Nuclear Archaeology for Nonproliferation, Disarmament and Transparency

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Abstract:

Uncertainties about weapons-usable fissile material stockpiles are large. Nuclear archaeology is a concept to reconstruct fissile material histories. It can comprise measurements in shut-down facilities and of radioactive wastes, analyzing documentation of fuel cycle operations and carrying out related simulations. Here, we examine various future scenarios where conducting nuclear archaeology would be helpful. These include typical verification efforts related to confirming the absence of undeclared materials, but also options for transparency efforts absent a formal verification regime.

Keywords: Disarmament, Fissile Materials, Verification, Nuclear Archaeology

1. Introduction

While there is extensive experience in verifying both the correctness and completeness of nuclear material declarations issued by non-weapon states that are members of the Non-Proliferation Treaty (NPT), there is a lack of methods to verify the completeness of nuclear material baseline (or initial) declarations, i.e. the first verified declaration a state makes upon entering an agreement.

The International Atomic Energy Agency requires states concluding a Comprehensive Safeguards Agreement to submit such initial declarations, it has experience in its verification, in particular from states that had already had substantive nuclear programmes when they signed such agreements. At least partially, it seems to be based on gaining confidence over time as safeguards are being applied in a routinely manner, if no suspicions arise. However, from a technical point of view, there is only a limited capability to verify the completeness of such declarations when issued, in particular in states with a significant fuel cycle history.

Also nuclear weapon states face challenges in assessing the completeness of their inventories. Most large-scale fissile-material production programs were driven by a sense of urgency and typically shrouded in secrecy. It is generally believed that accounting for these military operations was poor. The fissile material production uncertainty is very large, and even states themselves have had difficulty reconciling production records with physical inventories.

As was attempted after South Africa had joined the NPT in 1991,[i] the most promising approach to verify the completeness and correctness of baseline declarations is the reconstruction of the state's fissile material production history.[ii] This is called nuclear archaeology, a concept introduced in 1990.[iii] Since then, however, there has only been

limited research; there remains a research gap on applicable tools and methods, which must be developed for a systematic and effective nuclear archaeology approach.

This paper will introduce nuclear archaeology, including a new proposal for an integrated approach, and discuss the various scenarios, that could benefit from nuclear archaeology methods.

2. Nuclear Archaeology

In order to reconstruct past fissile material production, a first approach is performing fuel cycle simulations, encompassing reactor simulations and uranium enrichment calculations. Codes that are more accurate than those used decades ago could be utilized, being a first method to resolve inconsistencies. Re-calculating fissile material production based on records has indeed been a major aspect of the verification in South Africa.

In addition, however, measurements have been performed in South Africa as an additional source of information (specifically, measurements of depleted uranium tails).[i] The nuclear archaeology research so far has focused on measurements of waste and samples from shut-down production facilities: Some initial research has been conducted on measurement concepts for nuclear archaeology in uranium enrichment plants.[iv,v,vi] Other techniques under development include quantitative estimates of the plutonium production in graphite-moderated reactors[vii,viii,ix] and heavy water reactors[x,xi] by examining the graphite moderator (GIRM) or structural reactor elements. Of all published research, only GIRM has been experimentally validated to a larger extent.

3. Scenarios for Nonproliferation, Disarmament and Transparency

Scenarios where nuclear archaeology can be relevant do not only include nonproliferation as described above, or disarmament scenarios, that nuclear archaeology is most often associated with, but also applying nuclear archaeology in the context of nuclear security, and as a transparency tool for nuclear weapon states to support confidence-building absent formal arms control agreements.

3.1. Improving knowledge of fissile material inventories for nuclear security

As mentioned above, states with large nuclear programmes – in particular nuclear weapon states – have large uncertainties regarding their own fissile material inventories. Therefore, undertaking a process of fully characterizing and accounting for all weapons-usable materials by applying nuclear archaeology methods would create immediate security benefits.

It should be assumed that all states with significant nuclear programmes have accountancy systems in place covering the fissile materials they are knowledgeable of. Likely, the degree of knowledge on fissile material stocks nevertheless varies, especially in the nuclear weapon states. In any case, states face issues in reconciling production records with physical inventories. In the United States, for example, estimated plutonium acquisitions exceeded the actual inventory by 2.4 tons.[xii]

When reconstructing the fissile material history results in higher fissile material estimates than the known inventory, it raises the question whether the additional material ever existed

or perhaps even still exists. Applying nuclear archaeology could lead to a more accurate fissile material history reconstruction, which may reduce current deviations.

Conducting nuclear archaeology to improve states' own inventory assessments would act as a confidence-building measures that they take their nuclear security commitments seriously. Furthermore, such states – no matter whether nuclear or non-nuclear weapon state, would have a stronger case when demanding other states to better assess and secure their fissile materials.

3.2. Verifying completeness of declarations for nonproliferation

States newly joining the NPT and signing Comprehensive Safeguards Agreements, need to submit initial declarations of their fissile material inventories. As under these agreements, *all* nuclear materials are subject to safeguards, the completeness of the initial declarations must be assessed. Conducting nuclear archaeology would make this verification process more effective.

The most important case here would be North Korea dismantling its nuclear weapons and joining the NPT. In fact, the United States have developed verification options for North Korea, which includes nuclear archaeology.

3.3. Fissile material transparency

It was agreed at the 2010 NPT Review Conference that, "as a confidence-building measure, all the nuclear-weapon States are encouraged to agree as soon as possible on a standard reporting form […] for the purpose of voluntarily providing standard information without prejudice to national security."[xiii]

Transparency into fissile material inventories is one element: The Non-Proliferation and Disarmament Initiative, a cross-regional group of non-nuclear-weapon states, proposed a specific reporting form foreseeing declarations of aggregate amounts of plutonium and highly enriched uranium produced for national security purposes/nuclear weapon purposes.[xiv]

To date, only the United States and the United Kingdom have issued public declarations of their respective plutonium and HEU inventories, accounting for both production (uranium enrichment and separation of weapon-grade plutonium) and removals (for example, the use of HEU in naval reactor fuel or use of fissile materials in tests).[xv, xvi, xvii]

Unfortunately, apart from the previously existing U.S. and U.K. declarations, nuclear weapon states so far do not seem interested in further moving forward with fissile material declarations. There are, however, options for transparency and confidence-building related to nuclear archaeology, which do not require issuing new declarations on fissile material inventories. Such options can therefore provide alternative pathways.

International exercises

First, confidence in the existing U.S. and U.K. declarations could be built by holding an international exercise, where the methodology of reconstructing fissile material inventories is discussed. This will at the same time advance the state of knowledge about nuclear archaeology. Such an exercise need not even be held in a nuclear weapon state. Some

civilian programmes have technical characteristics as military programmes, for example the use of heavy water reactors fuelled with natural uranium, and reprocessing.

Even without strong nuclear weapon state participation, non-nuclear weapon states that have less experience with preparing baseline declarations would gain an understanding of this process, thus being in a better situation to put into context the U.S. and U.K. declarations and the uncertainties they mention.

Inspection visits in one or few facilities

Moving from exercises to implementation, an inspection could be carried to assess a part of an existing declaration, either in the U.S. or in the U.K. With regard to plutonium, for instance, the U.S. has released the amount of plutonium produced per site per year, along with some additional information regarding the operation of facilities such as the power levels of the reactors. The U.K. has declared information on plutonium transfers from the reprocessing facility in Sellafield to the weapons programme in Aldermaston, also per year.

As above, a specific time period could be chosen to verify yearly data of the declaration based on documentation. When weapon states are ready to do so, the history of a production site – partially or in its entirety - could be assessed. Beyond examining documentation, measurement data could be examined. In the U.S., measurements of samples from reactors could be used to infer a reactor's life-long plutonium production. In the U.K. case with its information on shipped plutonium after reprocessing, measurement data from reprocessing waste could be examined.

3.4. Verified declarations for disarmament

While nuclear archaeology is helpful for confidence-building and transparency measures, it appears indispensable for the disarmament process in the long-term, as will be discussed now.

Even if verification of warhead dismantlement will be taking place, existing fissile material stocks could be used to build new warheads. States must at some point declare the complete stocks of weapons-usable fissile materials they possess and allow for verification, in order to create confidence in and enable stability of arms reduction processes.[xviii]

Should states require strategic stability during draw-downs, it will even become inevitable at low warhead levels that this re-armament potential and possibly imbalances between nuclear weapon states will play a role in negotiating further reduction measures.

A verification process must build confidence that no large amounts of weapons-usable materials stocks are deliberately hidden. Undeclared storage facilities do, however, do not need to have any remotely detectable signatures, for example using satellite imagery or wide-area environmental sampling. Their detection probability is low. Therefore, nuclear archaeology is the most promising method.

4. Conclusion

In the presented comprehensive overview of scenarios where nuclear archaeology would become important, some cases could occur in the medium term, in particular those relating to nuclear security and fissile material transparency.

At the same time, advancing the nuclear archaeology toolbox will require extensive research. Based on past progress in this field, it seems plausible that it will take at least another decade until the methods have been fully developed and tested. Luckily, the nuclear security and transparency options do not require that the methods are developed to their full extent. Actually, as discussed, some of these options will actually support nuclear archaeology research.

In any case, it is important to pursue an ambitious research agenda now, to ensure the methods are available when they are required. Therefore, academic research should be supported, along with international discussions in fora for verification debates, such as the International Partnership on Disarmament Verification, or new venues such as perhaps a Group of Scientific Experts for nuclear disarmament verification.

5. Acknowledgments

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6. Endnotes

[i] A. von Baeckmann, G. Dillon, D. Perricos, "Nuclear Verification in South Africa," IAEA Bulletin 1/1995, 1995.
[ii] A. Glaser and M. Göttsche, “Fissile Material Stockpile Declarations and Cooperative Nuclear Archaeology," in FM(C)T Meeting Series, Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions, United Nations Institute for Disarmament Research Resources, 2017.
[iii] F. von Hippel, “Warhead and Fissile-material Declarations," in Reversing the Arms Race: How to Achieve and Verify Deep Reductions in the Nuclear Arsenals, New York, Gordon and Breach Science Publishers, 1990.
[iv] M. Sharp, “Applications and Limitations of Nuclear Archaeology in Uranium Enrichment Plants.” Science & Global Security 21, 2013: 70-92.
[v] S. Philippe, and A. Glaser. “Nuclear Archaeology for Gaseous Diffusion Enrichment Plants.” Science & Global Security, 2014: 27-49.
[vi] T. Wood, et al. “The Future of Nuclear Archaeology: Reducing Legacy Risks of Weapons Usable Material.” Science & Global Security, 2014: 4-26.
[vii] S. Fetter, “Nuclear Archaeology: Verifying Declarations of Fissile-Material Production.” Science & Global Security 3, 1993: 237-259.
[viii] C. Gesh, “A Graphite Isotope Ratio Method Primer - A Method for Estimating Plutonium Production in Graphite Moderated Reactors.” PNNL-14568, Richland, Washington, USA, 2004.
[ix] B. Reid, D. Gerlach, P. Heasler, and J. Livingston. “Trawsfynydd Plutonium Estimate.” PNNL-13528, Richland, Washington, USA, 2009.
[x] A. Gasner, and A. Glaser. “Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors.” Science & Global Security 19, 2011: 223-233.
[xi] J. de Troullioud de Lanversin, Julien, M. Göttsche & A. Glaser. “Nuclear Archaeology to Distinguish Plutonium and Tritium Production Modes in Heavy-Water Reactors.” Science & Global Security 26, 2019: 70-90.
[xii] U.S. Department of Energy, “The United States Plutonium Balance, 1944-2009,” 2012.
[xiii] *2010 NPT Review Conference Final Document*, vol. 1, NPT/CONF.2010/50, New York, 2010.
[xiv] *Proposal by the Non-Proliferation and Disarmament Initiative to enhance transparency for strengthening the review process for the Treaty on the Non-Proliferation of Nuclear Weapons*, NPT/CONF.2020/PC.II/WP.26
[xv] The United States Plutonium Balance, 1944-2009, op. cit.
[xvi] United States, Department of Energy, Highly Enriched Uranium: Striking a Balance (Revision 1), 2001, www.ipfmlibrary.org/doe01.pdf; United States, Department of Energy, Highly Enriched Uranium Inventory: Amounts of Highly Enriched Uranium in the United States, 2006, www.ipfmlibrary.org/doe06f.pdf.

[xvii] United Kingdom, Ministry of Defence, Plutonium and Aldermaston—An Historical Account, 2000, fissilematerials.org/library/mod00.pdf and United Kingdom, Ministry of Defence, Historical Accounting for UK Defence Highly Enriched Uranium, March 2006, www.ipfmlibrary.org/mod06.pdf.

[xviii] J. Fuller, J. Carlson, M. Göttsche, et al., New Tools and New Actors to Reduce Nuclear Risks: Verifying Baseline Declarations of Nuclear Materials and Warheads, ed. Nuclear Threat Initiative, 2014.