

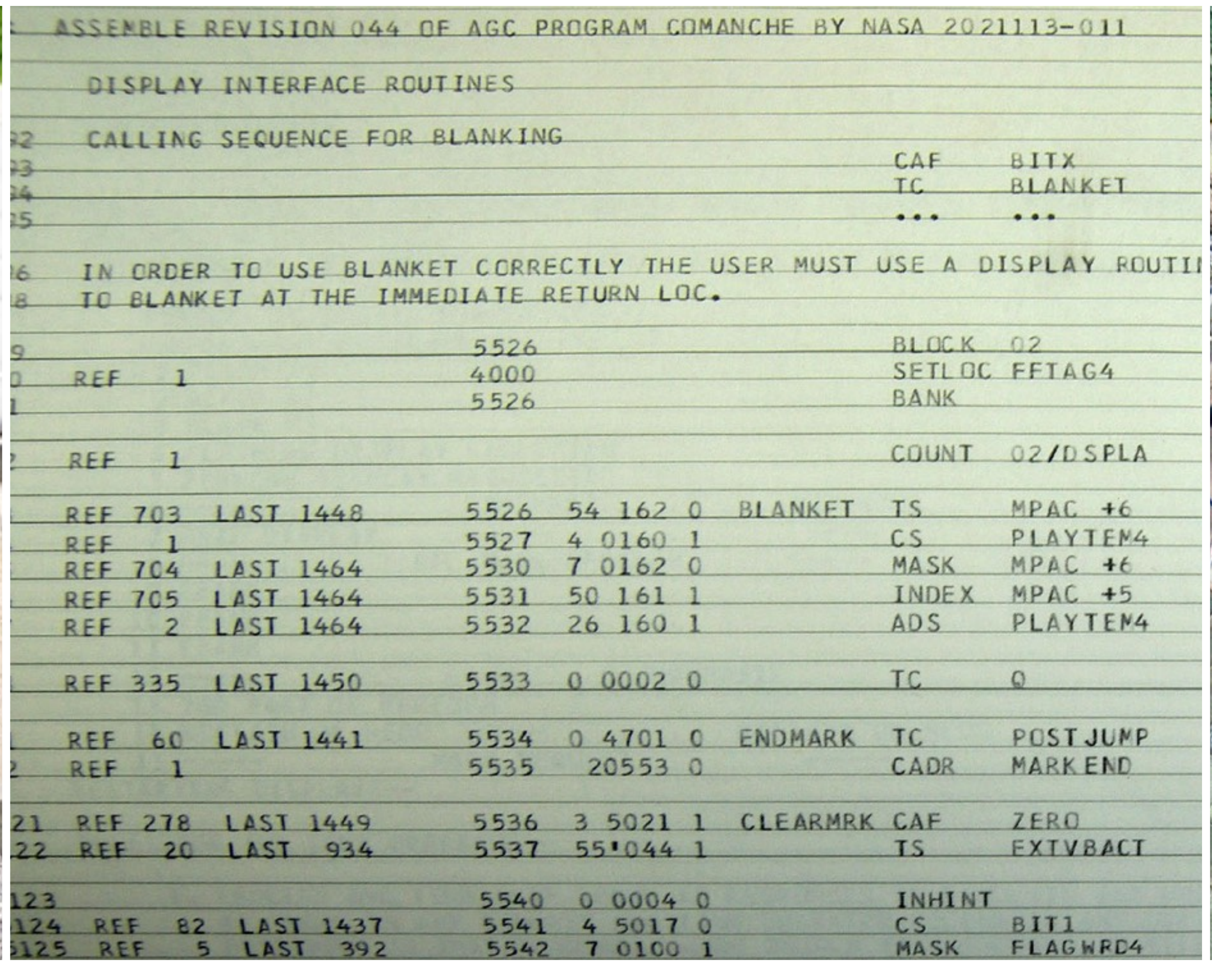
ASSEMBLE REVISION 044 OF AGC PROGRAM COMANCHE BY NASA 2021113-011

DISPLAY INTERFACE ROUTINES

CALLING SEQUENCE FOR BLANKING

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... ...

IN ORDER TO USE BLANKET CORRECTLY THE USER MUST USE A DISPLAY ROUTI
TO BLANKET AT THE IMMEDIATE RETURN LOC.

PRESERVING THE RECORD

A DOCUMENT-BASED APPROACH TO NUCLEAR ARCHAEOLOGY

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Einstein Center Digital Future, Berlin

Helmholtz Zentrum Berlin
January 22, 2021

Revision 1c

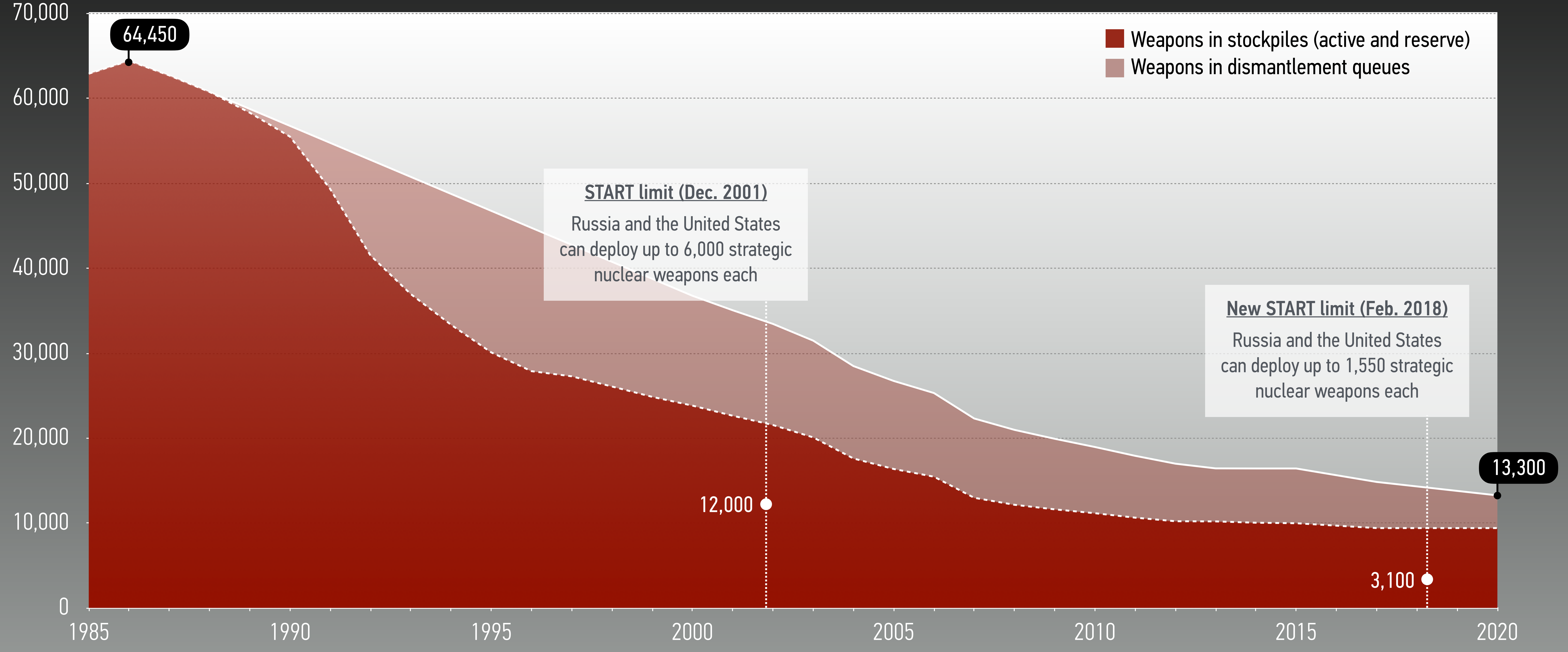
BACKGROUND

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

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

PROGRESS TOWARD NUCLEAR DISARMAMENT HAS BEEN REAL

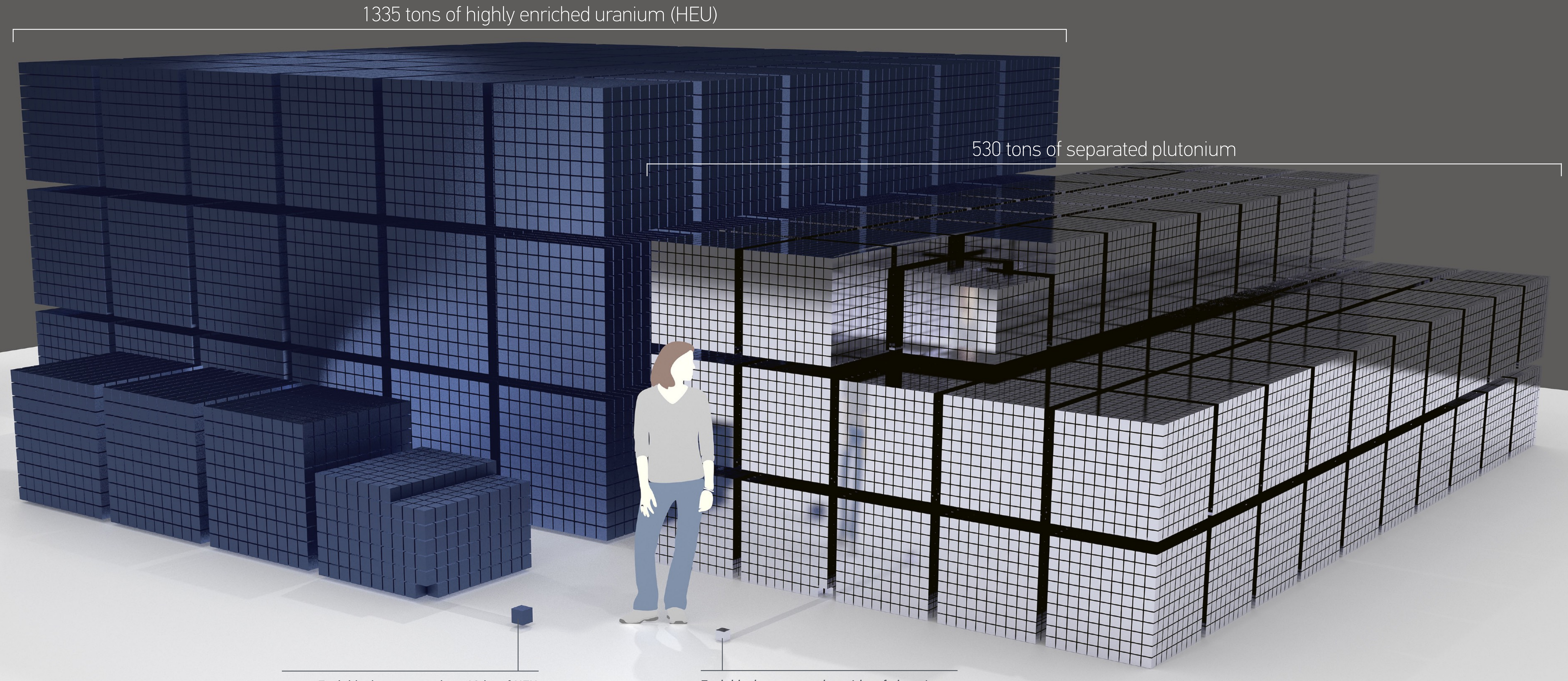
(BUT IT HAS SLOWED DOWN SIGNIFICANTLY OVER THE PAST DECADE)



Based on the Nuclear Notebook, maintained by Hans M. Kristensen and Matt Korda, thebulletin.org/nuclear-notebook/

There is enough nuclear explosive material worldwide to make over 200,000 nuclear weapons

Graphic/concept by Alex Wellerstein and Tamara Patton
Status as of the beginning of 2019

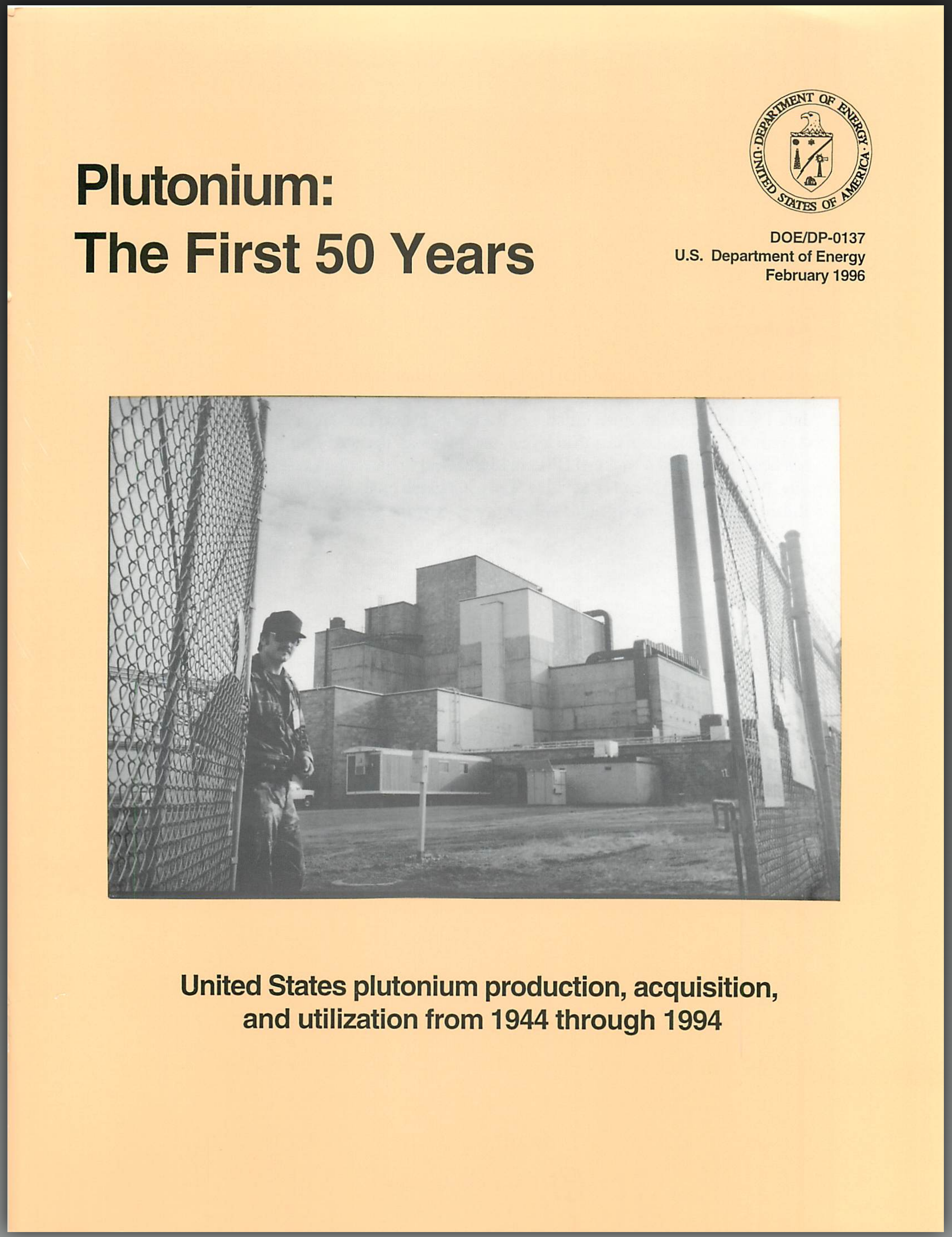


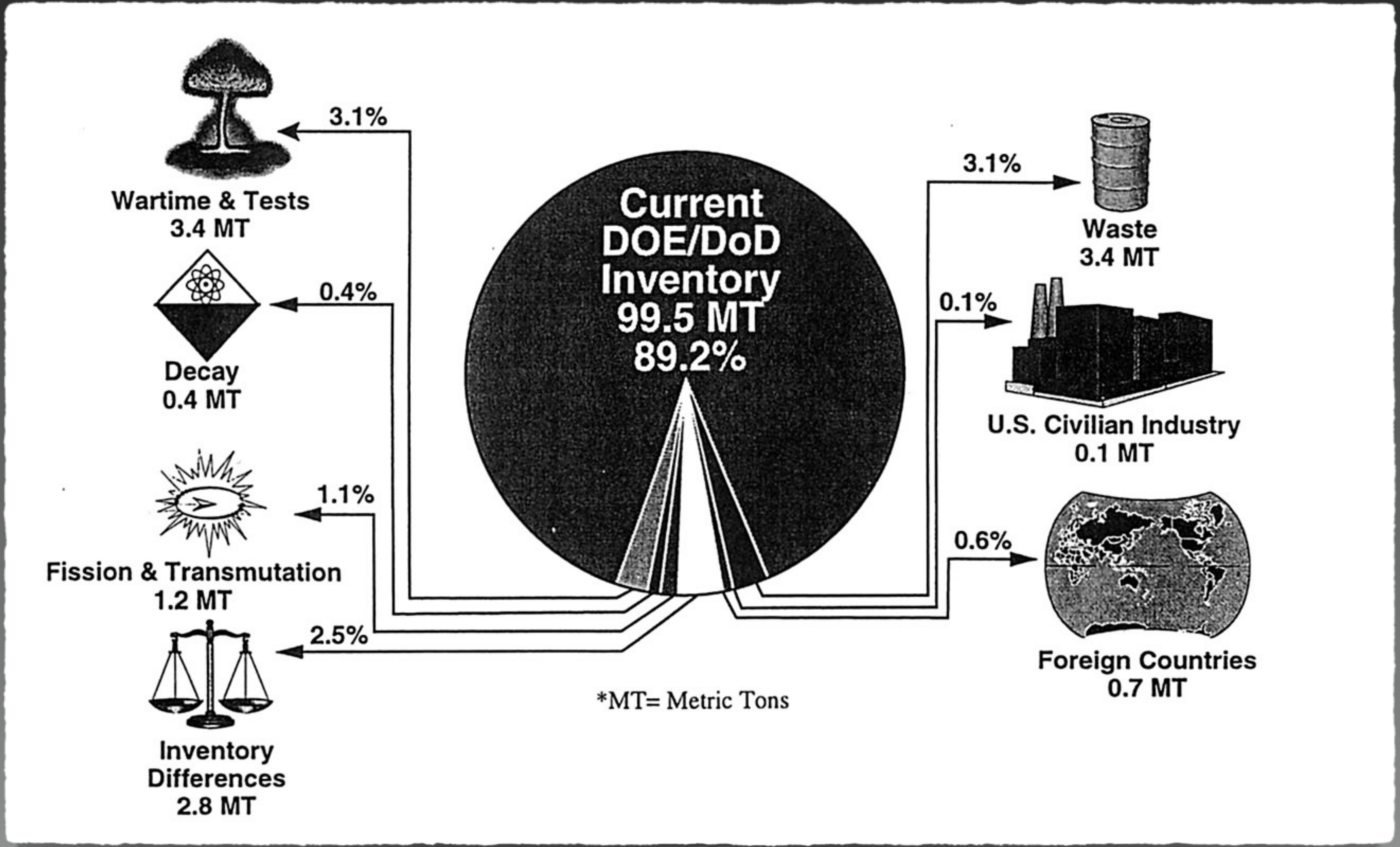
Each block corresponds to 12 kg of HEU, the amount necessary to make a fission bomb; about 111,670 bombs-worth total

Each block corresponds to 4 kg of plutonium, the amount necessary to make a fission bomb; about 130,000 bombs-worth total

ESTIMATING INVENTORIES CAN BE HARD

(AN EXAMPLE FROM THE 1996 U.S. PLUTONIUM DECLARATION)



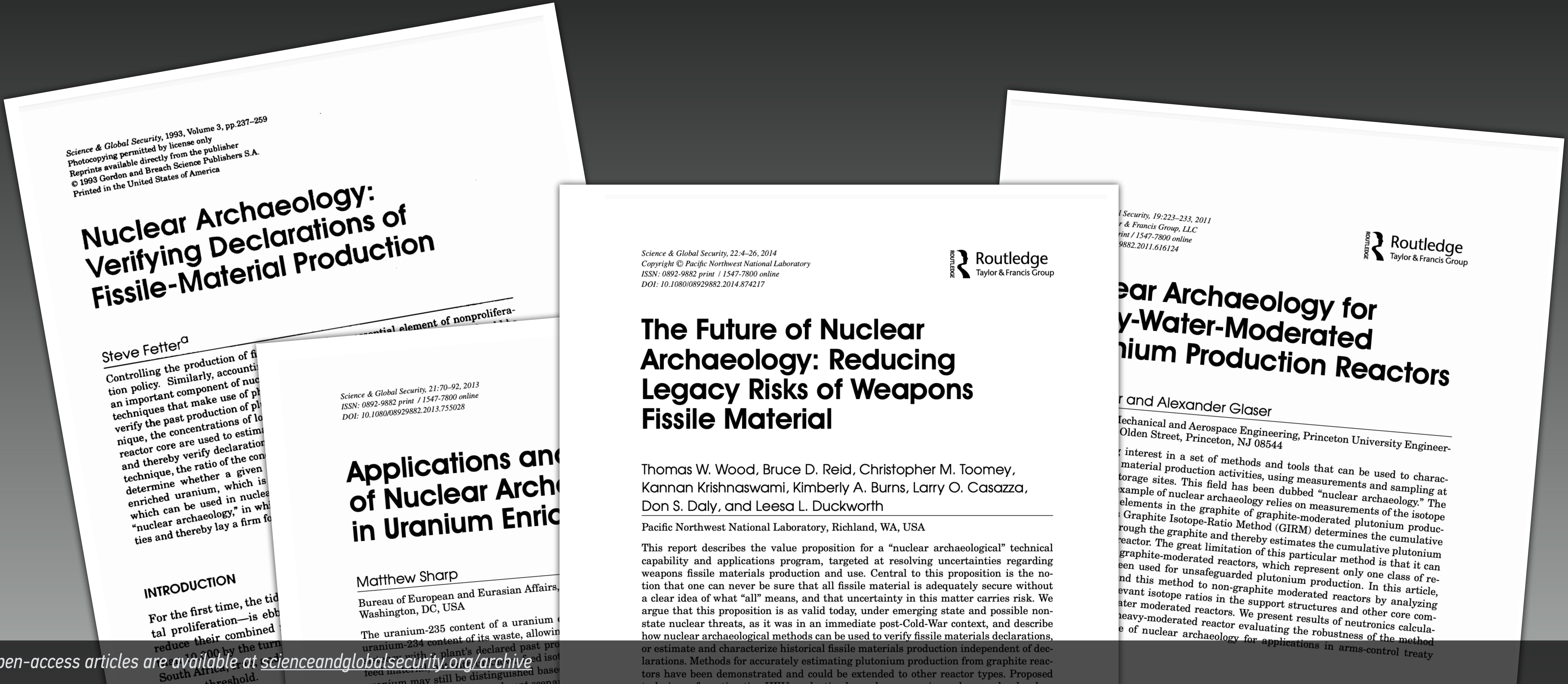


Plutonium: The First 50 Years, DOE/DP-0137, U.S. Department of Energy, Washington, DC, February 1996, www.ipfmlibrary.org/doe96.pdf

K Reactor, Savannah River Site, i.imgur.com/CPrBoCK.jpg

NUCLEAR ARCHAEOLOGY

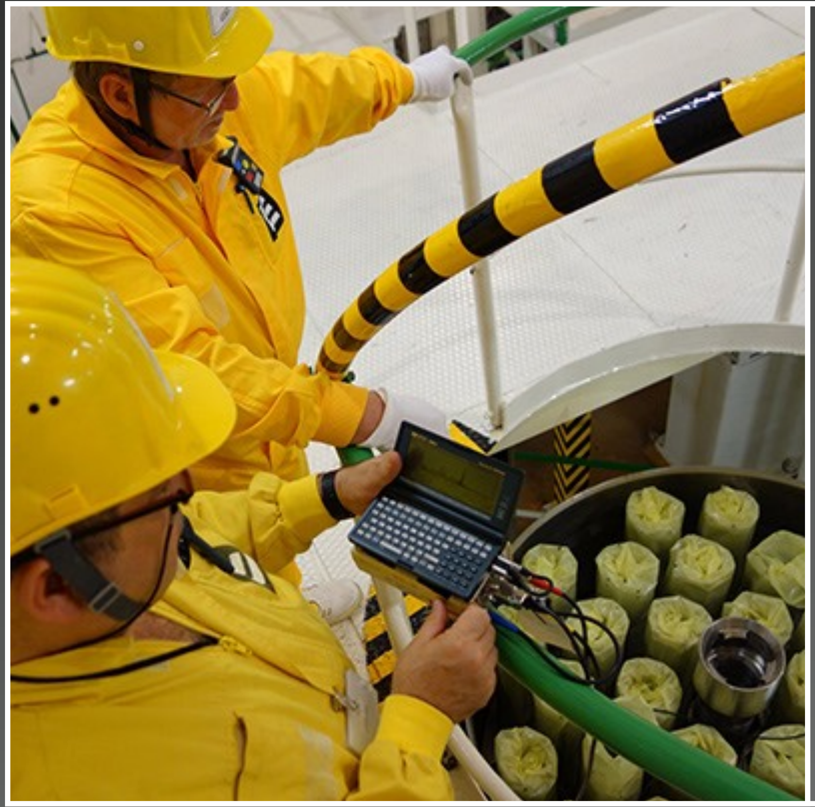
UNDERSTANDING THE OPERATIONAL HISTORY OF NUCLEAR FACILITIES



Open-access articles are available at scienceandglobalsecurity.org/archive

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

WHY GERMANY?

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

www.ipndv.org

Source: ipndv.org

GROUP OF GOVERNMENTAL EXPERTS ON DISARMAMENT VERIFICATION

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

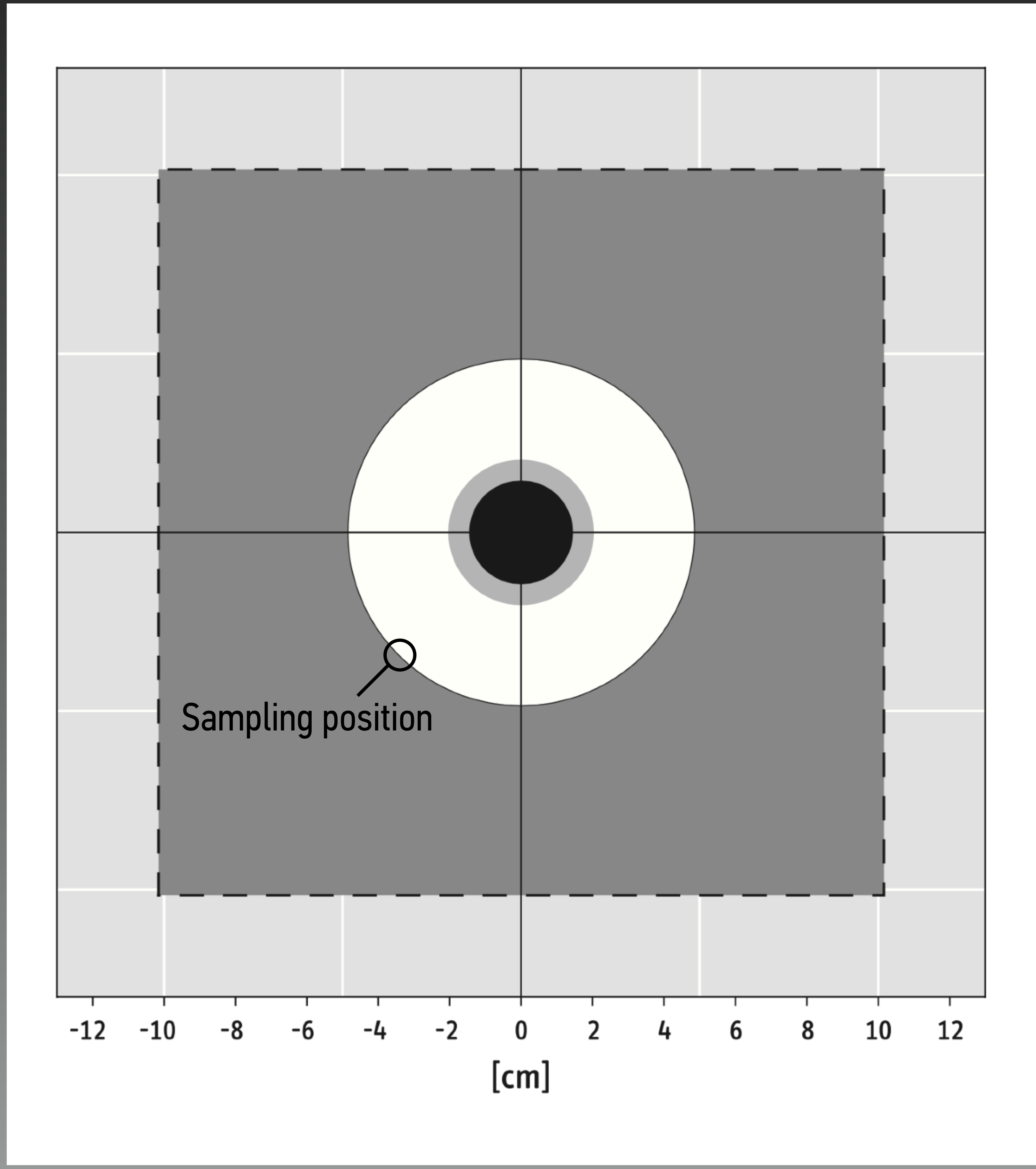
Source: www.flickr.com/photos/gruban/336920038

SAMPLE-BASED NUCLEAR ARCHAEOLOGY

(A case study)

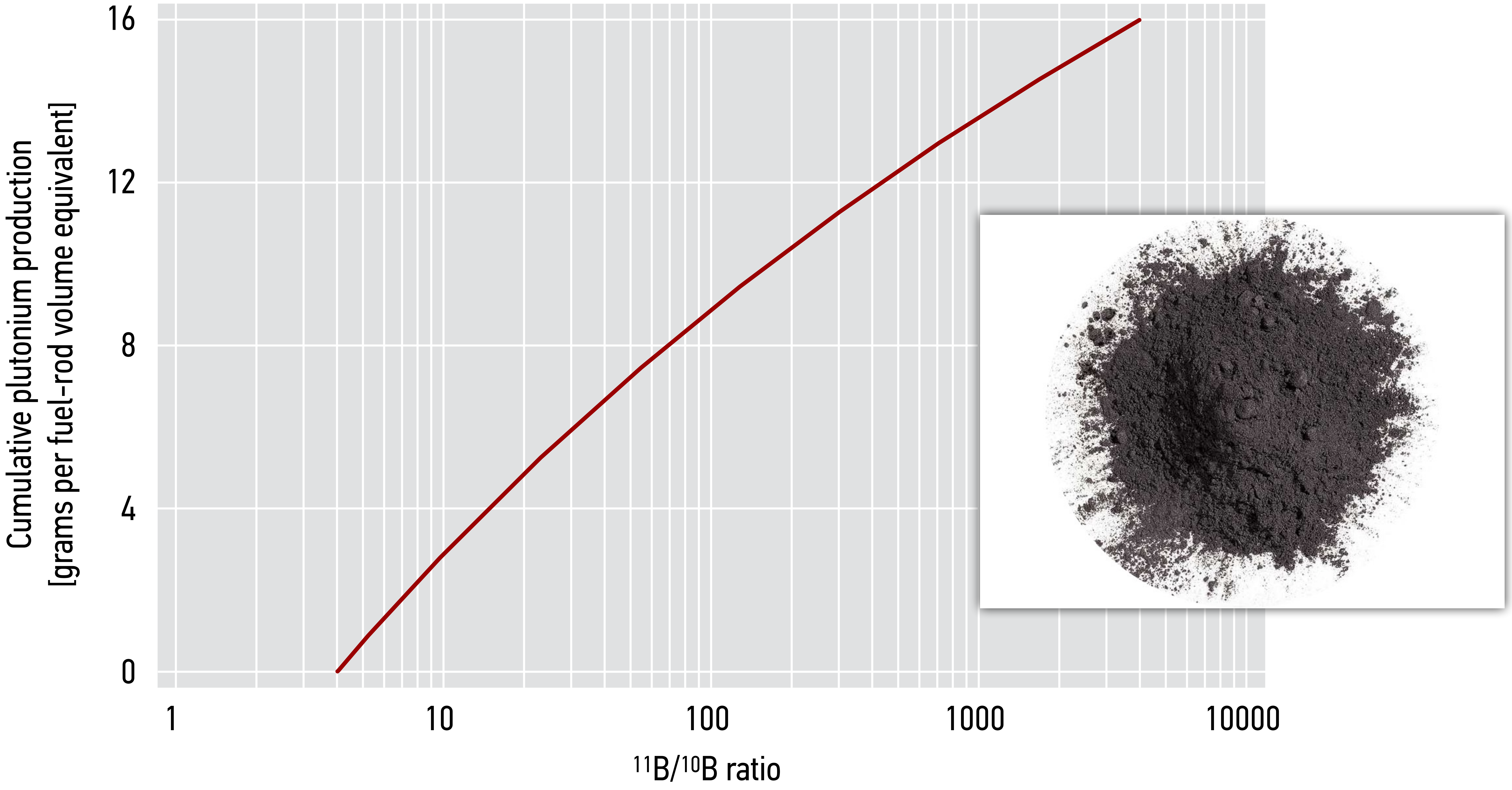
NUCLEAR ARCHAEOLOGY COULD BE USED TO VERIFY A NORTH KOREAN PLUTONIUM DECLARATION

Credit: CNN/Brian Rokus, 2008



Unit cell of the North Korea's Yongbyon reactor

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

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.

<u>The verification regime consists of experts of the six parties and is responsible to the Working Group on Denuclearization of the Korean Peninsula.</u>

- Six Party Experts will be
  coordinate their actions i

- Experts will be permitted
  course of exercising their responsibilities, to include measurement devices, radiation
  d GPS receivers.

- 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.

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

DOCUMENT-BASED NUCLEAR ARCHAEOLOGY

(A case study)

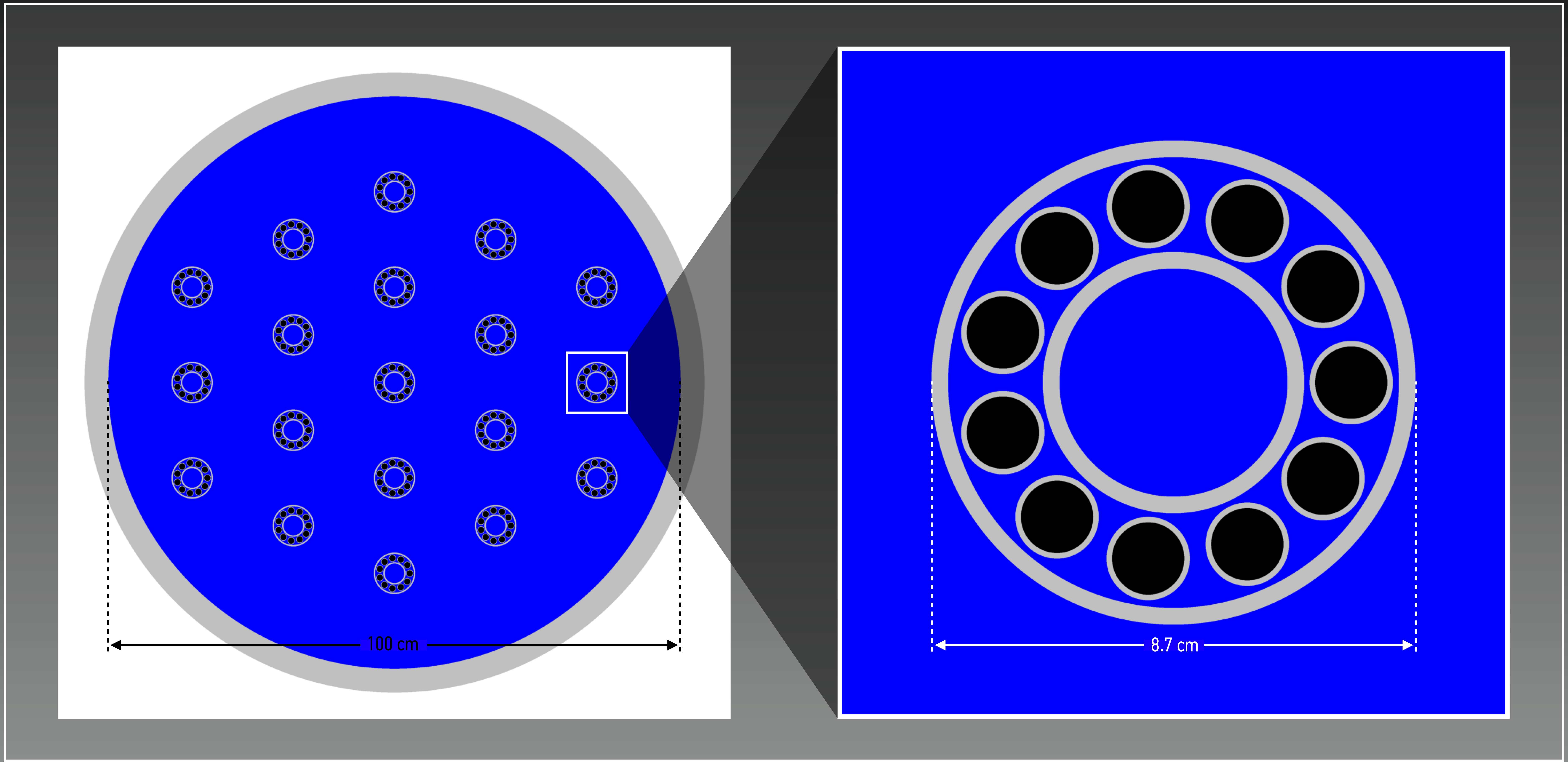
Indiana Jones: Raiders of the Lost Ark
Paramount Pictures, 1981

JEEP II Reactor

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

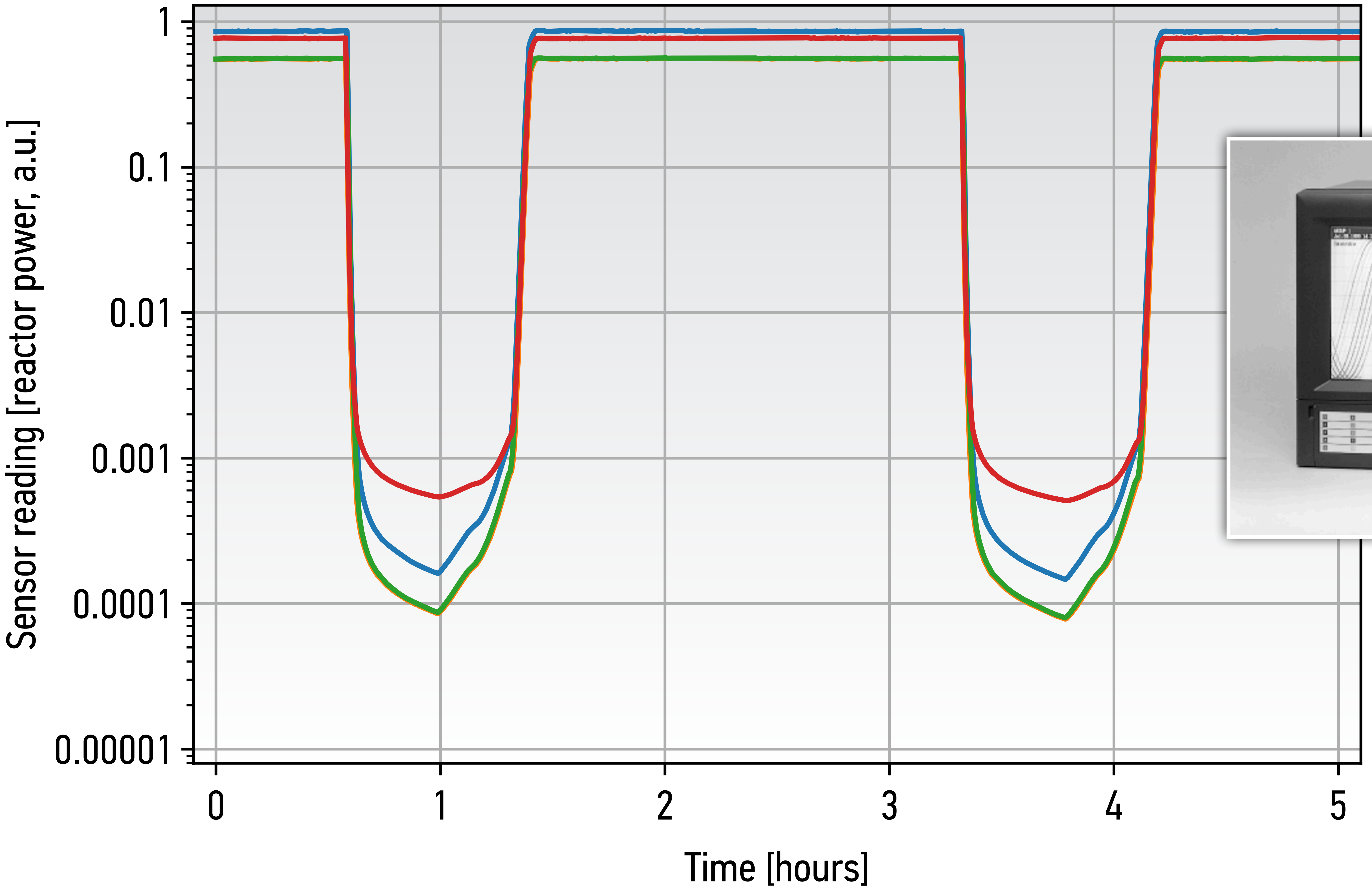
2 MW
Heavy-water moderated and cooled
3.5%-enriched uranium fuel

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

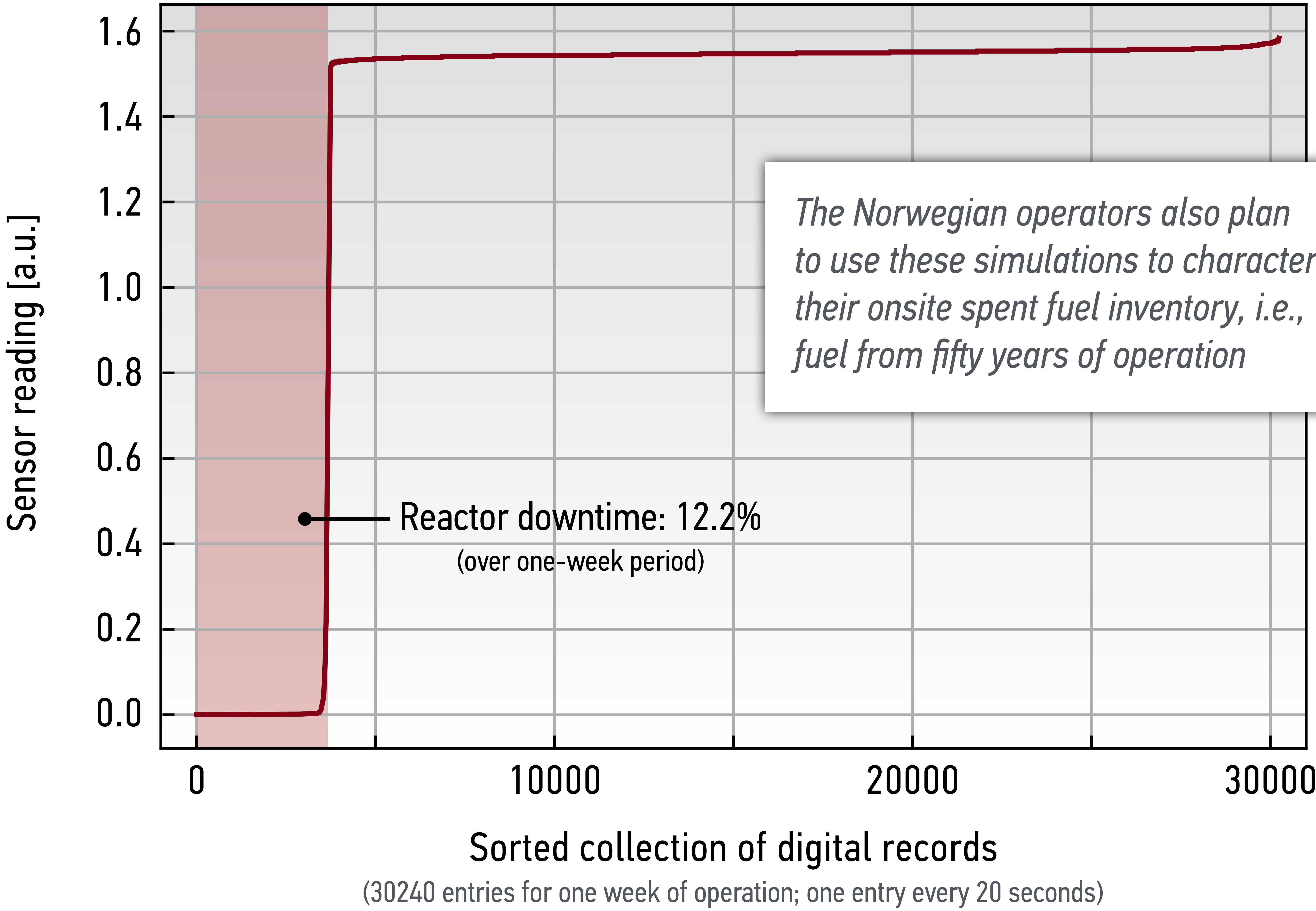
FIRST LOOK AT DIGITAL RECORDS OF JEEP II



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

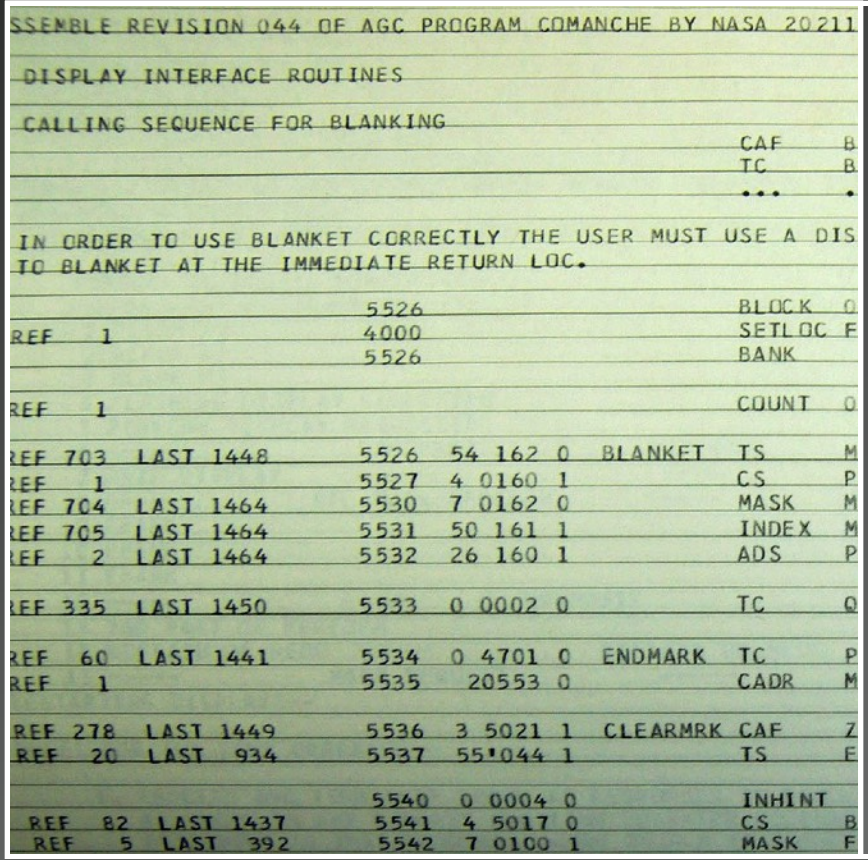


The Norwegian operators also plan to use these simulations to characterize their onsite spent fuel inventory, i.e., fuel from fifty years of operation

WHAT'S NEXT?

WHAT AN ACTUAL PROJECT COULD LOOK LIKE

("THE PROOF OF THE PUDDING IS IN THE EATING")



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SSEMBLE REVISION 044 OF AGC PROGRAM COMANCHE BY NASA 20211
 DISPLAY INTERFACE ROUTINES
 CALLING SEQUENCE FOR BLANKING
                                                      CAF       B
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 IN ORDER TO USE BLANKET CORRECTLY THE USER MUST USE A DIS
 TO BLANKET AT THE IMMEDIATE RETURN LOC.
                        5526                          BLOCK     0
REF    1                4000                          SETLOC    F
                        5526                          BANK
REF    1                                              COUNT     0
REF 703  LAST 1448      5526  54 162 0  BLANKET       TS        M
REF   1                 5527   4 0160 1               CS        P
REF 704  LAST 1464      5530   7 0162 0               MASK      M
REF 705  LAST 1464      5531  50 161 1                INDEX     M
REF   2  LAST 1464      5532  26 160 1                ADS       P
REF 335  LAST 1450      5533   0 0002 0               TC        Q
REF  60  LAST 1441      5534   0 4701 0  ENDMARK      TC        P
REF   1                 5535    20553 0               CADR      M
REF 278  LAST 1449      5536   3 5021 1  CLEARMRK     CAF       Z
REF  20  LAST  934      5537  55'044 1                TS        E
                        5540   0 0004 0               INHINT
 REF  82  LAST 1437     5541   4 5017 0               CS        B
 REF   5  LAST  392     5542   7 0100 1               MASK      F
```

REVIEW TYPES OF RECORDS AND DATA AVAILABLE

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

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

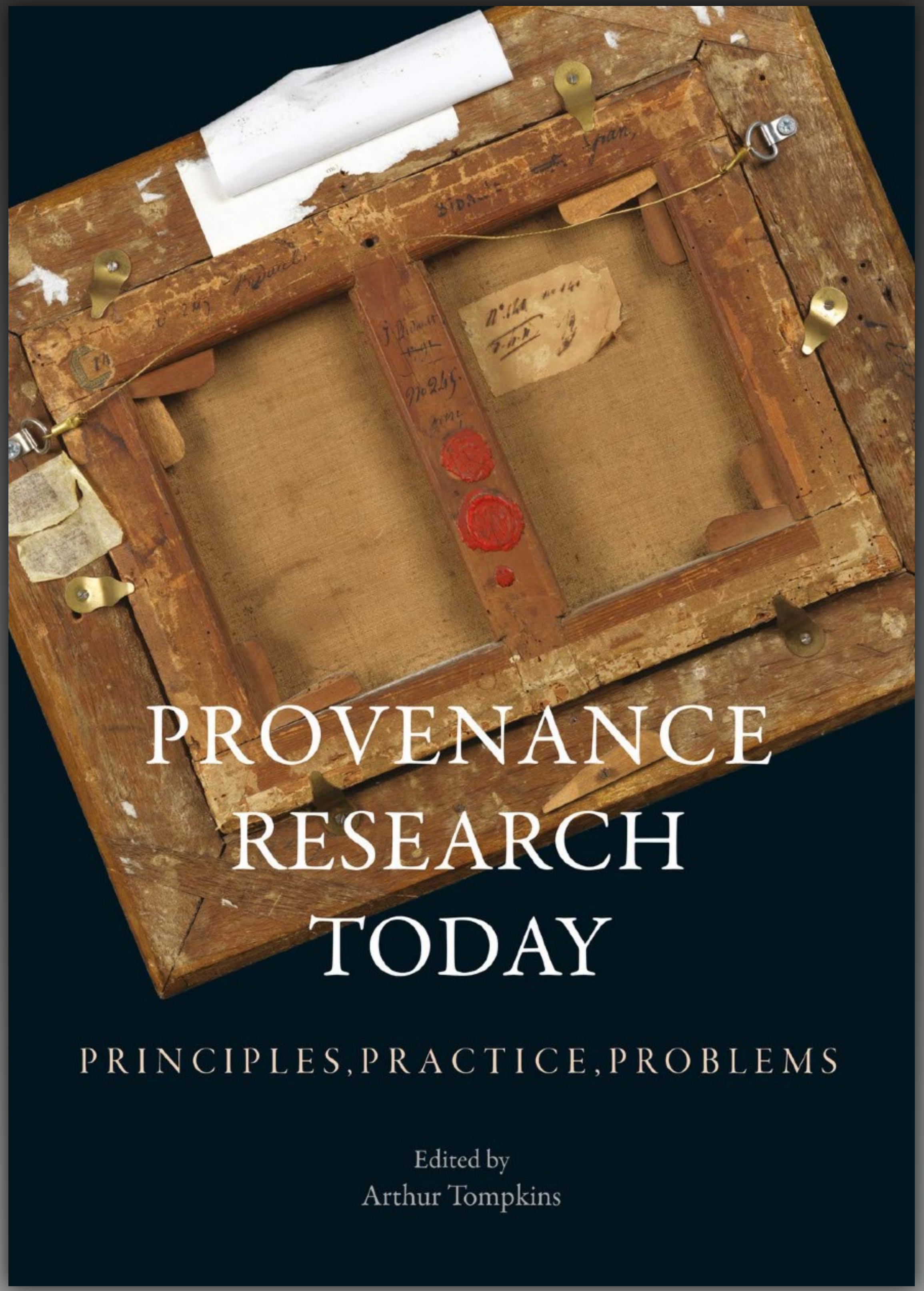
Note: Possibly of interest for RERTR 2021 or INMM 2021/2022

Source: www.flickr.com/photos/iaea_imagebank (bottom)

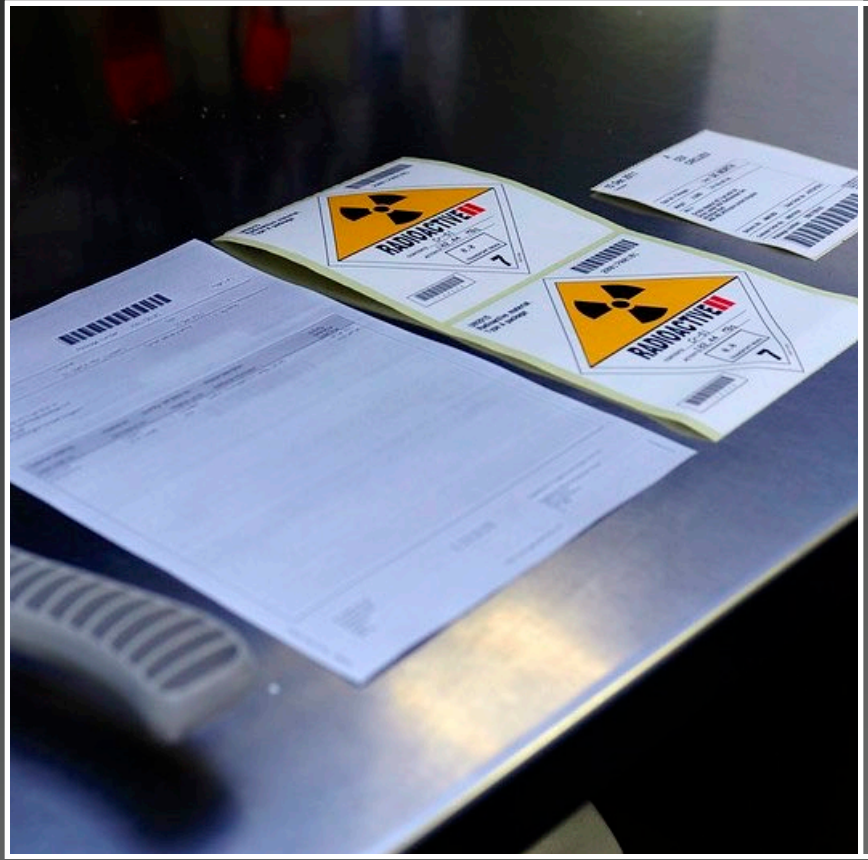
A MULTIDISCIPLINARY EFFORT

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

Source: asian-defence-news.blogspot.com



WHY IT MATTERS



DEVELOP BEST PRACTICES FOR DOCUMENTING AND ARCHIVAL

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)

SUPPORT ONGOING & FUTURE DECOMMISSIONING EFFORTS (FOR CIVILIAN FACILITIES)

Lead by example with regard to openness and transparency

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

Source: www.flickr.com/photos/iaea_imagebank (top) and www.jen-juelich.de (bottom)

SCIENCE AND GLOBAL SECURITY
PRINCETON UNIVERSITY