A VERY SHORT INTRODUCTION TO MAE'S

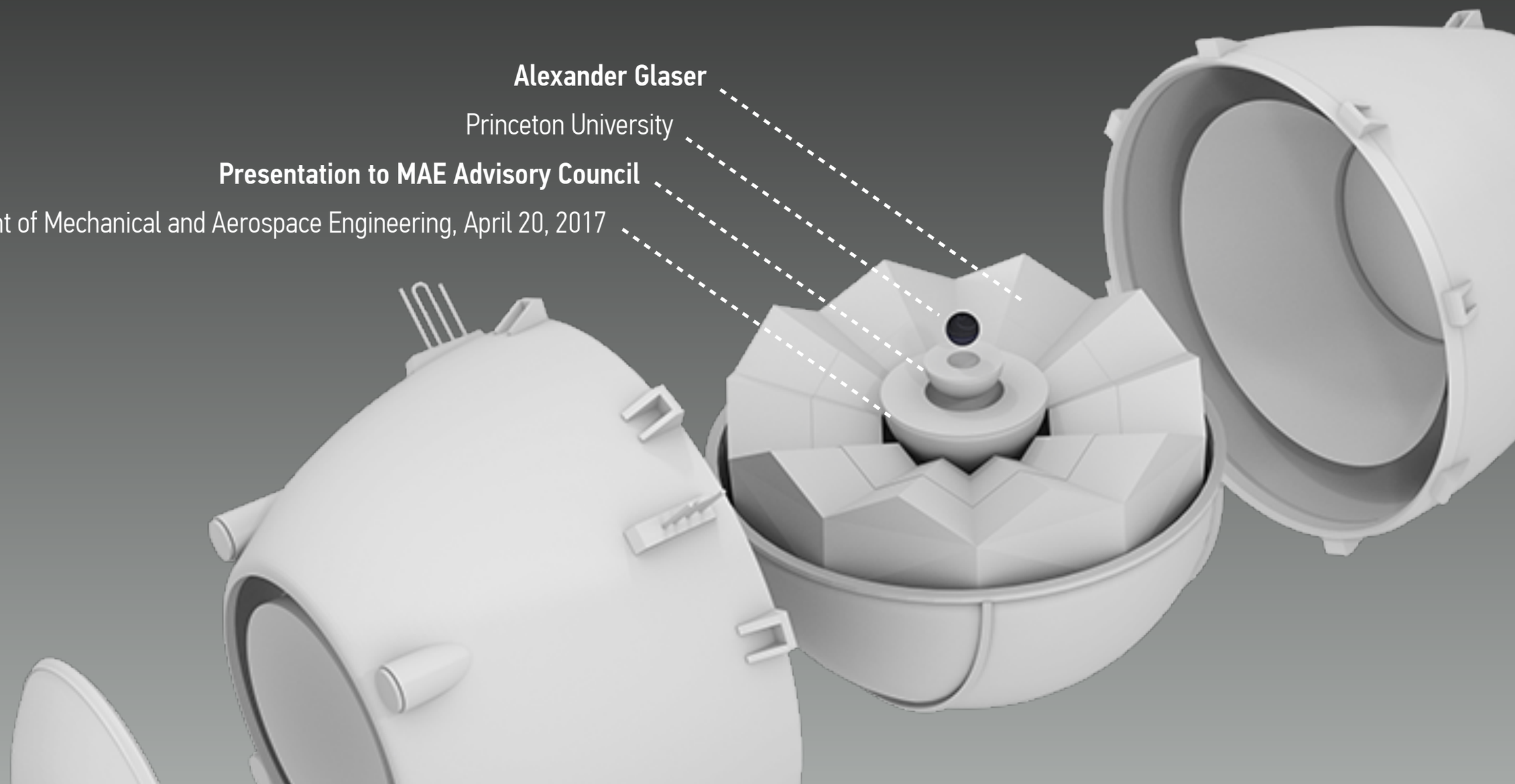
NUCLEARFUTURES LAB

Alexander Glaser

Princeton University

Presentation to MAE Advisory Council

Department of Mechanical and Aerospace Engineering, April 20, 2017



Revision 2

CURRENT AREAS OF RESEARCH

nuclearfutures.princeton.edu/projects

NUCLEAR ENERGY AND CLIMATE CHANGE

Are there new reactor technologies that could be potential "game changers" for nuclear power?

NUCLEAR ENERGY AND PROLIFERATION

Can one safely expand the use of nuclear power without increasing the risk of nuclear proliferation?

VERIFICATION OF NUCLEAR ARMS CONTROL AGREEMENTS

Can one dismantle and atomic bomb without learning anything about its design?

Source: Author (bottom)

NUCLEAR ENERGY & CLIMATE CHANGE

Some Small Reactors Are Smaller Than Others

Graphics: David LeBlanc, www.terrestrialenergyinc.com

NuScale

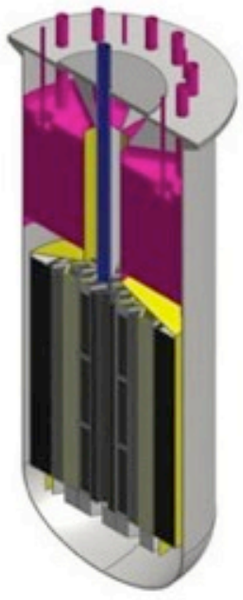
125MWth / 45MWe

B&W mPower

540MWth / 160MWe

IMSR 300

650 MWth / 300 MWe



SmAHTR

125 MWth / 50 MWe

IMSR 25

60MWth / 25MWe

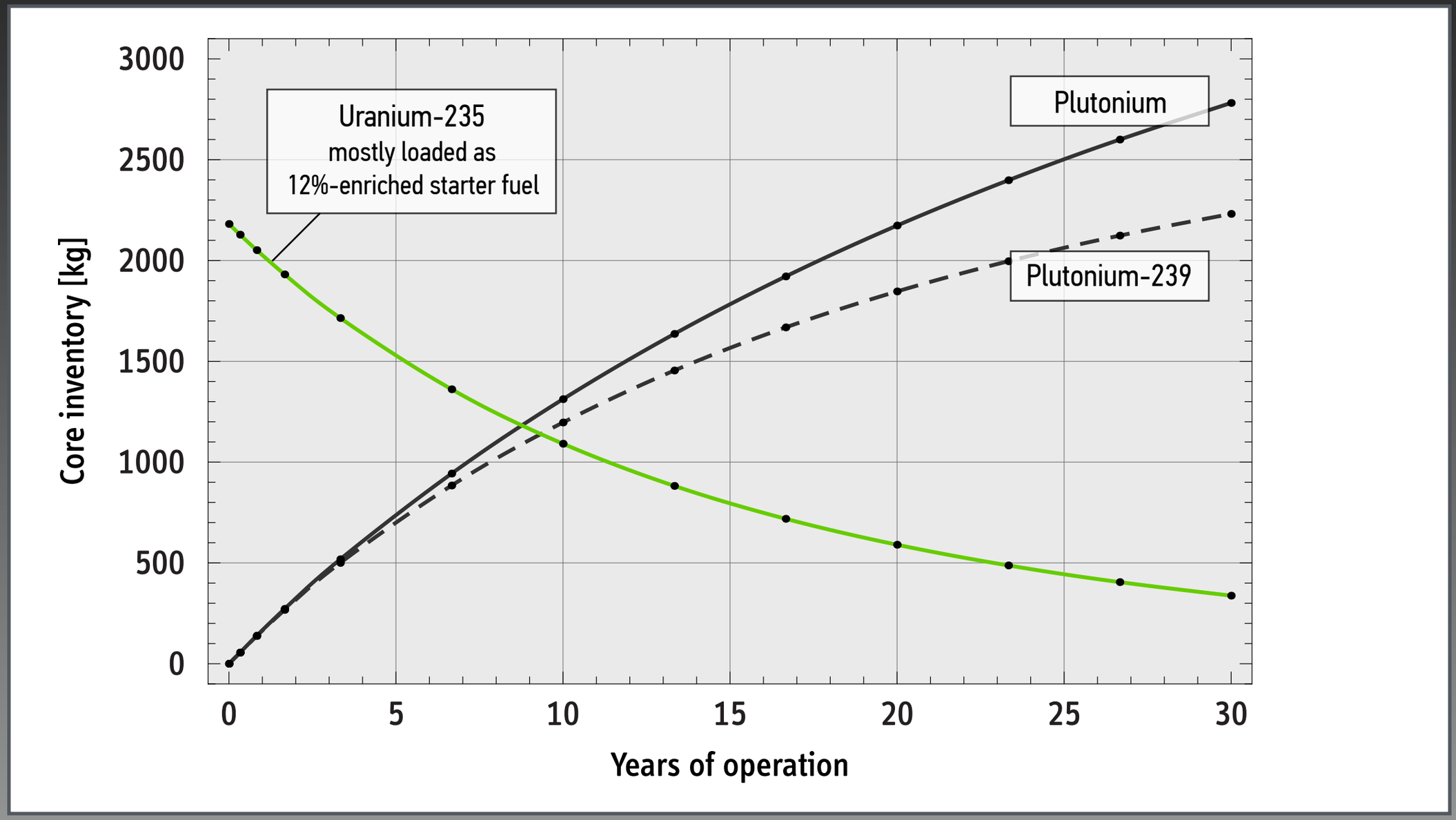
WHY CONSIDER SMALL MODULAR REACTORS?

- **Substantially lower investment risks**
  $1 billion vs $10 billion projects; combined with shorter construction times
- **Better suited for electricity markets with low growth rates**
  Modules can be added to existing facilities “on demand”
- **Promise of meeting emerging (or niche) market needs**
  Replacement of aging coal/oil-fired plants, non-electricity applications, etc.
- **Promise of enhanced safety and security**
  Almost all designs envision underground siting
- **Potential nonproliferation benefits**
  Long-lived cores

- **BUT: Ultimately, most will hinge on the economics**

SMRS WITH LIFETIME CORES CAN HAVE SIGNIFICANT INVENTORIES OF FISSILE MATERIAL

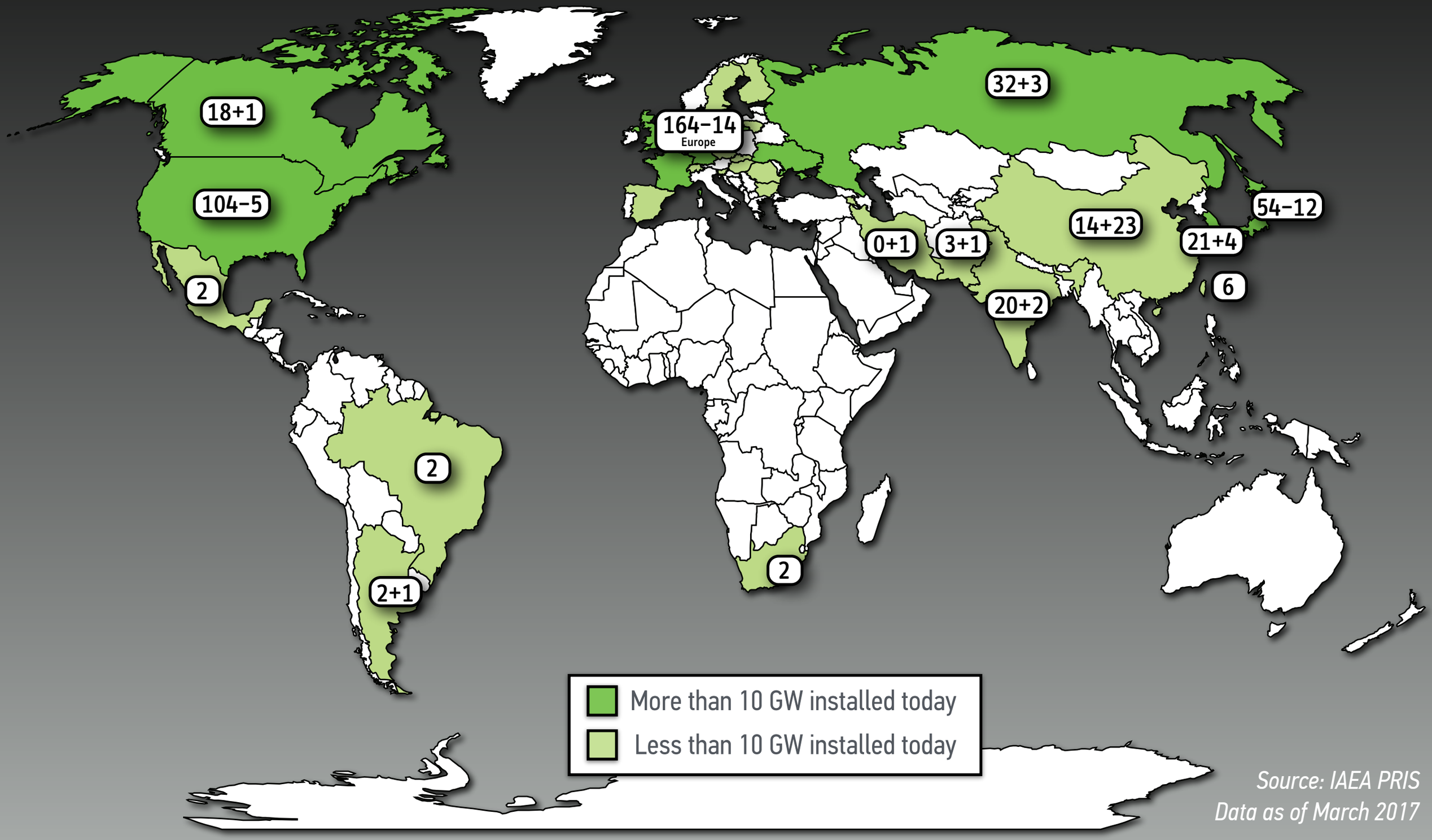
(Neutronics calculations for a notional design, 200 MWe, 30-year core life, 300 days per year)



Alexander Glaser, Laura Berzak Hopkins, M. V. Ramana, "Resource Requirements and Proliferation Risks Associated with Small Modular Reactors," *Nuclear Technology,* 184, October 2013, pp. 121–129

NUCLEAR POWER REACTORS IN THE WORLD, 2017

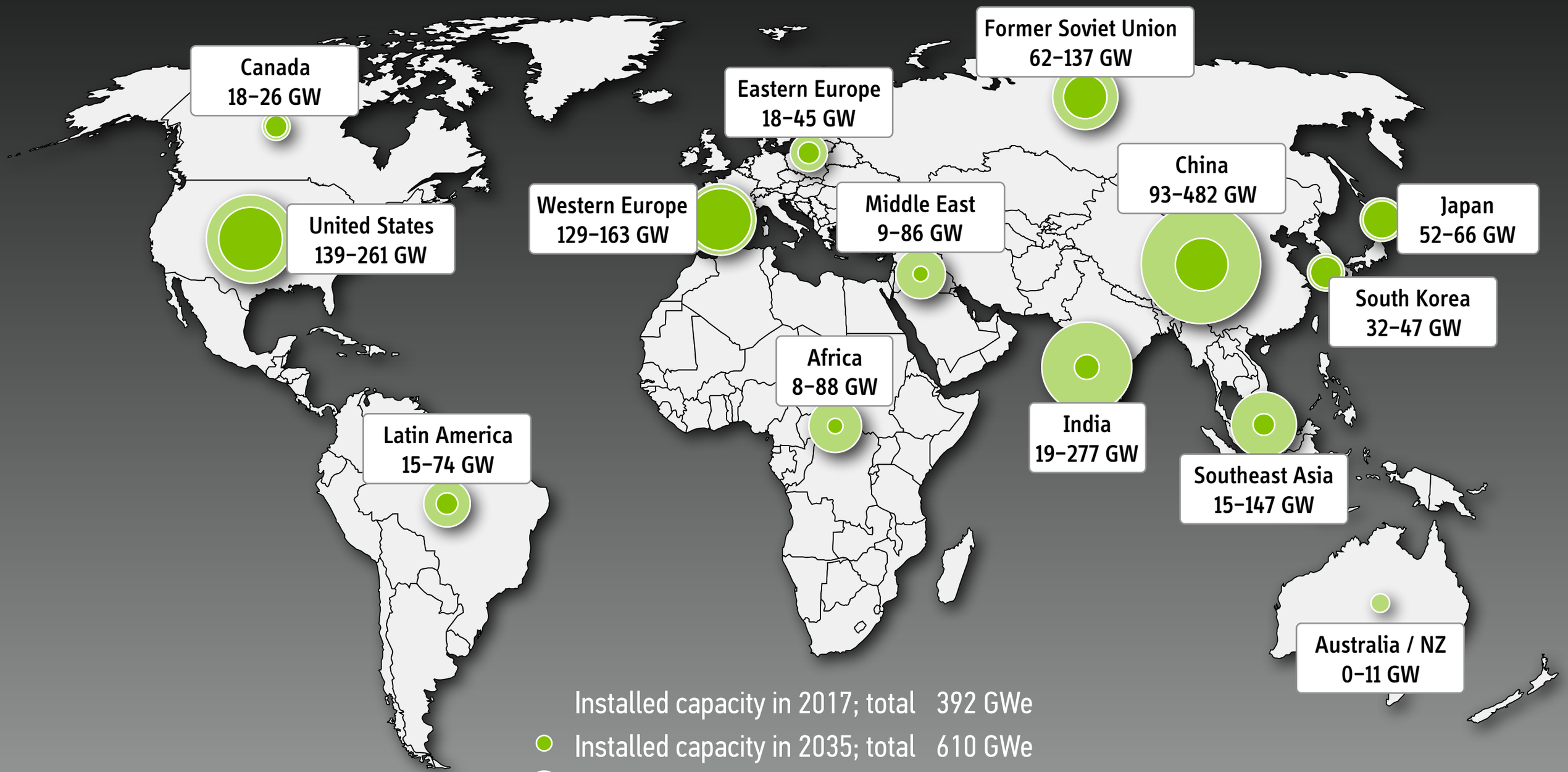
(449 operational reactors (5 more than in February 2011) in 31 countries currently provide ~10% of global electricity)



Source: IAEA PRIS
Data as of March 2017

SCENARIO FOR GLOBAL NUCLEAR CAPACITY, 2035–2060

GCAM policy scenario (450 ppm, stabilizes at ΔT = 2.25 °C by the end of the century)



Installed capacity in 2017; total 392 GWe

Installed capacity in 2035; total 610 GWe

Installed capacity in 2060: total 1910 GWe

Global Change Assessment Model, www.globalchange.umd.edu/models/gcam/

NUCLEAR ENERGY & NUCLEAR PROLIFERATION

SHAPING THE IRAN NUCLEAR DEAL

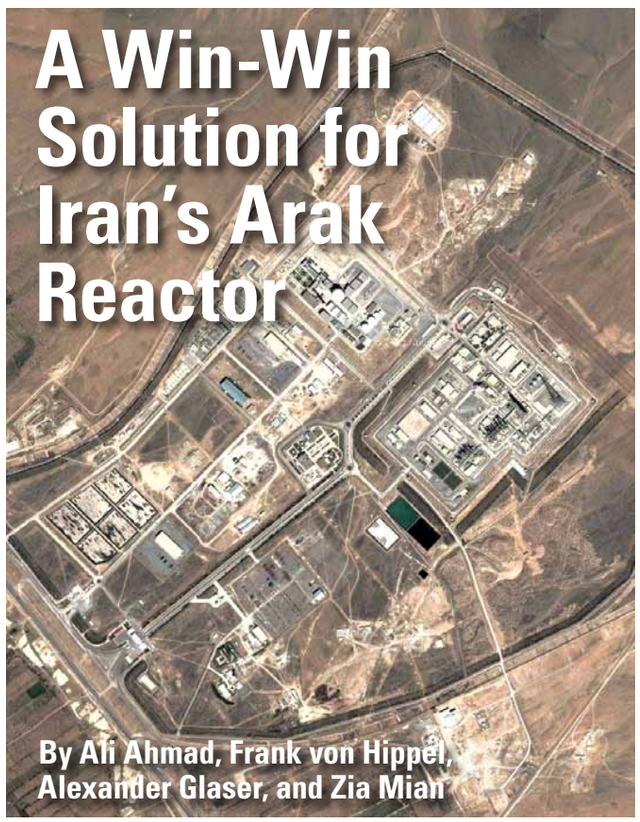
ON THE POLICY SIDE, SPRING/SUMMER 2014

INSIDE | Drone Proliferation Tests Arms Control

Arms Control TODAY

THE SOURCE ON NONPROLIFERATION AND GLOBAL SECURITY

Volume 44
Number 3
APRIL 2014



IN THIS ISSUE

Advancing the Arms Trade Treaty: An Interview With U.S. ATT Negotiator Thomas Countryman

Rough Seas Ahead: Issues for the 2015 NPT Review Conference
By Gaukhar Mukhatzhanova

IN THE NEWS

States Commit to Nuclear Rules at Summit

U.S. Nuclear Arms Spending Set to Rise

Missile Defense Budget Holds Steady

Gottemoeller Confirmed by Senate

Arms Checks Unaffected By Ukraine Crisis

Iran, P5+1 Hold 'Constructive' Talks

Syria Steps Up Removal of Chemicals

UN Report: Enforce N. Korea Sanctions

U.S. $7.00
Canada $8.00

A Publication of the Arms Control Association
www.armscontrol.org

INSIDE | Last Chemical Arms Materials Leave Syria

Arms Control TODAY

THE SOURCE ON NONPROLIFERATION AND GLOBAL SECURITY

Volume 44
Number 6
JULY/AUGUST 2014

IN THIS ISSUE

Russian-U.S. Cooperative Threat Reduction Beyond Nunn-Lugar and Ukraine
By Richard Weitz

Disarmer in Chief: An Interview With The UN's Angela Kane

Getting to Know
Tun Channareth

IN THE NEWS

Iran, P5+1 Make Progress on Nuclear Deal

U.S. Formally Ends Landmine Production

Fate of Space Code Remains Unclear

China Seen Nearing Sea-Based Deterrent

Troubled Missile System Hits Target

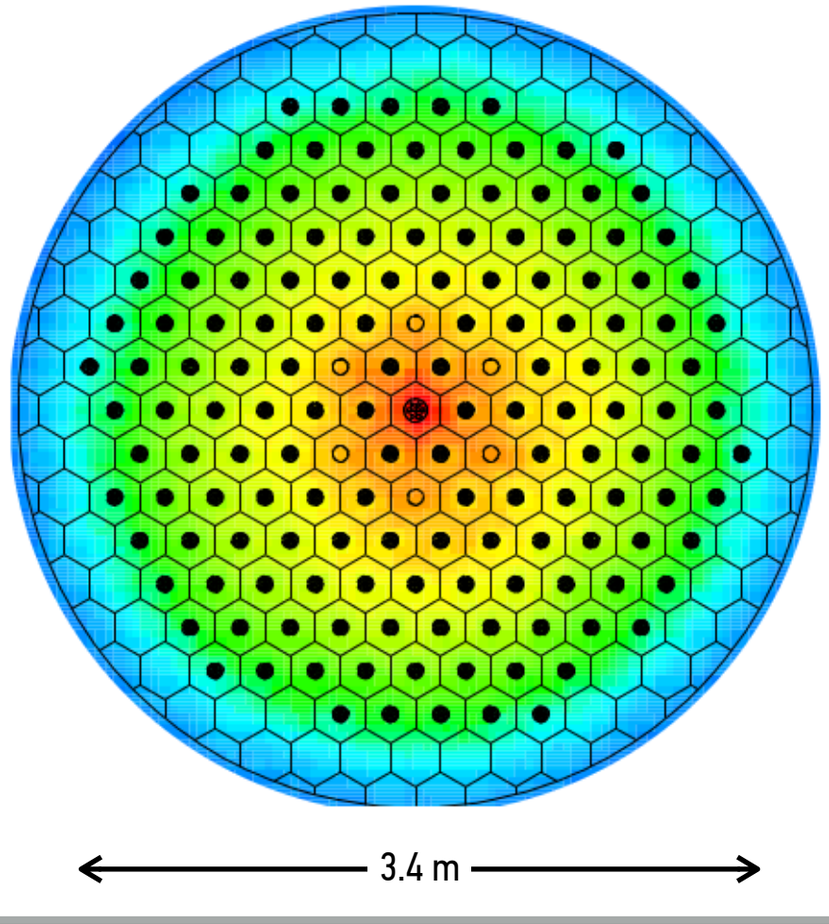
U.S. Sends Nuclear Bombers to Europe

U.S. $7.00
Canada $8.00

A Publication of the Arms Control Association
www.armscontrol.org

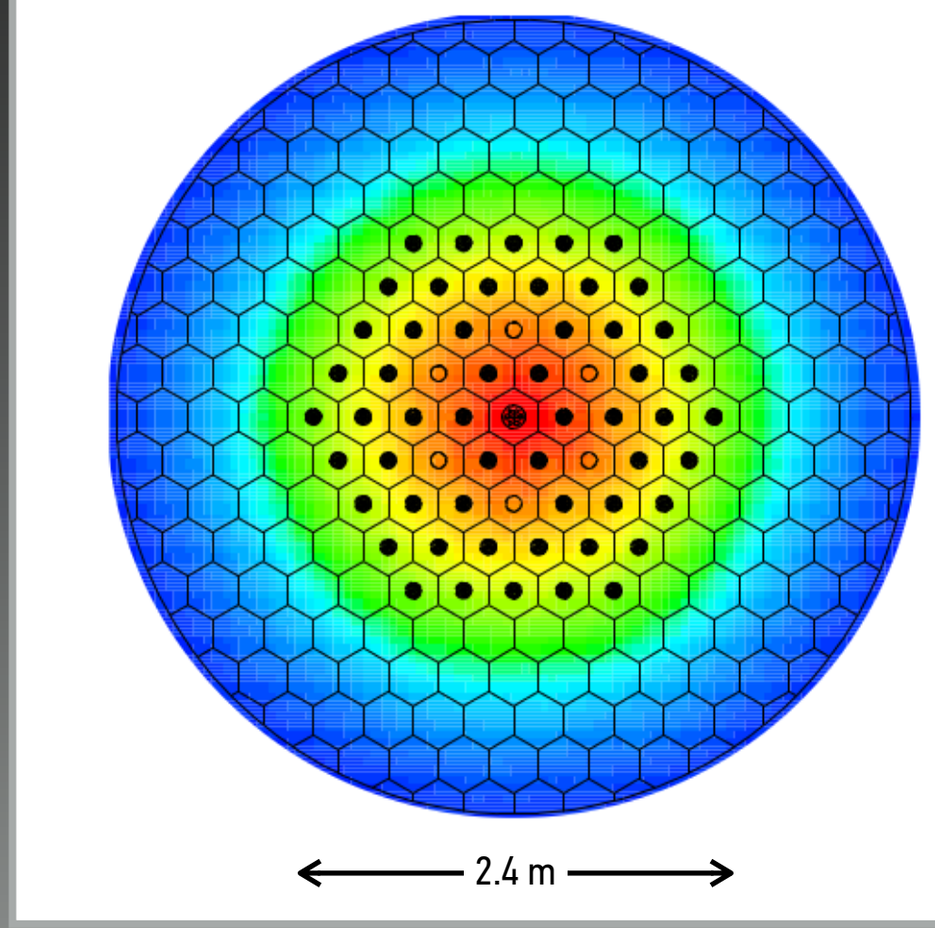
THE MODIFIED CORE IS MORE COMPACT

It has a much higher neutron flux, which compensates for usability



Original core

(40 MW with natural uranium fuel)



Modified core

(10 MW with 5%-enriched fuel)

A. Ahmad and A. Glaser, "A Conversion Proposal for Iran's IR-40 Reactor with Reduced Plutonium Production," *Science & Global Security,* 23 (1), 2015

"All the News That's Fit to Print"

The New York Times

VOL. CLXIV . . . No. 56,928
© 2015 The New York Times
WEDNESDAY, JULY 15, 2015

Washington Edition
Today, variable cloudiness, a shower or thunderstorm, high 87. **Tonight,** partly cloudy, low 67. **Tomorrow,** mostly sunny, less humid, high 84. Weather map is on Page A22.

$2.50

WORLD LEADERS STRIKE AGREEMENT WITH IRAN TO CURB NUCLEAR ABILITY AND LIFT SANCTIONS

G.O.P. Pledges to Kill Pact, but Veto Looms

By JONATHAN WEISMAN and JULIE HIRSCHFELD DAVIS

WASHINGTON — Before Congress had even begun its official review, Republican leaders vowed Tuesday to kill President Obama's nuclear accord with Iran, setting up a fierce fight to save the president's signature diplomatic achievement.

Congress will have 60 days to review the deal, once all documents have been sent to the Capitol, after which it can pass a resolution of approval, pass one of disapproval or do nothing. Mr. Obama would veto a resolution of disapproval, and the opponents could derail the agreement only if they could rally the required two-thirds vote of Congress to override his action.

"I want to go through this pro- s and make sure we fully un- and what we're voting on," enator Bob Corker, Repub- f Tennessee and chairman enate Foreign Relations ee. "In the end, those ve this truly is going to rom getting a nuclear vote for it. Those hat is not the case, hat it's not going to be me ways it may r them to get a — will vote

Page A10

CAN IRAN KEEP ENRICHING URANIUM?

Yes. It will be allowed to produce and stock a small amount of uranium enriched at low levels — not suitable for a bomb without further processing. The stockpile limit lasts 15 years.

Accord Is Based on Verification, Not Trust, Obama Says

By MICHAEL R. GORDON and DAVID E. SANGER

VIENNA — Iran and a group of six nations led by the United States reached a historic accord on Tuesday to significantly limit Tehran's nuclear ability for more than a decade in return for lifting ...

beginning a 60-day review, declaring, "I will veto any legislation that prevents the successful implementation of this deal."

Almost as soon as the agreement was announced ...

"All the News That's Fit to Print"

The New York Times

VOL. CLXIV . . . . No. 56,825
© 2015 The New York Times
NEW YORK, FRIDAY, APRIL 3, 2015

Late Edition
Today, cloudy, a rain shower, warm, high 65. **Tonight,** plenty of clouds, rain tapering off, low 48. **Tomorrow,** breezy, cooler, clouds and sun, high 52. Weather map is on Page B14.

$2.50

IRAN AGREES TO DETAILED NUCLEAR OUTLINE

NEWS ANALYSIS

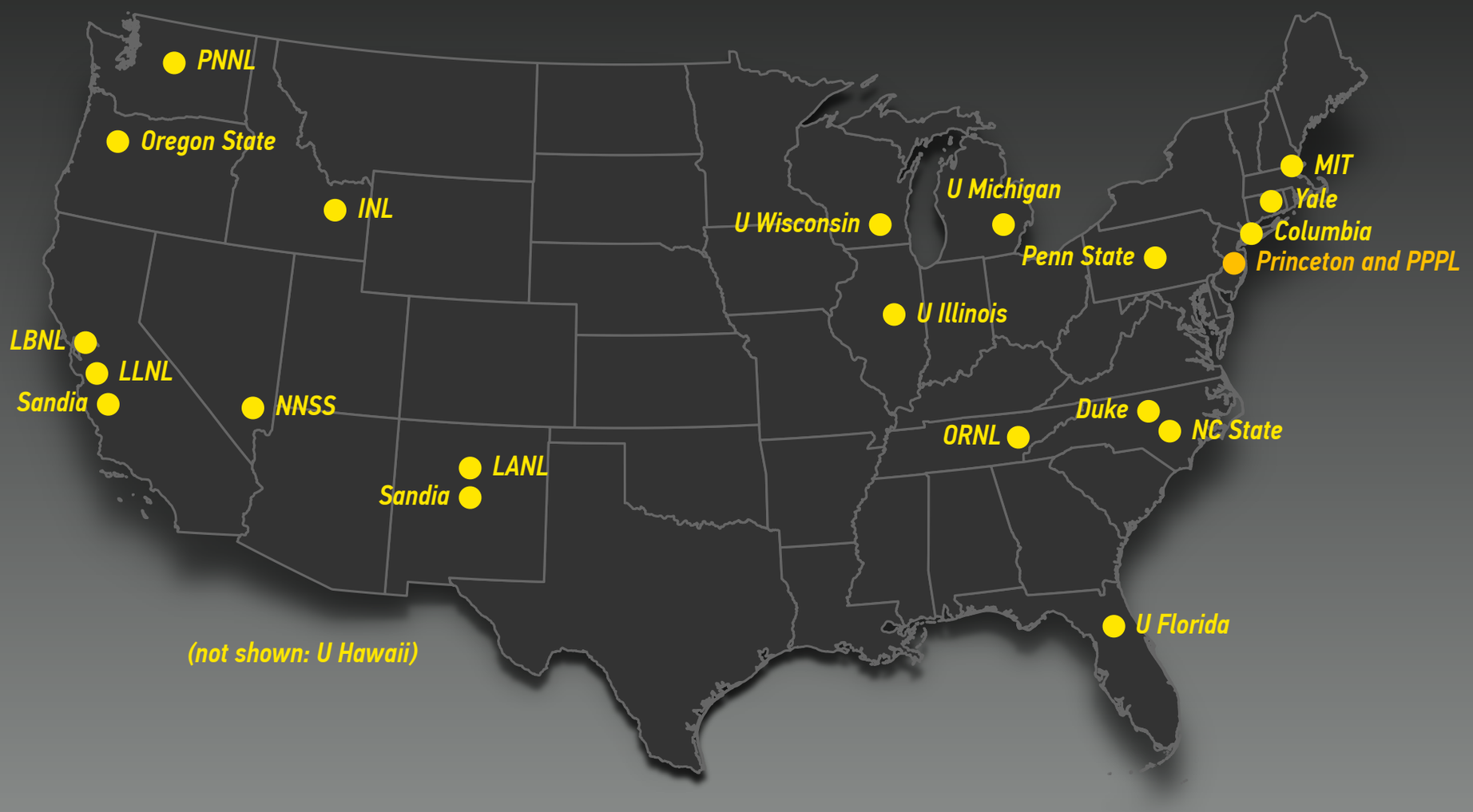
Clenched Fist Loosens a Bit

A Gamble by ...

First Step Toward a Wider Deal by June

NUCLEAR VERIFICATION

CONSORTIUM FOR VERIFICATION TECHNOLOGY



Five-year project, funded by U.S. DOE, 13 U.S. universities and 9 national labs, led by U-MICH

Princeton participates in the research thrust on disarmament research
(and leads the research thrust of the consortium on policy)

RELEVANT NUCLEAR ARMS CONTROL TREATIES

NUCLEAR NON-PROLIFERATION TREATY

Bans the acquisition of nuclear weapons by non-weapon states and commits the five weapon states to nuclear disarmament; verified by IAEA safeguards

COMPREHENSIVE TEST BAN TREATY

Bans all nuclear explosions in all environments and would be verified by extensive verification mechanisms (International Monitoring System, CTBTO)

FISSILE MATERIAL (CUTOFF) TREATY

At a minimum, treaty would ban fissile material production for weapons purposes; Issue about treaty scope: Would it also cover existing stocks?

NEXT-GENERATION NUCLEAR DISARMAMENT TREATIES

Agreements that place limits on total number of nuclear warheads in arsenals would pose qualitatively new verification challenges

THOUSANDS OF NUCLEAR WEAPONS

ARE CURRENTLY NON-DEPLOYED (i.e., IN RESERVE OR AWAITING DISMANTLEMENT)

W87/Mk-21 Reentry Vehicles in storage, Warren Air Force Base, Cheyenne, Wyoming

Photo courtesy of Paul Shambroom, www.paulshambroom.com

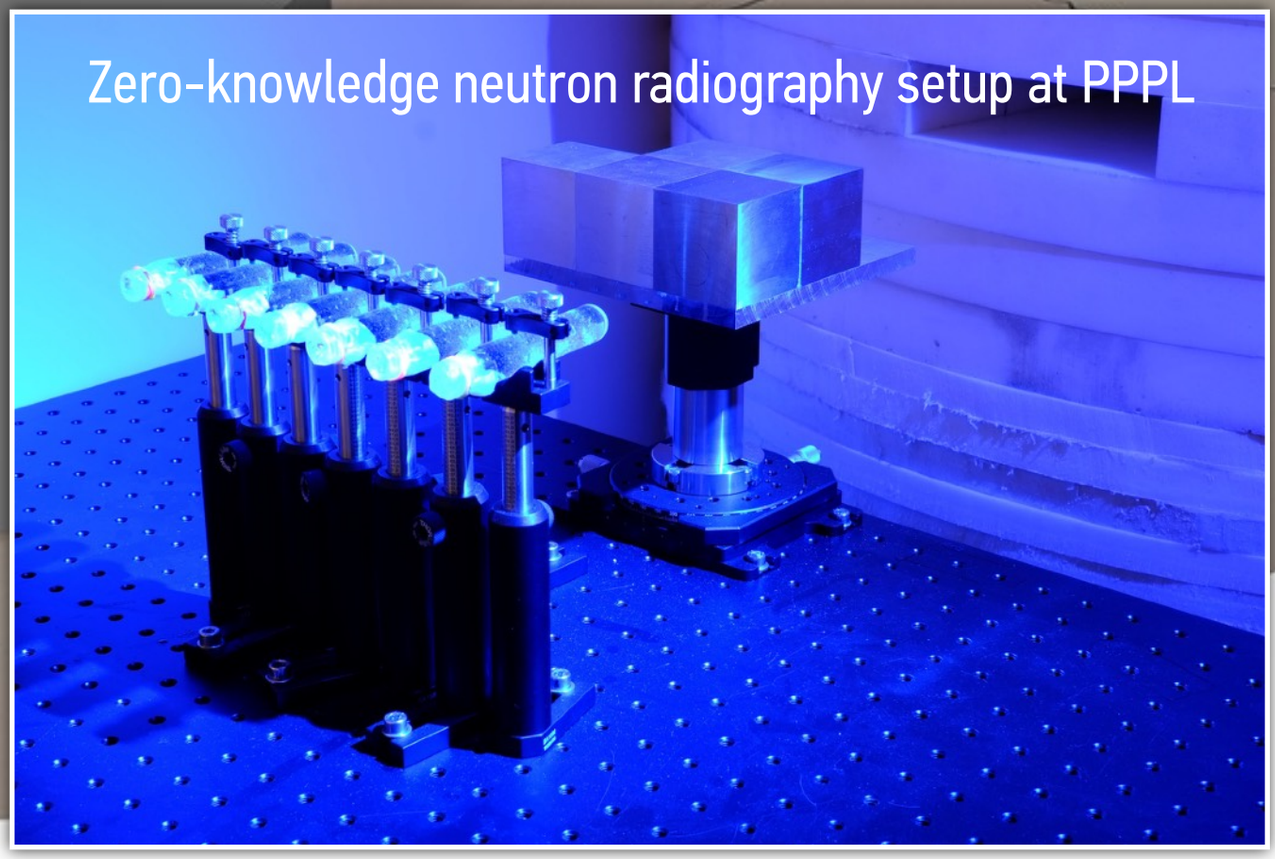
Collimator slot

Test object

Detector array

14 MeV neutron generator
(Thermo Scientific P 385)

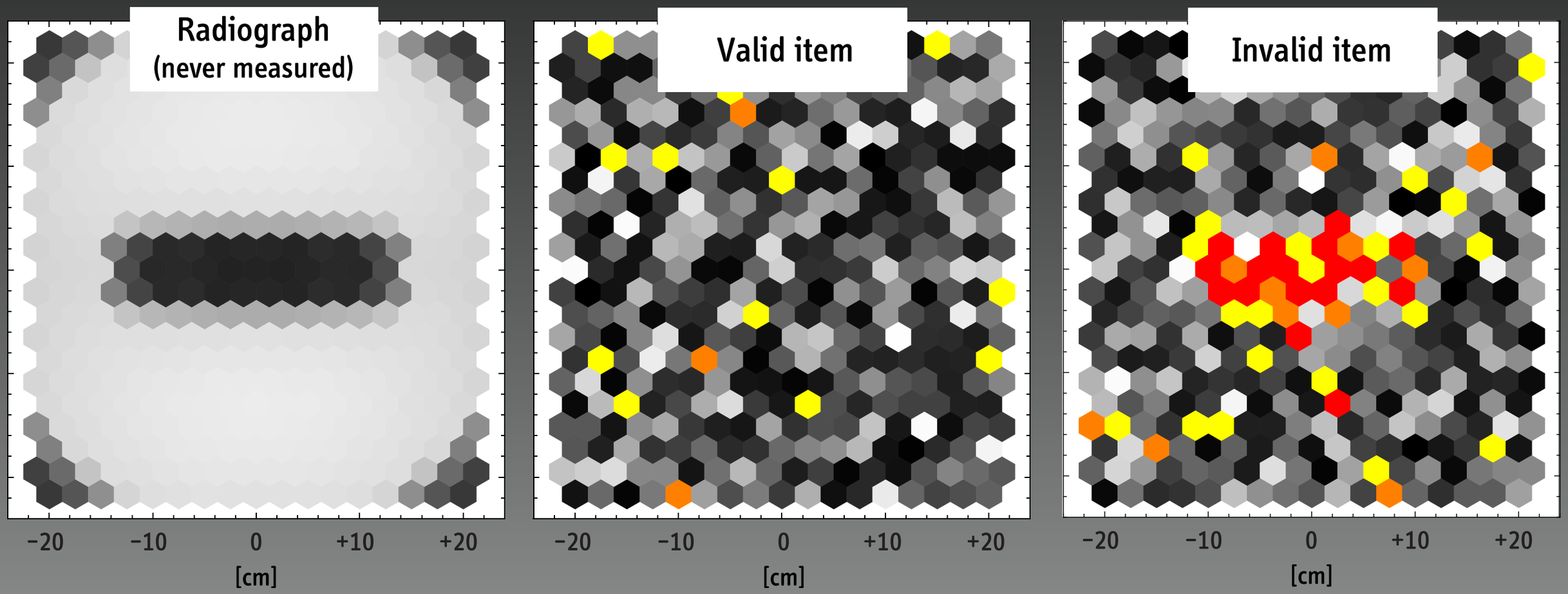
Collimator



ZERO-KNOWLEDGE VERIFICATION

RADIOGRAPHY WITH 14 MeV NEUTRONS

(Tungsten rings replaced by lead rings)



Simulated data from MCNP calculations; neutron detection energies > 10 MeV; N(max) = 5,000

A. Glaser, B. Barak, R. J. Goldston, "A Zero-knowledge Protocol for Nuclear Warhead Verification," *Nature,* 510, 26 June 2014, 497–502

ARTICLE

A zero-knowledge prot… warhead verification

Alexander Glaser[1], Boaz Barak[2] & Robert J. Goldston[3]

The verification of nuclear warheads for arms control involves a pa… confidence in the authenticity of submitted items while learnin… featuring 'information barriers', designed to hide measurements … and snooping. Here we show the viability of a fundamentally new… porates a zero-knowledge protocol, which is designed in such a … so does not need to be hidden. We interrogate submitted items … measurements of both neutron transmission and emission. Calcu… a test object show that a high degree of discrimination can be ac… physical zero-knowled… system could have applications beyo… technique suggests a w… the data in the first pla…

Existing nuclear arms-cont… and Russia place limits on… weapons. Verification of th… that deployed weapons are… able delivery platforms, th… bombers, to which agreed… next round of nuclear arm… limits on the total numb… arsenals. This would inclu… non-deployed weapons. S… tion approaches, includin… in storage and warheads… qualitatively new challeng… classified information tha… A viable verification appr… reliably verifying that th… disclosure of informatio…

Practitioners and po… undrum, and prior wo… Russia and the United… barriers[2,4]. These barr… that process highly clas… but only display result… complex, and require … hidden from the inspe… invalid objects as auth… could leak classified in… are serious obstacles …

In this work we c… problem. Rather than… an engineered infor… zero-knowledge pro…

nature COMMUNICATIONS

ARTICLE

Received 27 Feb 2016 | Accepted 12 Aug 2016 | Published xx xxx 2016

DOI: 10.1038/ncomms12890 OPEN

A physical zero-knowledge object-comparison system for nuclear warhead verification

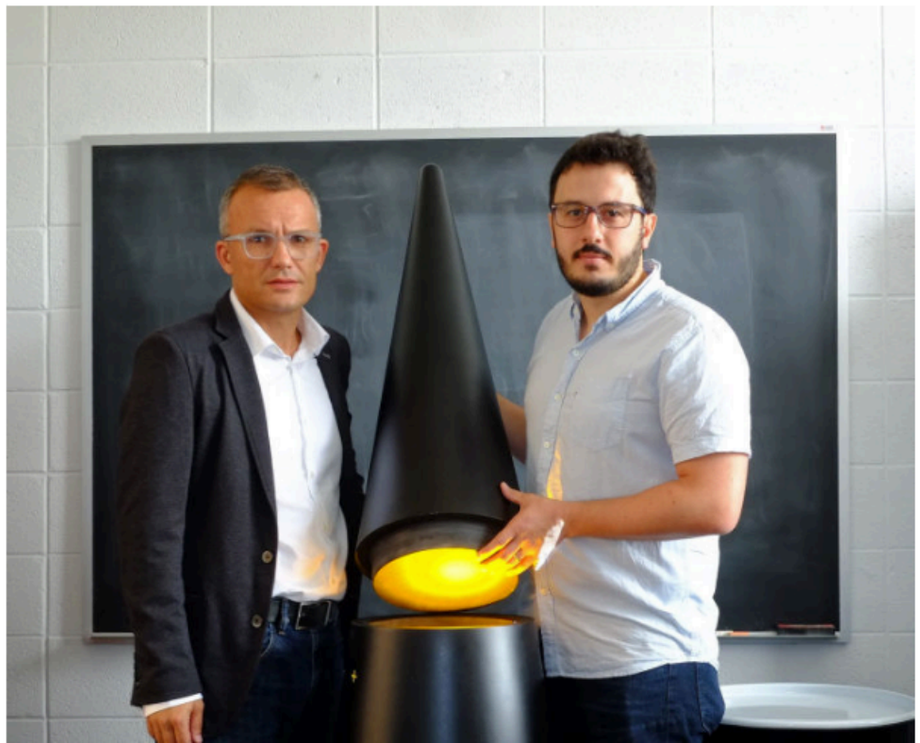
Sébastien Philippe[1], Robert J. Goldston[2], Alexander Glaser[1] & Francesco d'Errico[3,4]

THE NEW YORKER

ELEMENTS SEPTEMBER 20, 2016

THE VIRTUES OF NUCLEAR IGNORANCE

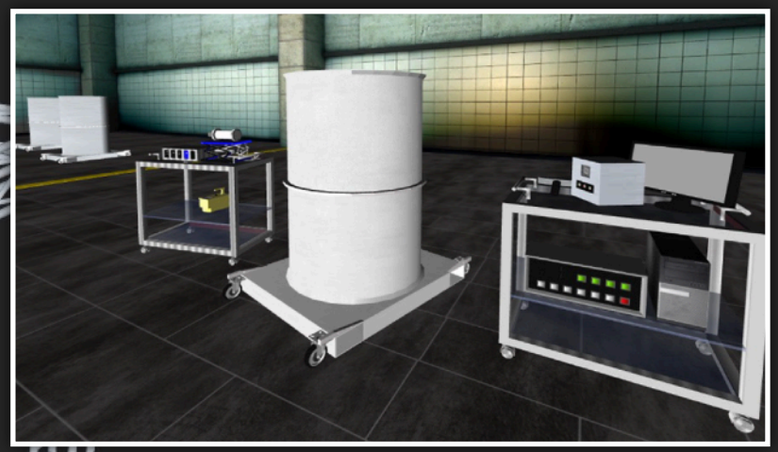
By Alex Wellerstein



VIRTUAL REALITY FOR NUCLEAR ARMS CONTROL

(with full-motion capability, co-presence, and real-time virtual radiation fields)

TO ENGAGE THE PUBLIC AND INTERNATIONAL GOVERNMENT PARTNERS



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