NUCLEAR ARCHAEOLOGY

VERIFYING DECLARATIONS OF PAST FISSILE MATERIAL PRODUCTION

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PVTS–SGS Workshop on Verification Technologies
Beijing, June 15–16, 2015
World Stockpiles of Fissile Materials

1345 tons of highly-enriched uranium
1880 tons of separated plutonium

each block = 50 kg of HEU, the amount necessary to make a first-generation fission bomb; 27,600 bombs-worth total

499 tons of separated plutonium
495 tons of separated plutonium

each block = 5 kg of Pu, the amount necessary to make a first-generation fission bomb; 99,000 bombs-worth total

Graphic by Alex Wellerstein, nuclear secrecy.com
WILL WE EVER KNOW HOW MUCH FISSION MATERIAL EXISTS WORLDWIDE?

RECONSTRUCTING HISTORIC FISSION 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

Nuclear Archaeology: Verifying Declarations of Fissile-Material Production

Steve Ritter

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 ratio of the concentration of long-lived radionuclides in permanent components of the reactor core to that of U-235 in the production of fissile material provides a direct measure of the fissile materials produced. In the second technique, the ratio of the concentration of long-lived radionuclides deposited in the gaseous diffusion enrichment plants to that of U-234 in the production of fissile material provides a direct measure of the fissile materials produced. These techniques can be used to verify the past production of fissile materials and thereby lay a foundation for verifying the past production of fissile materials for military purposes in NWS.

INTRODUCTION

For the first time, a global proliferation-verification treaty will reduce their capacity to produce more than 10,000 tons of weapons-grade uranium. South Africa, Iran, Libya, and Libya have turned over their nuclear technologies and thereby lay a foundation for verifying the past production of fissile materials for military purposes in NWS. This article presents a separation method for the military production of highly enriched uranium. Since June 2013, all gaseous diffusion enrichment plants worldwide have been 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 best-established example of nuclear archaeology relies on measurements of the isotope ratios of graphite-moderated plutonium production. In this article, we present results of neutronics calculations and advice on nuclear archaeology for heavy-water reactors during a visit in Argentina, Brazil, and explore the role of nuclear archaeology for arms-control treaty

Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors

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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 reactors. The analysis methods are used for unsafeguarded plutonium production. In this article, we present results of neutronics calculations and analysis of neutron production in the reactor. The great limitation of this particular method is that it can only be applied to graphite-moderated reactors, which represent only one class of reactors. This Graphite Isotope-Ratio Method (GIRM) determines the cumulative plutonium production by analyzing the support structures and other core components. We present results of neutronics calculations and evaluation of the robustness of the method for applications in arms-control treaty
NUCLEAR ARCHAEOLOGY

THE CASE OF PLUTONIUM PRODUCTION
COMPUTER MODEL OF NRX/CIRUS
(40–50 MW, HEAVY-WATER MODERATED, NATURAL-URANIUM FUELED)

MANY ELEMENTS ARE PRESENT AS IMPURITIES IN ALUMINUM

<table>
<thead>
<tr>
<th>Element</th>
<th>Content</th>
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<tbody>
<tr>
<td>5 Boron</td>
<td>2 ppm</td>
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<tr>
<td>12 Magnesium</td>
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</tr>
<tr>
<td>14 Silicon</td>
<td>1900 ppm</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>24 Chromium</td>
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</tr>
<tr>
<td>26 Iron</td>
<td>5100 ppm</td>
</tr>
<tr>
<td>28 Nickel</td>
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<tr>
<td>29 Copper</td>
<td>1400 ppm</td>
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<tr>
<td>30 Zinc</td>
<td>200 ppm</td>
</tr>
<tr>
<td>40 Zirconium</td>
<td>&lt;100 ppm</td>
</tr>
<tr>
<td>82 Lead</td>
<td>&lt;100 ppm</td>
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</table>

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

Need to identify isotope ratios that correlate well with neutron fluence
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. Glaser, PVTS-SGS Workshop, Beijing, June 2015
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
<table>
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<tr>
<th></th>
<th>Graphite moderated</th>
<th>Heavy-water moderated</th>
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<tr>
<td></td>
<td>$H_2O$ cooled</td>
<td>$CO_2$ cooled</td>
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<td><strong>United States</strong></td>
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<td><strong>United Kingdom</strong></td>
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<td><strong>France</strong></td>
<td>G-Series</td>
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<tr>
<td><strong>China</strong></td>
<td>“Jiuquan”</td>
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<td><strong>Israel</strong></td>
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<tr>
<td><strong>India</strong></td>
<td></td>
<td>Cirus/NRX</td>
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<tr>
<td><strong>Pakistan</strong></td>
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<td>Khushab</td>
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<td><strong>DPRK</strong></td>
<td>Yongbyon</td>
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WHAT’S NEXT
FOR NUCLEAR ARCHAEOLOGY?
NUCLEAR ARCHAEOLOGY FOR HISTORIC PRODUCTION OF HIGHLY ENRICHED URANIUM HAS YET TO BE DEMONSTRATED

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

PREPARING FOR FUTURE VERIFICATION

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

THE CASE OF PLUTONIUM

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
“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