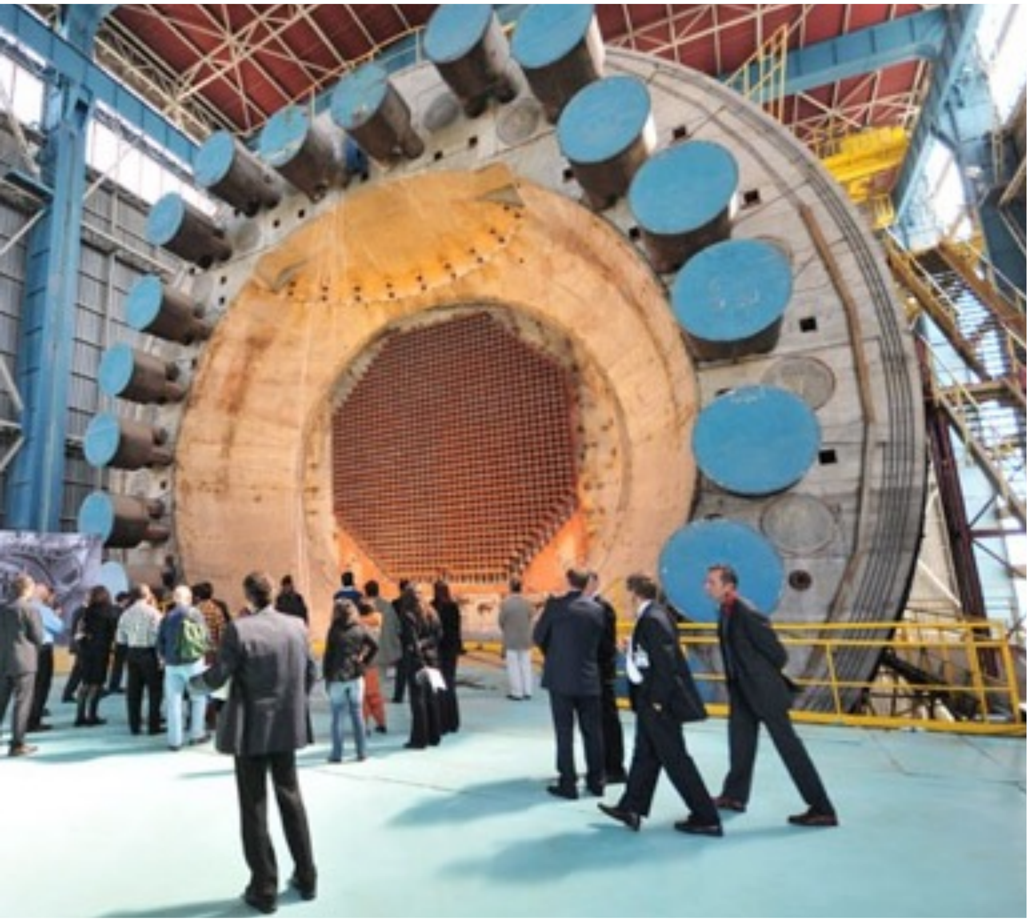


NUCLEAR ARCHAEOLOGY

VERIFYING DECLARATIONS OF PAST FISSILE MATERIAL PRODUCTION

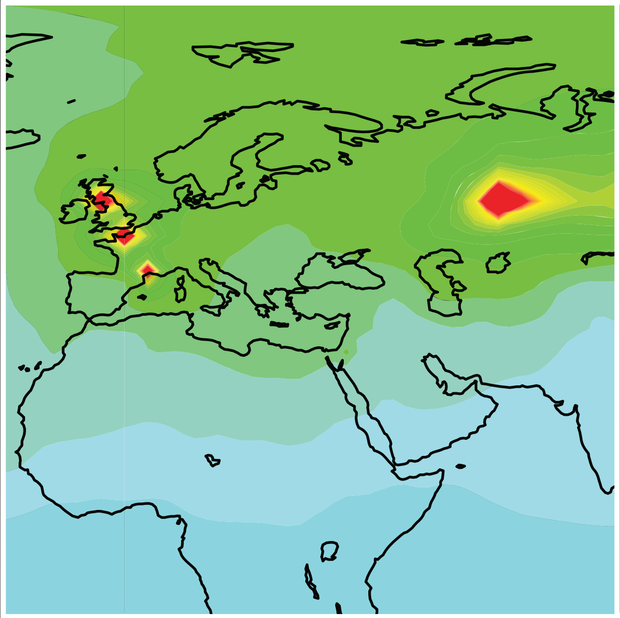
Alexander Glaser
Princeton University

PVTS-SGS Workshop on Verification Technologies
Beijing, June 15–16, 2015

Revision 2

Graphic by Alex Wellerstein, nuclearsecrecy.com

WILL WE EVER KNOW HOW MUCH FISSILE MATERIAL EXISTS WORLDWIDE?



RECONSTRUCTING HISTORIC FISSILE MATERIAL PRODUCTION

Many aspects of declared production histories can be reviewed for consistency even without verification

(for example, by comparison with historic krypton emissions)

DATA EXCHANGE AND NUCLEAR ARCHAEOLOGY

Verification could begin with data exchanges (e.g. sharing of available operating records) and, eventually, envision onsite inspections

Nuclear archaeology is based on nuclear forensic analysis of samples taken at former production facilities

Source: Ole Ross and www.francetnp2010.fr

Science & Global Security, 1993, Volume 3, pp.237–259
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Nuclear Archaeology: Verifying Declarations of Fissile-Material Production

Steve Fetter[a]

Controlling the production of fissile material is an essential element of nonproliferation policy. Similarly, accounting for the past production of fissile material should be an important component of nuclear disarmament. This paper describes two promising techniques that make use of physical evidence at reactors and enrichment facilities to verify the past production of plutonium and highly enriched uranium. In the first technique, the concentrations of long-lived radionuclides in permanent components of the reactor core are used to estimate the neutron fluence in various regions of the reactor core and thereby verify declar[...]tions of plutonium production in the reactor. In the secon[...] technique, the ratio of th[...] of U-235 to that of U-234 in the tails is used [...] determine whether a g[...] [...]d in the production of l[...] enriched uranium, whi[...] [...]hed urani[...] which can be used in [...] "nuclear archaeology," [...] ties and thereby lay a [...]

INTRODUCTION

For the first time, [...] tal proliferation– [...] reduce their com[...] than 10,000 by t[...] South Africa, Ir[...] nuclear thresho[...]

It is impor[...] capabilities a[...]

a. School of [...]

Science and Global Security, 19:223–233, 2011

ISSN: 0892-9882 print / 1547-7800 online
DOI: 10.1080/08929882.2011.616124

Routledge
Taylor & Francis Group

Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors

Alex Gasner and Alexander Glaser

Department of Mechanical and Aerospace Engineering, Princeton University Engineering Quadrangle, Olden Street, Princeton, NJ 08544

There is growing interest in a set of methods and tools that can be used to characterize past fissile material production activities, using measurements and sampling at production and stora[...] [...]as been dubbed "nuclear archaeology." The [...]ology relies on measurements of the isotope [...] of graphite-moderated plutonium produc[...] Method (GIRM) determines the cumulative [...]hereby estimates the cumulative plutonium [...]ion of this particular method is that it can [...]tors, which represent only one class of re[...] [...]led plutonium production. In this article, [...]raphite moderated reactors by analyzing [...]e support structures and other core com[...] We present results of neutronics calcula[...] evaluating the robustness of the method [...] for applications in arms-control treaty

[...]1.
[...]ted at the 51st INMM Annual Meeting, [...]ltimore, MD, July 11–15, 2010.
[...] Department of Geosciences, for advic[...]
[...] Matos from Argonne Nati[...]
[...] trace anal[...]

Science & Global Security, 22:27–49, 2014

ISSN: 0892-9882 print / 1547-7800 online
DOI: 10.1080/08929882.2014.871881

Routledge
Taylor & Francis Group

Nuclear Archaeology for Gaseous Diffusion Enrichment Plants

Sébastien Philippe and Alexander Glaser

Nuclear Futures Laboratory, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ, USA

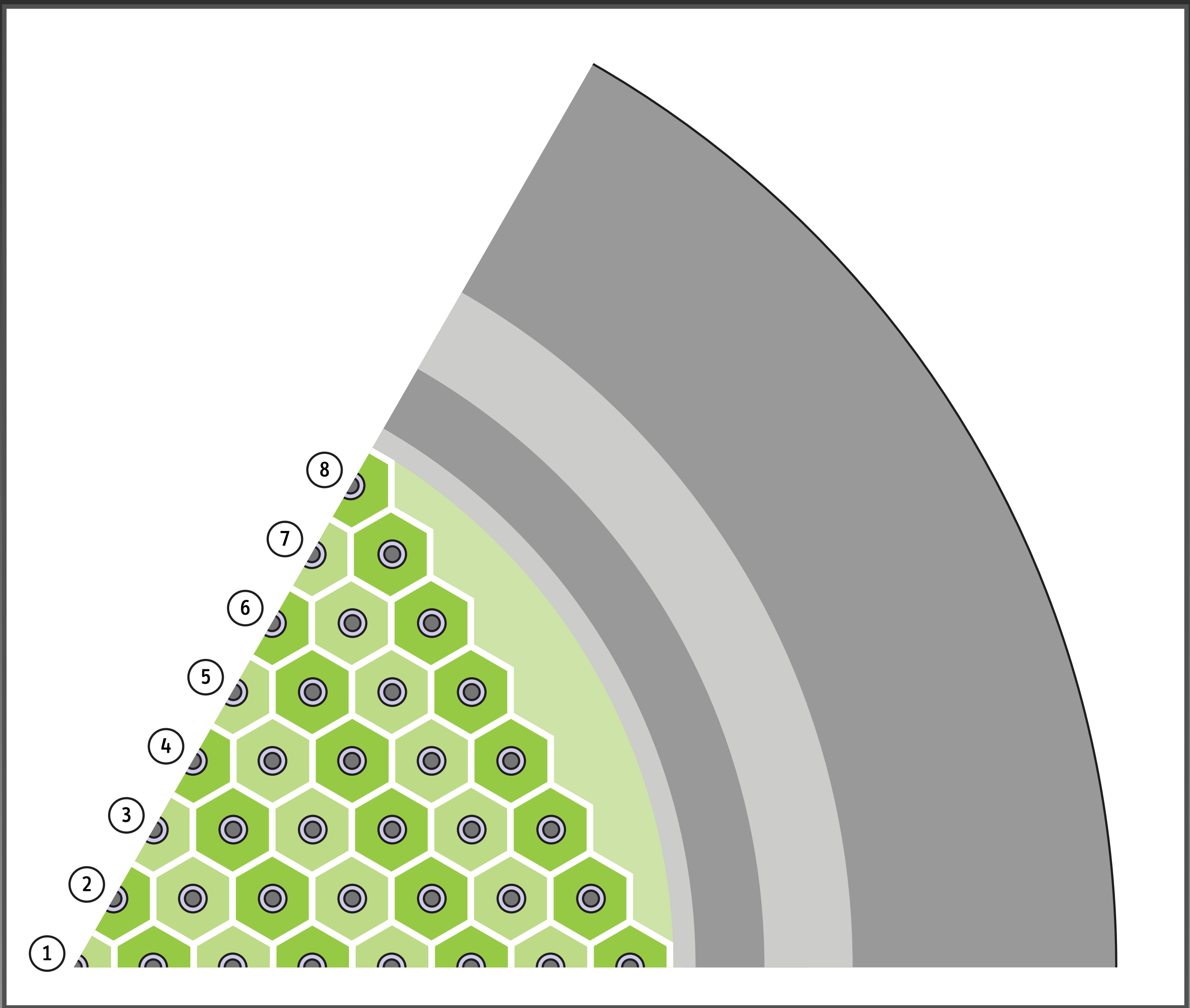
Gaseous diffusion was historically the most widely used technology for military production of highly enriched uranium. Since June 2013, all gaseous diffusion enrichment plants worldwide are permanently shut down. The experience with decommissioning some of these plants has shown that they contain large amounts of uranium particles deposited in the cascade equipment. This article evaluates the [...] uranium particle deposition to under[...] gaseou[...]

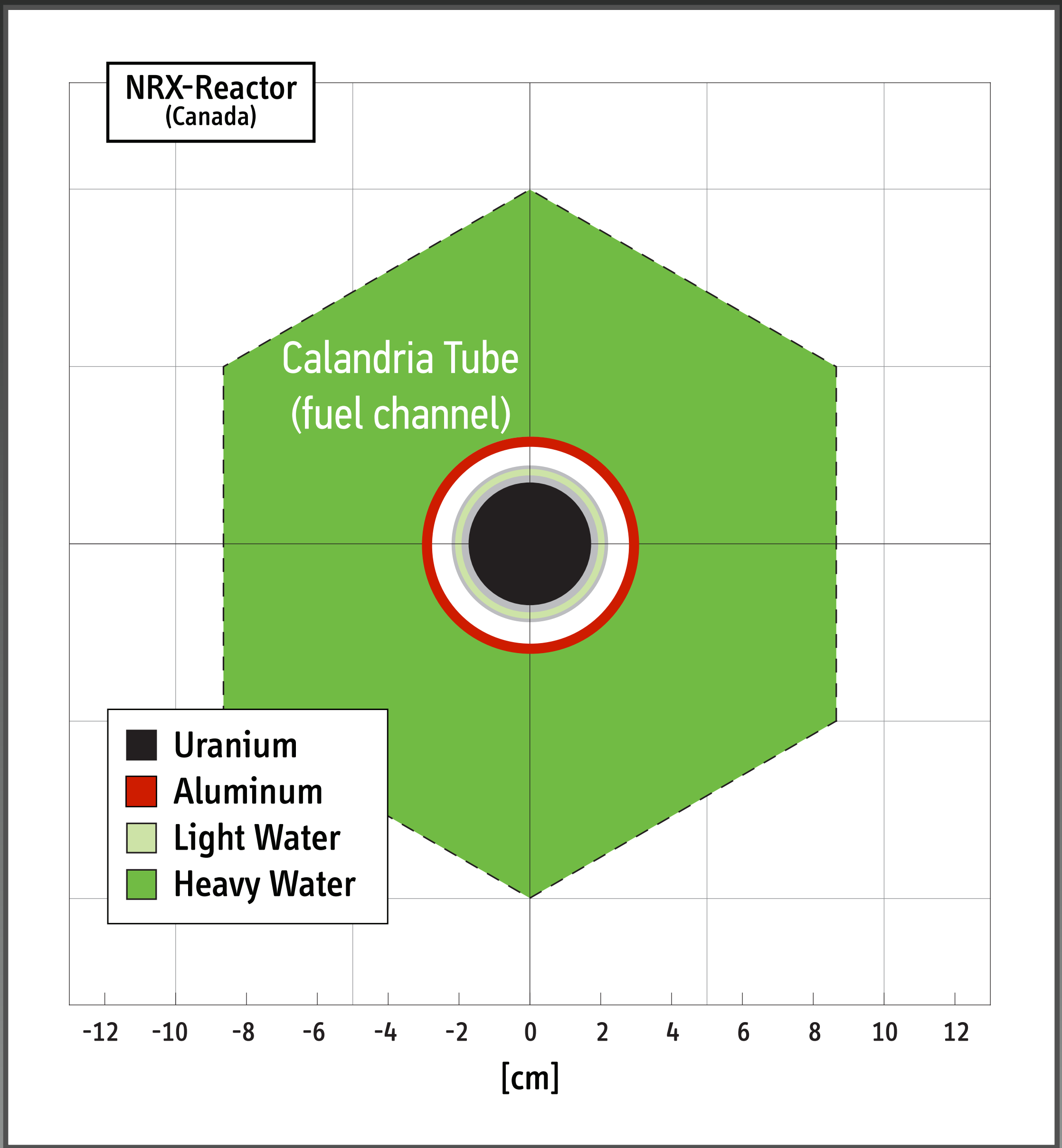
NUCLEAR ARCHAEOLOGY

THE CASE OF PLUTONIUM PRODUCTION

COMPUTER MODEL OF NRX/CIRUS

(40–50 MW, HEAVY-WATER MODERATED, NATURAL-URANIUM FUELED)

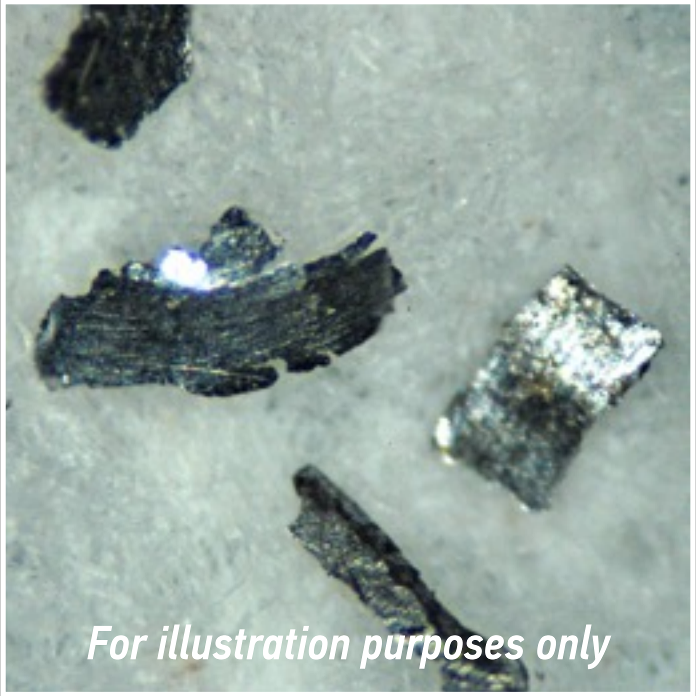




A. Gasner and A. Glaser, "Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors," *Science & Global Security,* 19, 2011

MANY ELEMENTS ARE PRESENT AS IMPURITIES IN ALUMINUM

RESULTS FROM ANALYSIS OF HISTORIC ALUMINUM SAMPLE FROM MANHATTAN COLLEGE ZERO POWER REACTOR (MCZPR)



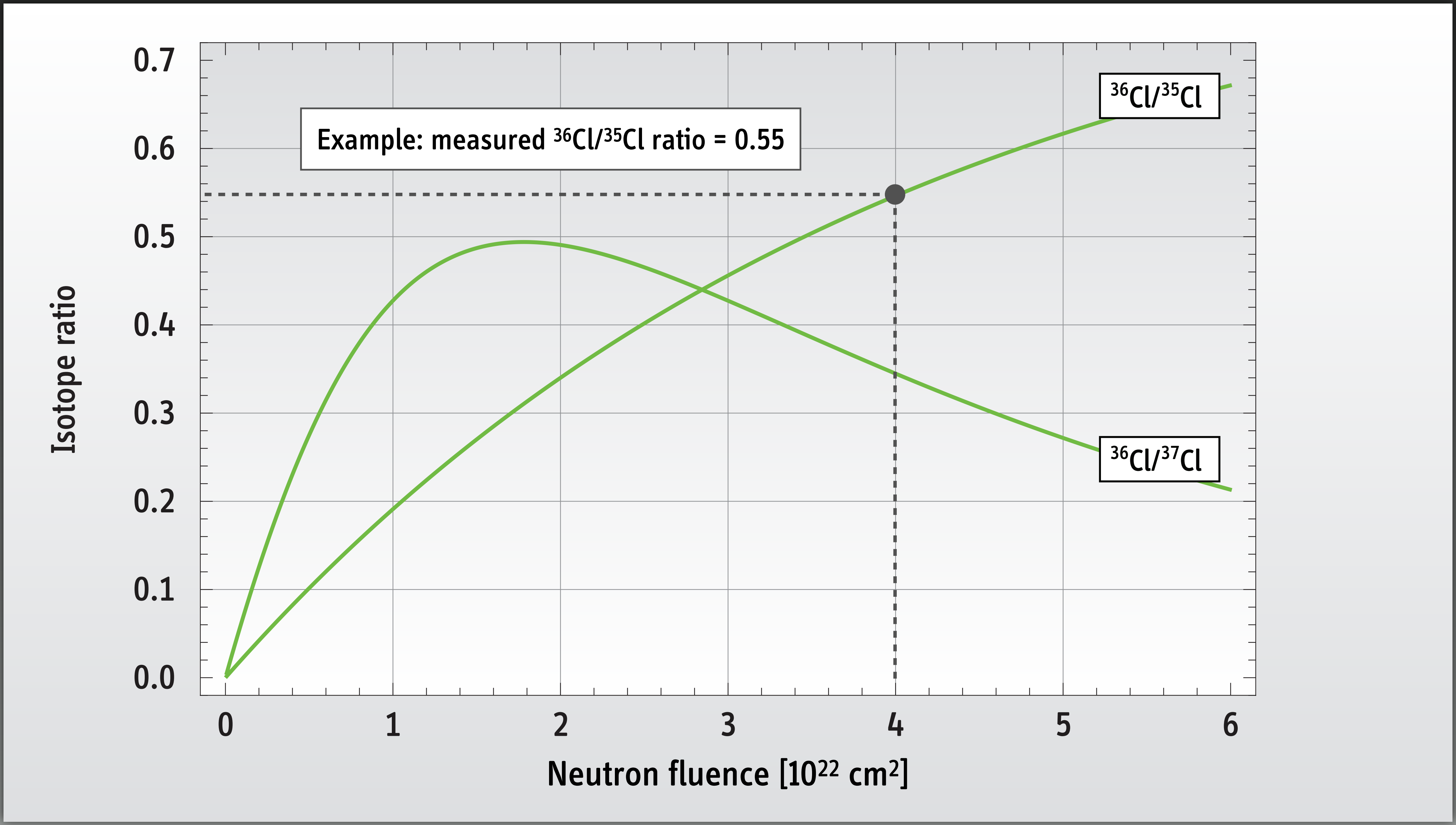
Element	Content
5 Boron	2 ppm
12 Magnesium	<100 ppm
14 Silicon	1900 ppm
22 Titanium	200 ppm
23 Vanadium	<100 ppm
24 Chromium	<100 ppm

Element	Content
26 Iron	5100 ppm
28 Nickel	<100 ppm
29 Copper	1400 ppm
30 Zinc	200 ppm
40 Zirconium	<100 ppm
82 Lead	<100 ppm

Need to identify isotope ratios that correlate well with neutron fluence

ARCHAEOLOGY FOR CANADA'S NRX REACTOR

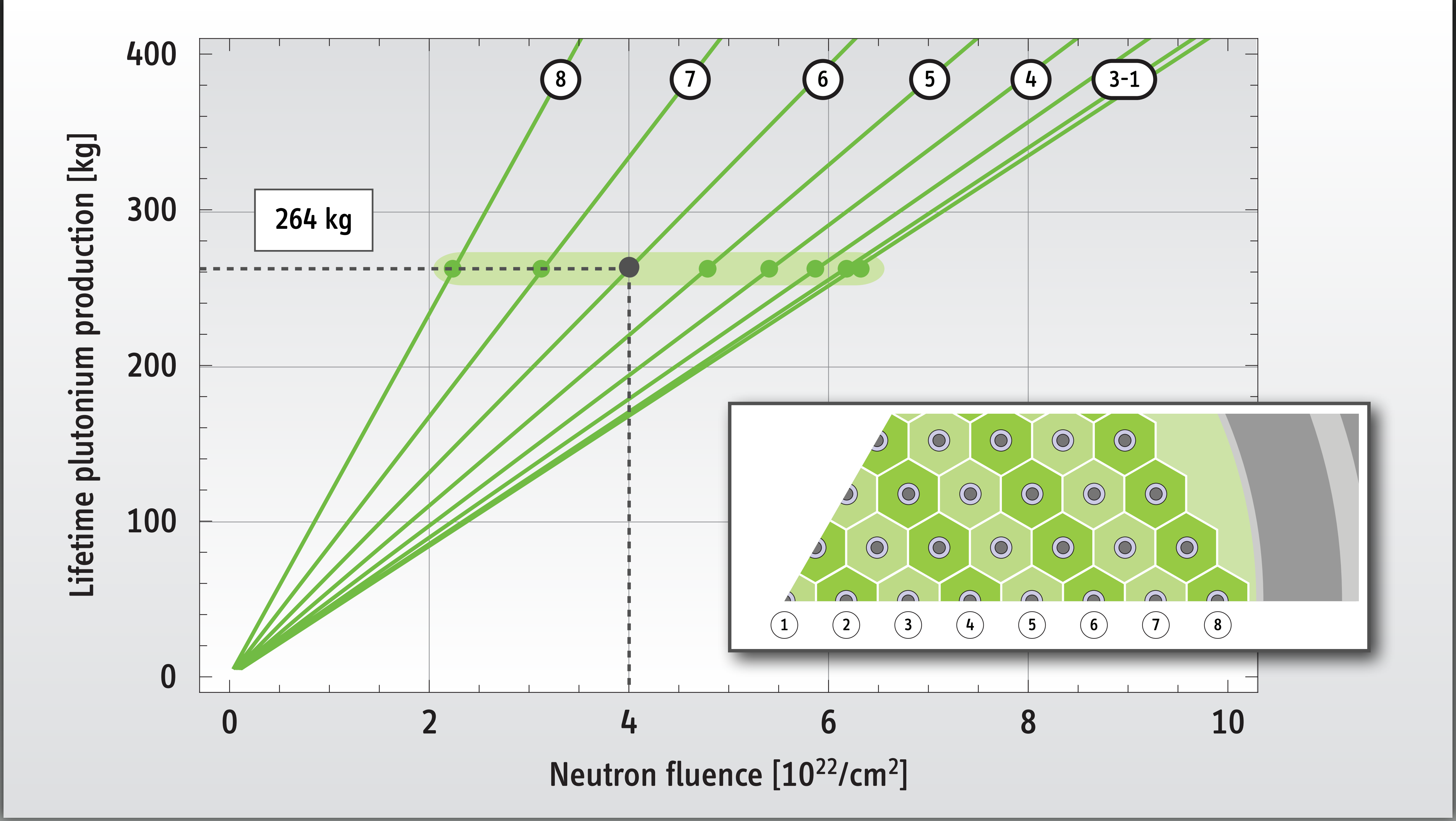
EVOLUTION OF SELECTED CHLORINE RATIOS, SIMULATED DATA



A. Gasner and A. Glaser, "Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors," *Science & Global Security,* 19, 2011

ARCHAEOLOGY FOR CANADA'S NRX REACTOR

"LOOKUP TABLES" CAN BE USED TO MAP FLUENCE VALUE (IN FUEL CHANNEL) TO LIFETIME PLUTONIUM PRODUCTION OF REACTOR

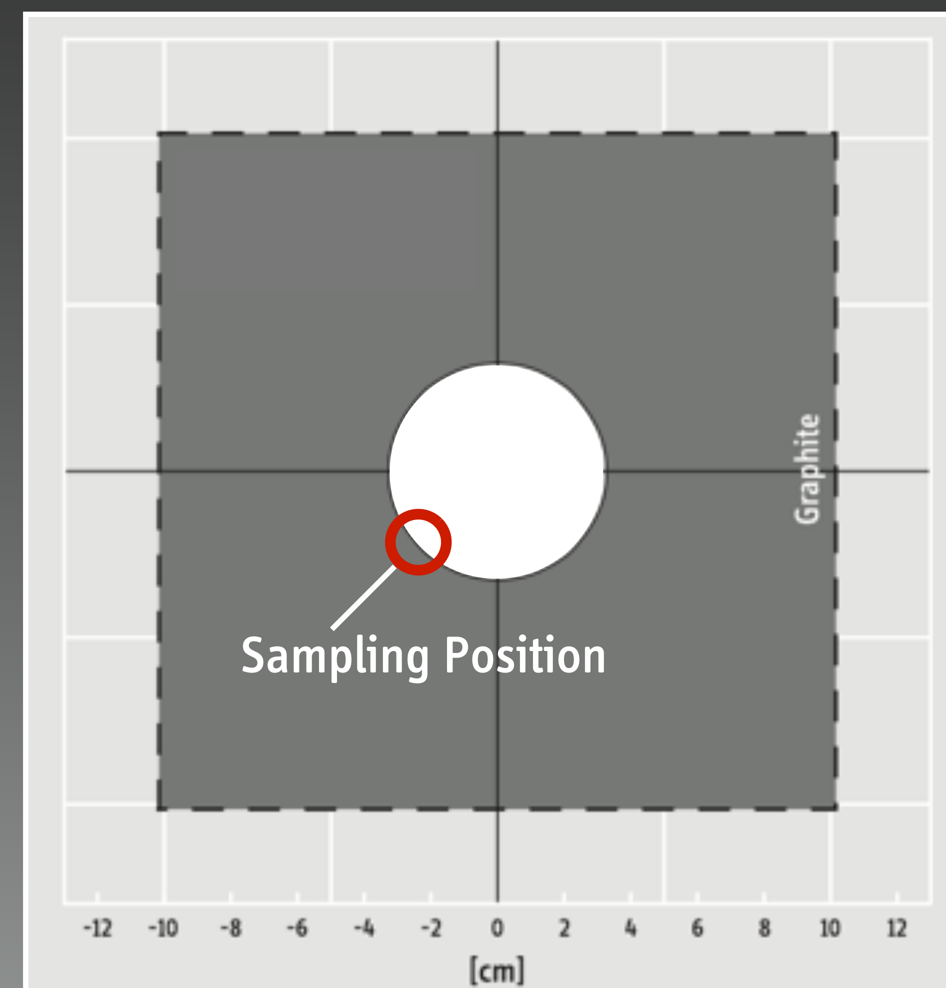


A. Gasner and A. Glaser, "Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors," *Science & Global Security,* 19, 2011

NUCLEAR ARCHAEOLOGY WOULD HAVE BEEN USED TO VERIFY NORTH KOREA’S PLUTONIUM DECLARATION

FORENSIC ANALYSIS OF GRAPHITE SAMPLES COULD CONFIRM TOTAL PLUTONIUM PRODUCTION IN NORTH KOREA WITHIN AN UNCERTAINTY OF ±2 KG

The banner reads: “Let’s protect Dear General Kim Jong Il desperately!”
Credit: CNN/Brian Rokus, 2008



Unit cell of the DPRK Yongbyon reactor

PLUTONIUM PRODUCTION REACTORS

BY TYPE AND COUNTRY

	Graphite moderated		Heavy-water moderated	
	H_2O cooled	CO_2 cooled	H_2O cooled	D_2O cooled
United States	Hanford			Savannah River
Russia	“Tomsk-7”			
United Kingdom		Calder Hall		
France		G-Series		Célestin
China	“Jiuquan”			
Israel				Dimona
India			Cirus/NRX	Dhruva
Pakistan			Khushab	
DPRK		Yongbyon		

A. Glaser, “Isotopic Signatures of Weapon-grade Plutonium from Dedicated Natural-uranium-fueled Production Reactors and Their Relevance for Nuclear Forensic Analysis,” *Nuclear Science & Engineering,* September 2009

WHAT'S NEXT

FOR NUCLEAR ARCHAEOLOGY?

NUCLEAR ARCHAEOLOGY FOR HISTORIC PRODUCTION OF HIGHLY ENRICHED URANIUM HAS YET TO BE DEMONSTRATED

Equipment in storage from the gaseous diffusion plant in Pierrelatte, June 2009, www.francetnp2010.fr

Storage area for cylinders of depleted uranium in 2001 at K-25 Site, Oak Ridge, TN

Nuclear archaeology for uranium enrichment is potentially more challenging because it is less obvious which signatures in equipment and waste materials would be most effective for verifying cumulative production of HEU

S. Philippe and A. Glaser, "Nuclear Archaeology for Gaseous Diffusion Enrichment Plants," *Science & Global Security,* 22, 1 (2014)

PREPARING FOR FUTURE VERIFICATION

MANY DIFFERENT MATERIALS, PROCESSES, AND SITES HAVE BEEN INVOLVED IN FISSILE MATERIAL PRODUCTION

THE CASE OF PLUTONIUM

Source material (Uranium)

Fuel fabrication

Plutonium production

Reprocessing of irradiated fuel

Waste storage

TO ALLOW FOR FUTURE VERIFICATION, STATES COULD:

1. Agree on the most important types of operating records to be preserved
2. Catalogue, characterize, and preserve waste materials

TEST BEDS FOR NUCLEAR ARCHAEOLOGY

To begin countries could offer single sites or facilities as test beds and invite partners with similar production facilities to engage in “site-to-site exercises” to jointly demonstrate verification approaches and measurement techniques

Left: Windscale Piles, www.sellafieldsites.com
Right: G2/G3, Marcoule, www.francetnp.fr

“THE CLOCK IS TICKING”

SHUTDOWN ENRICHMENT PLANTS AND PRODUCTION REACTORS ARE BEING DECOMMISSIONED OR DEMOLISHED

Demolition of the K-25 uranium enrichment plant began in December 2008 and has been completed in 2012
Source: Bechtel Jacobs

China’s unfinished underground plutonium production complex (Project 816), near Chongqing
Source: CQTV