

### PRESERVING THE RECORD A DOCUMENT-BASED APPROACH TO NUCLEAR ARCHAEOLOGY

Program on Science and Global Security, Princeton University Einstein Center Digital Future, Berlin

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#### Alex Glaser

#### Helmholtz Zentrum Berlin January 22, 2021

Revision 1c







U.S. Nuclear Weapon

### There remain about 13,000 nuclear weapons in the world today

215



Hans Kristensen, Matt Korda, and Robert Norris, Nuclear Notebook, Federation of American Scientists and thebulletin.org/nuclear-risk/nuclear-weapons/nuclear-notebook/

125

15

80

### PROGRESS TOWARD NUCLEAR DISARMAMENT HAS BEEN REAL (BUT IT HAS SLOWED DOWN SIGNIFICANTLY OVER THE PAST DECADE)



A. Glaser, Preserving the Record: A Document-based Approach to Nuclear Archaeology, Helmholtz Zentrum Berlin, January 2021







Graphic/concept by Alex Wellerstein and Tamara Patton

### ESTIMATING INVENTORIES CAN BE HARD (AN EXAMPLE FROM THE 1996 U.S. PLUTONIUM DECLARATION)

#### **Plutonium: The First 50 Years**



DOE/DP-0137 U.S. Department of Energy February 1996



United States plutonium production, acquisition, and utilization from 1944 through 1994



Wartime & Tests 3.4 MT





**Fission & Transmutation** 



Inventory Differences 2.8 MT

Plutonium: The First 50 Years, DOE/DP-0137, U.S. Department of Energy, Washington, DC, February 1996, <u>www.ipfmlibrary.org/doe96.pdf</u>





### NUCLEAR ARCHAEOLOGY UNDERSTANDING THE OPERATIONAL HISTORY OF NUCLEAR FACILITIES

Science & Global Security, 1993, Volume 3, pp.237–259 Photocopying permitted by license only Reprints available directly from the publisher © 1993 Gordon and Breach Science Publishers S.A. Printed in the United States of America

### Nuclear Archaeology: Verifying Declarations of Fissile-Material Production vial element of nonprolifera-

Science & Global Security, 21:70-92, 2013 ISSN: 0892-9882 print / 1547-7800 online DOI: 10.1080/08929882.2013.755028

#### Applications and of Nuclear Arch in Uranium Enric

#### Matthew Sharp

Bureau of European and Eurasian Affairs, Washington, DC, USA

The uranium-235 content of a uranium m-234 content of its waste, allowin

Open-access articles are available at <u>scienceandglobalsecurity.org/archive</u>ed in

Science & Global Security, 22:4-26, 2014 Copyright © Pacific Northwest National Laboratory ISSN: 0892-9882 print / 1547-7800 online DOI: 10.1080/08929882.2014.874217

#### The Future of Nuclear **Archaeology: Reducing** Legacy Risks of Weapons **Fissile Material**

Thomas W. Wood, Bruce D. Reid, Christopher M. Toomey, Kannan Krishnaswami, Kimberly A. Burns, Larry O. Casazza, Don S. Daly, and Leesa L. Duckworth

Pacific Northwest National Laboratory, Richland, WA, USA

This report describes the value proposition for a "nuclear archaeological" technical capability and applications program, targeted at resolving uncertainties regarding weapons fissile materials production and use. Central to this proposition is the notion that one can never be sure that all fissile material is adequately secure without a clear idea of what "all" means, and that uncertainty in this matter carries risk. We argue that this proposition is as valid today, under emerging state and possible nonstate nuclear threats, as it was in an immediate post-Cold-War context, and describe how nuclear archaeological methods can be used to verify fissile materials declarations, or estimate and characterize historical fissile materials production independent of declarations. Methods for accurately estimating plutonium production from graphite reactors have been demonstrated and could be extended to other reactor types. Proposed

Steve Fetter<sup>a</sup> Controlling the production of fi tion policy. Similarly, accounti an important component of nuc techniques that make use of pl verify the past production of pl nique, the concentrations of lo reactor core are used to estimate and thereby verify declaration technique, the ratio of the con determine whether a given enriched uranium, which is which can be used in nucles "nuclear archaeology," in wh ties and thereby lay a firm fo

#### INTRODUCTION

For the first time, the tid tal proliferation—is ebb reduce their combined



Security, 19:223-233, 2011 r & Francis Group, LLC int / 1547-7800 online 9882.2011.616124

Routledge

### ar Archaeology for y-Water-Moderated hium Production Reactors

#### r and Alexander Glaser

lechanical and Aerospace Engineering, Princeton University Engineer-

; interest in a set of methods and tools that can be used to characmaterial production activities, using measurements and sampling at torage sites. This field has been dubbed "nuclear archaeology." The xample of nuclear archaeology relies on measurements of the isotope elements in the graphite of graphite-moderated plutonium produc-Graphite Isotope-Ratio Method (GIRM) determines the cumulative rough the graphite and thereby estimates the cumulative plutonium eactor. The great limitation of this particular method is that it can graphite-moderated reactors, which represent only one class of reeen used for unsafeguarded plutonium production. In this article, nd this method to non-graphite moderated reactors by analyzing evant isotope ratios in the support structures and other core comater moderated reactors. We present results of neutronics calculaeavy-moderated reactor evaluating the robustness of the method e of nuclear archaeology for applications in arms-control treaty



### NUCLEAR ARCHAEOLOGY DOCUMENTING THE PAST TO ENABLE A NUCLEAR-WEAPON-FREE FUTURE



### THE CHALLENGE

Future progress toward verified nuclear disarmament will require a much better understanding of the stockpile of fissile materials that have been produced in unsafeguarded facilities; "nuclear archaeology" seeks to provide the tools to do so



#### THE IDEA

Develop of a framework that can provide a basis for preserving the history of relevant nuclear facilities; examine, in particular, the potential role of operating records to do so

Such a framework would complement other nuclear archaeology techniques, which rely on physical samples taken from structural components or waste materials for forensic analysis to draw conclusions about past activities

Source: IAEA (top), asian-defence-news.blogspot.com (bottom)





# DEVELOPING THE TOOLS FOR POSSIBLE NUCLEAR ARCHAEOLOGY IN NORTH KOREA



Uranium mine at Pyongsan Credit: Google Earth

Inside North Korea's Yongbyon Reactor Credit: CNN/Brian Rokus, 2008





*Operating records shared in 2008 Credit: Chung Sung-Jun* 





## ONGOING VERIFICATION INITIATIVES (AS OF 2021, ALL WITH GERMAN PARTICIPATION)

#### INTERNATIONAL PARTNERSHIP FOR DISARMAMENT VERIFICATION



#### Established in 2015; currently 29 participating countries

IPNDV seeks to identify challenges associated with nuclear disarmament verification and to develop potential procedures and technologies to address those challenges

Phase III will begin in Spring/Summer 2021 Germany is co-chairing two (out of three) working groups <u>www.ipndv.org</u>

Source: *ipndv.org* 



Group of Governmental Experts (GGE) considers "the role of verification in advancing nuclear disarmament"

Established by the UN Secretary General following a resolution of the UN General Assembly (A/RES/71/67, Dec. 2016), the first GGE delivered its final report in May 2019 (A/71/67)

The second GGE will be convening in Geneva in 2021 and 2022 25 members, including Germany

Source: <u>www.flickr.com/photos/gruban/336920038</u>



# SAMPLE BASED

## NUCLEAR ARCHAEOLOGY

(A case study)

## NUCLEAR ARCHAEOLOGY COULD BE USED TO VERIFY A NORTH KOREAN PLUTONIUM DECLARATION



Credit: CNN/Brian Rokus, 2008



Unit cell of the North Korea's Yongbyon reactor



14

# GRAPHITE ISOTOPE RATIO METHOD (GIRM)



Based on data from Jungmin Kang, "Using the GIRM to Verify the DPRK's Plutonium-Production Declaration," Science & Global Security, 19 (2), 2011

A. Glaser, Preserving the Record: A Document-based Approach to Nuclear Archaeology, Helmholtz Zentrum Berlin, January 2021



### VERIFICATION MEASURES DISCUSSION PAPER (U.S. GOVERNMENT, JUNE 2008)

#### VERIFICATION MEASURES DISCUSSION PAPER

Below is a list of measures that would be applied to undertake verification activities. These measures will form the basis for development of a verification implementation plan that assigns specific responsibilities and requirements. These measures provide a means to address all elements of a nuclear program, to include plutonium production, uranium enrichment, weapons, weapons production and testing, and proliferation activities.

The verification regime consists of experts of the six parties and is responsible to the Working Group on Denucleurization of the Korean Peninsula.

 Six Party Experts will be coordinate their actions i

As relates to a graphite-moderated reactor, collect, and remove from the Party physical samples of the graphite moderator after the core has been de-fueled.

 Experts will be permitted course of exercising their res

Available at fissilematerials.org/library/gov08.pdf and reproduced in Global Fissile Material Report 2009, fissilematerials.org/library/gfmr09.pdf

course of exercising their responsibilities, to include measurement devices, radiation



# DOCUMENTERSAS NUCLEAR ARCHAEOLOGY

### (A case study)



### JEEP II Reactor

Institute for Energy Technology (IFE) Kjeller, Norway, 12/1966–12/2018

> 2 MW Heavy-water moderated and cooled 3.5%-enriched uranium fuel



# OPENMC/ONIX MODEL OF JEEP II



Paul K. Romano et al., "OpenMC: A State-of-the-Art Monte Carlo Code for Research and Development," *Annals of Nuclear Energy*, 82, 2015 Julien de Troullioud de Lanversin, Moritz Kütt, and Alexander Glaser, "ONIX: An Open-source Depletion Code," *Annals of Nuclear Energy*, 151, 2021

A. Glaser, Preserving the Record: A Document-based Approach to Nuclear Archaeology, Helmholtz Zentrum Berlin, January 2021



# FIRST LOOK AT DIGITAL RECORDS OF JEEP II



A. Glaser, Preserving the Record: A Document-based Approach to Nuclear Archaeology, Helmholtz Zentrum Berlin, January 2021

- DDS file generated with Yokogawa DAQSTATION DX100/200 Series of Paperless Recorders
- Sensor readings are from RC6 ionization chamber and can be used to estimate the current power level of the reactor



### DETERMINING A CAPACITY FACTOR FROM DIGITAL DATA AVAILABLE IN THE ARCHIVE



A. Glaser, Preserving the Record: A Document-based Approach to Nuclear Archaeology, Helmholtz Zentrum Berlin, January 2021

(30240 entries for one week of operation; one entry every 20 seconds)







## WHAT AN ACTUAL PROJECT COULD LOOK LIKE ("THE PROOF OF THE PUDDING IS IN THE EATING")

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### <u>REVIEW TYPES OF RECORDS AND DATA AVAILABLE</u>

Determine which types of information are most relevant for nuclear archaeology purposes Determine what equipment and "tacit knowledge" are needed to read and correctly interpret the data; determine ways to best preserve the records and ensure their integrity

Note: The data itself is never made public



#### PERHAPS ALSO: CHOOSE A (SMALL) BENCHMARK PROBLEM TO DEMONSTRATE THE CONCEPT/IDEA

Focus on a well-defined episode/era of a plant's history

Source: <u>www.flickr.com/photos/iaea\_imagebank</u> (bottom)

- If/when needed, one could use computational tools to simulate a selected time period and develop a better understanding of the potential and the limits of the technique
- Note: Possibly of interest for RERTR 2021 or INMM 2021/2022



### A MULTIDISCIPLINARY EFFORT HOW TO CURATE AND PRESERVE ANALOG & DIGITAL DATA HOW TO CONFIRM INTEGRITY, AUTHENTICITY, AND PROVENANCE OF RECORDS



Source: asian-defence-news.blogspot.com

![](_page_24_Picture_4.jpeg)

Edited by Arthur Tompkins

![](_page_24_Picture_6.jpeg)

![](_page_25_Picture_1.jpeg)

#### **DEVELOP BEST PRACTICES FOR DOCUMENTING AND ARCHIVAL**

![](_page_25_Picture_4.jpeg)

#### SUPPORT ONGOING & FUTURE DECOMMISSIONING EFFORTS (FOR CIVILIAN FACILITIES)

Lead by example with regard to openness and transparency

Source: <u>www.flickr.com/photos/iaea\_imagebank</u> (top) and <u>www.jen-juelich.de</u> (bottom)

# WHY IT MATTERS

- No systematic efforts currently exist to archive and preserve the historical records of nuclear facilities at a level required for potential nuclear archaeology applications
- Make recommendations for data collection and storage at operational <u>and</u> future plants
- This is a time critical effort (as facilities are being demolished, records destroyed, and staff retires)

- Example of the Norwegian case: Document-based archaeology could help inform calculations to characterize spent fuel inventory using modern computer codes and cross-section data

![](_page_25_Picture_17.jpeg)

![](_page_26_Picture_0.jpeg)

### SCIENCE AND GLOBAL SECURITY

**PRINCETON** UNIVERSITY

### EINSTEIN CENTER Digital Future

![](_page_26_Picture_4.jpeg)