-political. For Hymans (2010), early nuclear weapons tests declared the arrival of a possible apocalypse and invented deterrence politics. This, of course, evolved as the end of cold war forms of deterrence led to greater emphasis on SQ-based approaches to the ambiguity of nuclear weapons stateness as it came to be seen as prudent to reverse the assumption of the necessity of tests and waiting until a test to assume nuclear weapons capability (Hymans 2010). Thus, the ambiguity of the moment of invention is politically stabilised but changeable. This does not mean that the political or the technical have primacy, but that technologies and politics are co-emergent and may settle or unsettle each other.

Collectively, this means three things: first, there is always some ambiguity as to when nuclear weapons come into existence (even possessing tested explosive devices may not mean full nuclear weapons possession – as in the ambiguity over North Korean delivery systems). Second, since some form of testing, some 'trial and error', is inherent in all developments of nuclear weapons – though the pathways may differ – proliferation is not mere application but is still invention. Third, if politics and technology are entangled with each other such that they are co-emergent, one must account for the production of actions and objects as a stabilisation: the production of a unity from heterogeneity.

Invention is heterogeneous-unity

Invention is the building of pathway, assembling a unity of action from disparate elements (each of which are also assemblages). John Law's (2002) study of the failed development of a military aircraft argues that invention is not about the modernist notions of knowledge, subjects and objects having a centre, an essence; nor about the 'postmodernist' notion that there is no centre; but rather the construction of a 'functional coherence'. New materialism does not simply deconstruct unity into heterogeneity, but follows the emergence and fragility of a functional degree of unity in which heterogeneity is stabilised but not eliminated.

Much nuclear politics operates by 'black-boxing' nuclear weapons: forgetting the complexity, heterogeneity and profound fragility of compositions which 'makes the joint production of actors and artefacts entirely opaque' (Latour 1999, 184). Black-boxing is not merely an error in accounting for this action, it is integral to it. Nuclear weapons and deterrence, for instance, are rendered rational and coherent by extensive forgetting, both of the fragility of nuclear weapons (argued here) and aspects of nuclear destruction that resist rationalisation and instrumental control, such as fire (Eden 2004) and near misses (Lewis et al. 2014), as well as by viewing 'proliferation' as autonomous and inevitable (Pelopidas 2011).

While black-boxing separates and solidifies 'objects', and thus hardens the expectation that uninvention is impossible, opening the black-boxes of weapons reveals that technology does not precede politics such that disarmament must contend with autonomous processes of technological development and diffusion, and politics does not precede technology as in instrumentalism or arguments that a different international system must be brought about before nuclear weapons abolition can be achieved (Bourne 2012). Rather politics and technics mix, Flank (1993) argues that assembling nuclear weapons entails the construction of large and stable networks of infrastructure composed of physical, political, cultural, economic and human and non-human elements. Likewise, Mackenzie's (1993) analysis of missile guidance systems showed a variety of political decisions, personal beliefs and doubts, material components and scientific processes that had to be engineered to produce narratives and artefacts of missile accuracy. Simply put, without assembling a unity of action among diverse elements, nuclear weapons would disintegrate.

Invention requires that this unity of action is produced in laboratories before the invented devices enter different networks (use, maintenance). Laboratories are often seen as areas for 'secluded research', but Callon, Lascoumes, and Barthe (2001, 47–8) argue that they always exist among 'ceaseless movement … permanent exchanges between specialists and the world that surround them … the laboratory is only one element in a larger set-up, one stage in a long succession of comings and goings'.

Following Handhold showed that these ceaseless movements were not rendered coherent by technology or politics, but as the emergent effect of techno-politics.

The goals of Handhold were to detect and identify CBRNE threats quickly, accurately, in a portable device. Techno-politics emerged from the start: it was not that political actors (European Union (EU) funders) set the targets and the scientists of Handhold simply diligently applied scientific knowledge to the task they had been set. Rather, diverse actants interacted in the 'dance of agency' to provisionally settle the goals and methods of Handhold. For instance, there were complex processes of selecting 'work objects' such as target radiation sources, batteries, chip-sets, software, scintillators and intangibles to control and reduce ('noise': various forms of interference). This process of selection was iterative, entailed frequent reversals and modifications, and was emergent from the negotiations between scientists, end-users, funders, equipment, radiation sources, national regulations, international standards and various imaginations of the future conditions and practices of use (Handhold 2013e).

Ideas still matter in new materialism – since they too are material things that are formative of functional coherence. For instance, processes of standardisation and the circulation of standards often shape the composition of a unity of action. International standards are 'objects for cooperation' that 'inhabit several communities of practice and satisfy the informational requirements of each … they are objects that are able both to travel across borders and maintain some sort of constant identity' (Bowker and Star 2000, 16). In Handhold, international standards imposed some force upon invention, but were not deterministic. There are multiple sets of standards for radiation detectors, leaving Handhold scientists the task of selecting which ones to aspire to. Anticipating a European market for the future device, they selected International Electrotechnical Commission standards that had been recently adopted by the EU. These covered numerous aspects of the portable detector, from detection times, to sensitivity and so forth (Handhold 2013a, 2014a). Standards may contribute to a degree of irreversibility in the process of invention by creating, Barry calls, 'technological zones' which resonates with Callon's definition of irreversibility: 'space[s] within which differences between technical practices, procedures or forms have been reduced, or common standards have been established' (Barry 2006b, 239). However, the fact that Handhold scientists chose which standards to strive for, and continually renegotiated their implications and possibilities alongside input from end-users, indicates some active translation of the politics of standards in the laboratory such that the pathway had not become fully automatic. Rather, they made provisional decisions on the basis of a combination of forces, including the international force of standards and also budget constraints, the limitations of physics, demands for early and demonstrable success as well as innovation and concerns about commercialisation and intellectual property (Handhold 2013b, 2013c, 2013d).

These competing forces were partly stabilised by other ideas and imaginations: particularly, the action of imagining a future world in order to stabilise and orient action in the present. A great deal of work in Handhold is devoted to anticipating future conditions of use, such as the shift-length and technical competencies of border guards. Here, negotiations between end-users and scientists were crucially important. In the process, however, these created a need for adjustments and invention not anticipated at the start of the project. For instance, the need for the device to function in widely varying environmental conditions meant that some components needed temperature controls to be developed. This unanticipated demand arose only after a year of work, and scientists quickly had to translate imaginations of weather conditions on the cold Polish border and the hot Greek border into solid material tasks. The key difficulty, though, was not in controlling temperature in general terms, but in rendering coherent the competing demands of temperature control, weight, speed and accuracy. Indeed, the central challenge in developing the RN (Radiological-Nuclear) sensor became engaging in the complex entanglement between the low energies of radiation sources and the widely varying energies of environmental temperature in a way that was fast and accurate:

> We are having problems with high temperatures. Low temperatures will degrade performance. I mean, that is normal low temperatures, minus thirty is a different, you know, we don't know how the electronics behave. But I think it can be mediated fine. But there are limitations in the technology that we are using that the performance degrades with higher temperature. So it's difficult to tackle. (Handhold 2013e)

In a small way, this entanglement of competing material forces demonstrates that within Handhold laboratories collectives of humans and non-humans work together, and upon each other, in order to 'make silent entities speak' (Callon, Lascoumes, and Barthe 2001, 54). This was a highly embodied process in which materials, machines and scientist's tacit know-how, dexterity and other skills and experiences made all the difference in processes of miniaturising radiation detection to enable portability. Circuit boards, sensor prototypes, wires and so forth were spread out on desks, tested and created on a scale determined by the need to manipulate them by hand. Only once their functioning was unified at one scale, virtually and then physically, and then tested, refined and begun again could progressively miniaturised versions of the laboratory set-up be produced. This, too, was an iterative process in which circuit boards (named D1, D2, D3, D4 and now D5) got progressively smaller as settlements were made, and printed circuits replaced wires (Handhold 2013f).

Ideas, political and scientific instruments and an array of material and social forces, therefore, act together. The direction of action is not merely from the social to the material. Rather, the technical and social unities of Handhold are deeply entangled. On laboratory benches, and then in the Handhold device, radioactive traces act upon other materials within the device which through hardware and software inscribe a signature as a peak on a graph, the underlying data are then compared with a library of other peaks for identification and finally translated into simplified graphics (a radiation symbol and the name of the source) displayed to the user. This translation of energy and matter into visual representation is the function of the device, but it also contributed to the social and functional cohesion of Handhold as graphical representations enabled scientists from different disciplines, as well as end-users, funders and observing social scientists, to understand the work of the nuclear laboratory and create a functional social unity among the consortium members (Handhold 2013g, 2013h, 2014a, 2014b).

Overall, these diverse movements and stabilisations within Handhold demonstrate that invention is a process of unifying the action of various material and immaterial entities each of which have different trajectories. This is the complex mundane work of developing a portable RN sensor. None of it derives from the inspired work of a genius (though there are some very smart people) or the simple linear application of scientific knowledge. It is a creative composition of the international, the political, the social, the material, the economic and the imagined.

(Re-)invention is continual

Once invented, technologies exist forever? Even if nuclear weapons and their infrastructures can be dismantled, the knowledge to produce weapons will still exist? In contrast to such disembodied notions of inherently irreversible invention, Mackenzie and Spinardi (1995) argued that embodied 'tacit' knowledge makes nuclear weapons a fragile invention. Tacit knowledge is, and is produced through, the skills and experience of scientists and engineers. It contrasts with the explicit knowledge found in documents, technical manuals, diagrams, etc. To continue to exist, the practical knowledge of nuclear weapons scientists has to be transmitted through inter-personal relations or be continually reinvented through experience and experimentation: otherwise, it will 'decay'. The loss of tacit knowledge, then, can be construed as uninvention. Mackenzie used a simple example to clarify this:

> Outside of the human, intellectual, and material networks that give them life and force, technologies cease to exist. We cannot reverse the invention of the motor, perhaps, but imagine a world in which there were no car factories, no gasoline, no roads, where no one alive had ever driven, and where there was satisfaction with whatever alternative form of transportation existed. The libraries might still contain pictures of automobiles and texts on motor mechanics, but there would be a sense in which that was a world in which the motor car had been uninvented. (1993, 426)

As governments have taken on – indeed captured – the issue of tacit knowledge, it has also been recast as a challenge to the maintenance of nuclear capabilities but not as something that can challenge the impossibility of uninvention. For instance, Sims and Henke (2012) study of the Science Based Stockpile Stewardship Program argued that tacit knowledge has been reframed and rearticulated in a more flexible and resilient way. Nevertheless, while tacit knowledge itself may have dynamic and evolving form, its significance conflicts with the assumption that nuclear weapons cannot be uninvented in three ways: it reinforces the argument of the heterogeneity of invention by exposing the different forms and fragilities of knowledge; it reveals the presence of the human in the supposedly objective non-human technology such that the division subject and object is unsustainable and it demonstrates that knowledge is always materially embodied (in people, texts or diagrams) and thus needs to be maintained and reproduced rather than existing perpetually. In other words, invention is neither ex nihilo nor in perpetuum.

The argument that knowledge exists permanently can only be sustained by forgetting its materiality. However, its force in implying that uninvention is impossible also rests on failing to question the easy equivalence drawn between knowledge about nuclear weapons and nuclear weapons themselves. This elision is founded on an instrumentalist view of technology and invention as mere application. Rather than viewing tacit knowledge as a singular (human) weak point in the nuclear weapons assemblage, then, it is important to recognise the similar fragility of the technological objects themselves.

'Objects' are processes too. They have their own trajectories, as do their components, and rendering them stable through time requires considerable work that means that invention in its highly material and contingent nature is continual. The end of nuclear testing presented a challenge those tasked with maintaining and modernising US (and other) nuclear weapons capabilities. Thus, alternative practices were invented (why risk unilateral uninvention?) in which the institutions of the nuclear weapons assemblage were both protected and reshaped. This reinvention of nuclear weapons quantitatively and qualitatively shifted the economy of action. In financial terms, the maintenance and modernisation of nuclear weapons of the nine states that possess them are estimated to cost over $100 billion per year (Blair and Brown 2011). In terms of wider action, in the US nuclear assemblage, the challenge was to produce 'nuclear confidence' by establishing new 'ways of knowing' emergent from the entangled actions of 'several thousand physicists, technicians, engineers, statisticians, metallurgists, chemists, computer scientists, and other researchers and technical experts' (McNamara 2008, 169). These thousands of people in extended networks of stockpile stewardship contrast with the small and diminishing number of weapons designers with direct experience of a nuclear weapons test (the last being conducted in 1992). David Jablonski, a weapons designer at Los Alamos National Laboratory, recently claimed that ‘when I came here, in 2002, I’m guessing there were 15 or 20 designers with test experience; today there are maybe 5 or less’ (Bennett et al. 2014, 27).

Reinventing nuclear weapons, through stockpile stewardship, involves enormous novel invention of new material entitites. Thus, former LANL Director Browne claimed that the pathway of work shifted from a standard ‘design-test-produce’ process to a ‘surveillance-evaluation-response’ process that involved ‘a fundamentally different set of tools’ especially software-based simulations and virtual techniques (McNamara 2008, 184). This has also involved new social and political negotiations that reproduce relations with local communities and national political elites (Gusterson 2004; Masco 2006). Such is the scale of invention in re-invention that Joseph Masco claims that ‘weapons gerontology’ (studying how weapons age) ‘is far more challenging than designing new weapons’ (2006, 79).

Even old weapons themselves are still not stable entities because the components and techniques that form them are not permanently existing assemblages either. As Jablonski claims:

> We’ve tried to keep the weapons as close to their original designs as possible. But there’s clearly a limit to how far we can do that. The suppliers of some weapons’ components have, after 30 years without a market, gone out of business. To make those components today, *we’d have to start all over*. But replicating the exact ways certain source materials were made, and how components were made using those materials, may not be possible in some cases. The people are gone. The tools are different. So the things we replace may look the same but really are not exactly the same. (Bennett et al. 2014, 27–28)

Nuclear weapons networks have not, by this measure at least, achieved the automation of reproduction characteristic of irreversibility. Science-based stockpile stewardship is a process of inventing stability in what already exists. Therefore, it is not that once invented, nuclear weapons exist. Rather, nuclear weapons assemblages want to uninvent themselves. In this sense, it is nuclear armament, not disarmament, that is an act of significant and costly resistance.

So each element of nuclear weapons assemblages may be fragile: the knowledge, the infrastructure, the weapons themselves, all consist of trajectories that seem to want to pull apart or decay. Enormous invention and investment are needed to delay that. This is certainly not a simple state of irreversibility. However, the fear of ‘break-out’ from nuclear abolition and the fear of nuclear terrorism rest on a wider sense that once a technology is mature and diffused it is easier to replicate: something that is subtly different but still a ‘nuclear weapon’ could be produced. So does technological maturity and diffusion create such irreversibility that the uncertainties of new invention are reduced?

Portable radiation detectors are more mature and diffuse technologies than nuclear weapons. They are also entangled with nuclear weapons: much early innovation was undertaken in what are now the Oak Ridge and Los Alamos laboratories due to health concerns for Manhattan Project scientists (Flakus 1981; http://national-radiation-instrument-catalog.com/new_page_142.htm), and much contemporary neutron detection relies on Helium-3 (a by-product of nuclear weapons that is now in short supply since such detectors were widely deployed following 9/11) (Shea and Morgan 2010; TRUST 2013). Nevertheless, they have become technologies that are widely dispersed, commercially sold and developed, and have far lower political, technical and economic barriers to entry than nuclear weapons. Does this mean that the pathway to inventing new detectors is relatively stabilised and standardised (and thus irreversible)? Clearly not, since while Handhold's RN sensor is not starting from scratch, very considerable new invention was required (see above). Even in this mature technology, tacit knowledge was central to invention:

> We were struggling more to get into the understanding of how it works, really, because you can read it in the book. When you make things there are practical challenges that…you cannot find them easily in the books, but those steps were done in a previous project so we start with some kind of direct experience for this [that] helped make it smoother. (Handhold 2013e)

Tacit knowledge did not eliminate uncertainty and risks inherent in reinvention. Instead, Handhold scientists developed multiple pathways concurrently, to try to 'de-risk' the process. Each pathway had its own uncertainties (manufacturability with one method, temperature issues for the other); such that again the choice between them was delayed and the pathway of invention formed through multiple commercial, political and technical forces (Handhold 2013e, 2013g). Even practices of risk assessment and risk management, so pervasive in technology companies (and universities), did not provide easy answers to which pathway to pursue since the judgements involved rested not on the apparent certainties of quantifiable probabilities and costs, but on 'subjective probabilities' which 'depend on the points of view, feelings, or convictions of the actors' (tacit knowledge again) (Callon, Lascoumes, and Barthe 2001, 19; Handhold 2013a, 2013b, 2013c, 2013d, 2013e). Nor can the process of invention be entirely risk-averse. In addition to technological risk judgements, political and economic risks arise in the need to reach out from the laboratories of the consortium to engage and sustain the interests of stakeholders and funders (Callon, Lascoumes, and Barthe 2001). A field demonstration of Handhold's RN sensor was conducted in 2014 in order to secure the next phase of funding from the European Commission. Hailed as 'brave' by the Commission staff, the event's success – however – required a flurry of renegotiations, tunings, failures and rapid solutions, in an intense moment in which the pathway and progress of the project were reinforced but not irreversibilised (Handhold 2014a). Reinvention of mature technologies, then, is an entangled set of technological, political, social and economic factors, risks and uncertainties that require similar stabilisation and creative processes to the invention of entirely novel technologies.

Conclusion

The facile claim that nuclear weapons cannot be uninvented can be recast by engaging assumptions about invention and deeper assumptions about ontology, action and causation. In place of assumptions of irreversible invention and reversible disarmament, new materialism understands invention as the difficult production of a functional unity among diverse actants. Irreversibility cannot be assumed for technology and denied to politics, but rather degrees of reversibility are emergent properties of techno-politics.

It is not that nuclear weapons cannot be uninvented because no technology can be uninvented. Rather, nuclear weapons may be uninvented because all 'objects' want to uninvent themselves. In place of singular objects that are stable across time and space, new materialism draws attention to the fragility of 'quasi-objects' that are only ever provisionally stabilised. Since the actors and actions that constitute this assemblage are fragile, the pathways emergent from their 'dance of agency' are not wholly irreversible.

Reinvention remains substantially inventive, for both new devices made on the basis of mature technologies and existing devices being made to last. Even supposedly eternal knowledge is a process. Tacit knowledge shows the diversity, materiality and fragility of forms of knowledge. This material understanding of knowledge resists the forgetting of the power of forgetting so active in stabilising nuclear weapons. Alone it is insufficient, since it can still locate action as residing solely in humans. Yet knowledge forms are one type of energetic actant among many others that must be brought together and sustained to maintain the unity of nuclear weapons. The fact that 'material' as well as 'social' reproduction are needed, and that in practice the social and the material are inseparable due to emergent causation and the distribution of agency should indicate that a great deal of costly and inventive work is being done in dancing to stand still.

Invention and inventions (technological 'objects') are both processes that are ambiguous. They should not be assumed to be irreversible, particularly since they are ongoing processes rather than a moment that passed many decades ago. 'Objects' are relational entities with functional coherence. Uninvention is not time travel, the total eradication of all components or irreversibly rendering any future invention entirely impossible. Uninvention is the stopping of reproduction of stabilised relations among entities. The assumption of perpetual existence (in some form) of nuclear weapons is an assertion of the perpetual stability of objects. Since 'objects' are really 'quasi-objects' composed of many moving parts, perpetual existence is akin to perpetual motion (no friction, no entropy). Uninvention is not impossible time travel, but autonomous permanent existence is impossible perpetual motion. Advocates for nuclear weapons abolition need not accept or evade the claim that nuclear weapons cannot be uninvented. Invention and reinvention are not so clearly distinct, and both are fragile, thus abolition and uninvention need not be discursively separated. To do so is to give too much credence to the facile gesture. The burden of proof can shift: 'You can't uninvent nuclear weapons!' the response need not be 'Of course not, but …' Rather, it could be: 'They're irreversible? Really? Wow! That's a remarkable achievement. When did that happen?' Or, for those not inclined to counter the facile with the facetious, simply 'Why not?'

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