The Space Reactor Community Must Preserve the Norm Against the Civil Use of HEU

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Security risks of highly enriched uranium

- Experts generally believe that a significant capability to enrich uranium remains beyond the reach of sub-national terrorist groups
- However, terrorists could obtain HEU by theft or diversion
- HEU can be used in a "gun-type" improvised nuclear device

> "With modern weapons-grade uranium … terrorists, if they had such material, would have a good chance of setting off a high-yield explosion simply by dropping one half of the material onto the other half." – Luis Alvarez, 1988

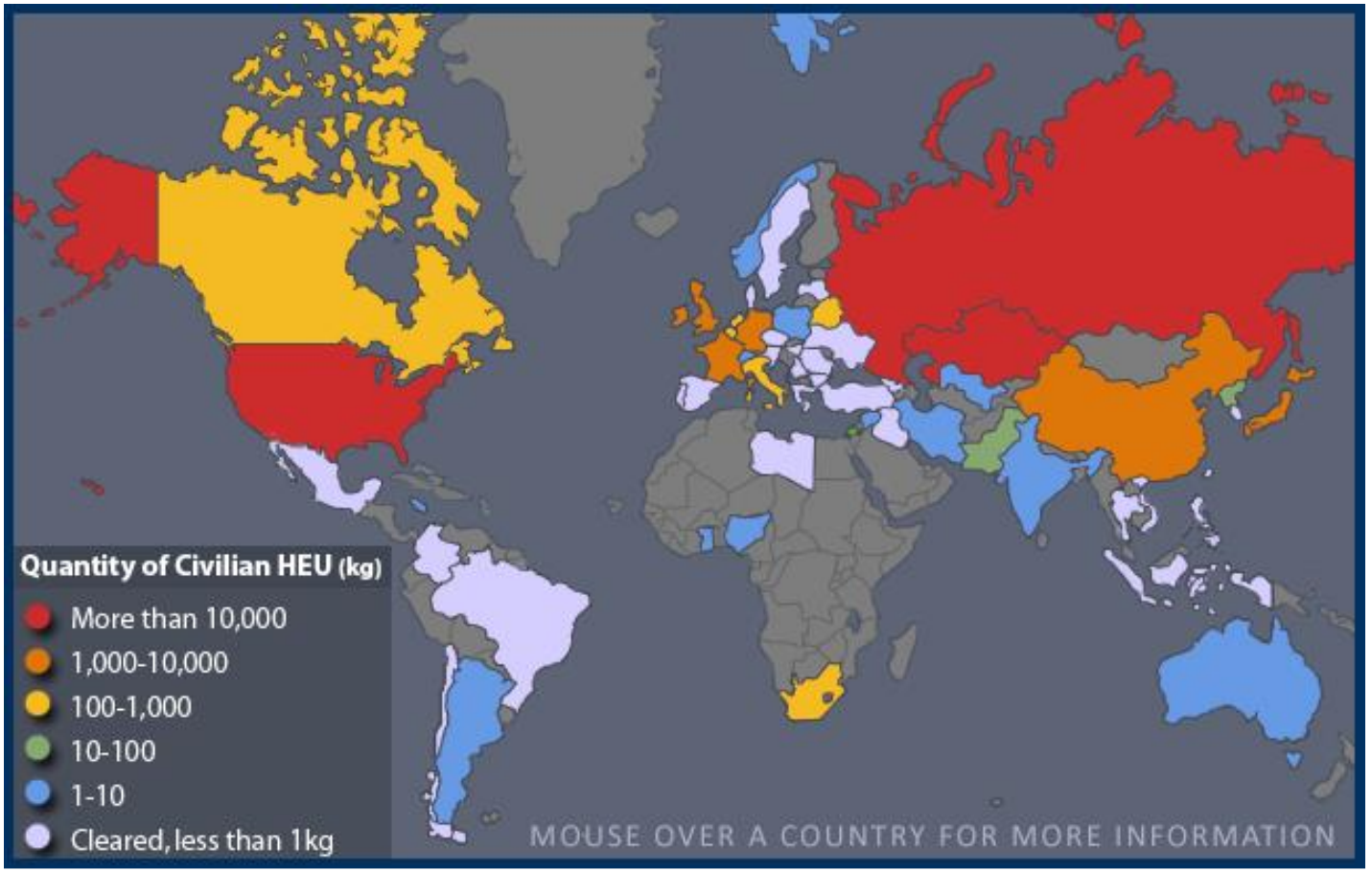
- In order to get a significant yield from such a crude device, a relatively large amount of HEU (~50 kilograms) is needed
  - Small in comparison to the vast stockpiles of HEU around the world
  - Large in comparison to **most** civilian uses
- Nations with moderate technical capability could build implosion nuclear weapons with much less HEU
  - 25 kg ("significant quantity") down to 12 kg

Reducing civil HEU use

- Over decades, the U.S. and the Soviet Union exported tens of tons of HEU around the world to fuel civil research reactors
- In the 1970s, the HEU exporter states began to appreciate the dangers of such practices
- Reduced Enrichment in Research and Test Reactors (RERTR) and Foreign Research Reactor Takeback Program
  - Effort to convert HEU-fueled research and test reactors and (later) medical isotope production facilities to LEU (19.75% U-235)
  - Return to the U.S., Russia, and China of HEU-containing spent fuel
- Research reactor operators and medical isotope producers resisted LEU conversion, arguing it would unacceptably diminish the performance and economic competitiveness of their facilities
  - Instead, it drove innovation

Status of civil HEU elimination

- According to Assistant Secretary of State Christopher Ford, as of September 2018
  - About 100 HEU facilities around the world have converted to LEU or shutdown
  - About 4.5 metric tons of HEU has been repatriated to the U.S. and Russia
  - 33 countries and Taiwan are now HEU-free


Quantity of Civilian HEU (kg)
More than 10,000
1,000-10,000
100-1,000
10-100
1-10
Cleared, less than 1kg
MOUSE OVER A COUNTRY FOR MORE INFORMATION

Space reactors: stimulating demand for civil HEU

- Kilopower reactors are designed to use strategically significant quantities of 93% enriched HEU:
  - 1 kWe Moon surface reactor: 28.4 kg U-235
  - 10 kWe Mars surface reactor: 43.7 kg U-235

U.S. development of HEU space reactors will:

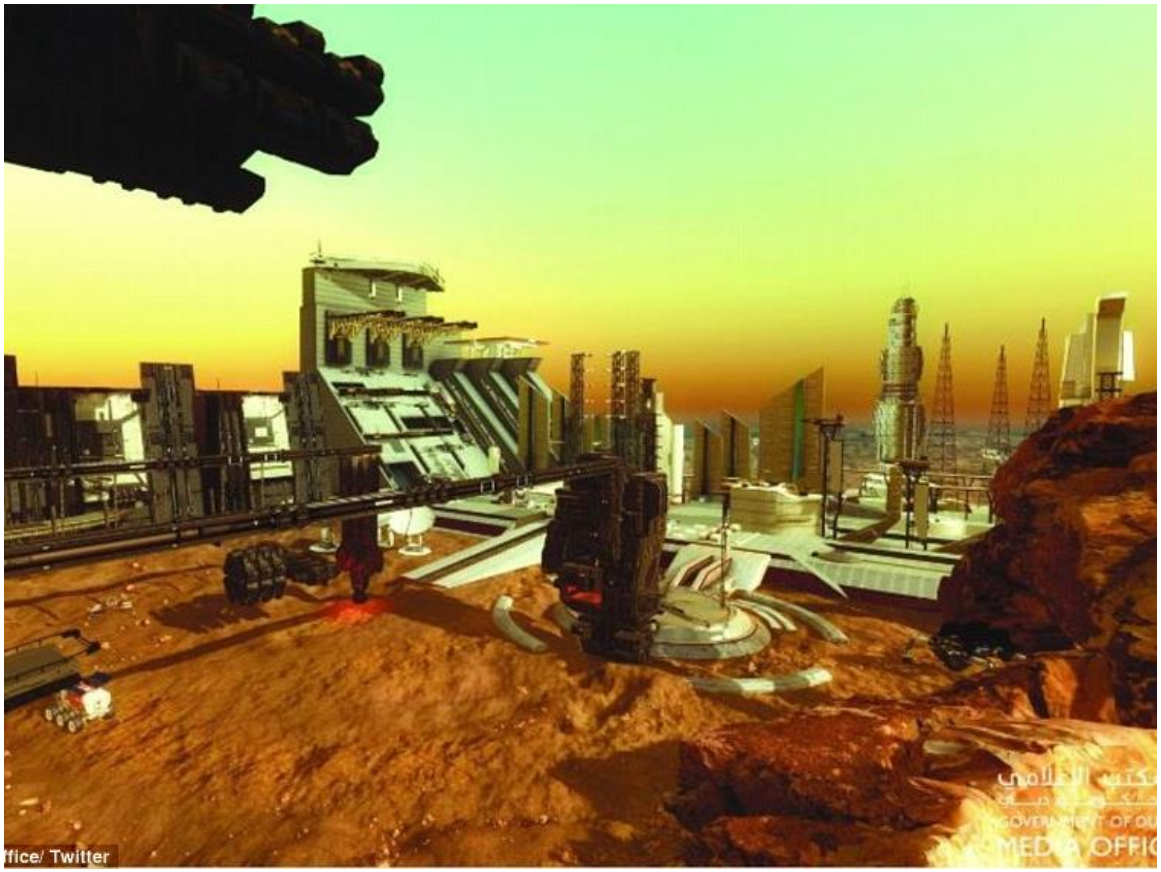
- Undermine the norm against civil HEU use and start an international “space race to the bottom”
- Increase security costs and risks associated with research, development, and deployment
- Stimulate HEU demand to the extent that new production could be necessary around the world
- Potentially require the extraterrestrial deployment of international safeguards inspectors
- Foster opposition to space reactors among the nonproliferation community

Undermining the norm

- If the U.S. asserts that HEU is essential for space power reactors, it will set the standard for other countries and for private transnational enterprises (Space X, Blue Origin)
  - No other entity, public or private, would unilaterally pursue an LEU option to make its space program less competitive

Increasing security costs

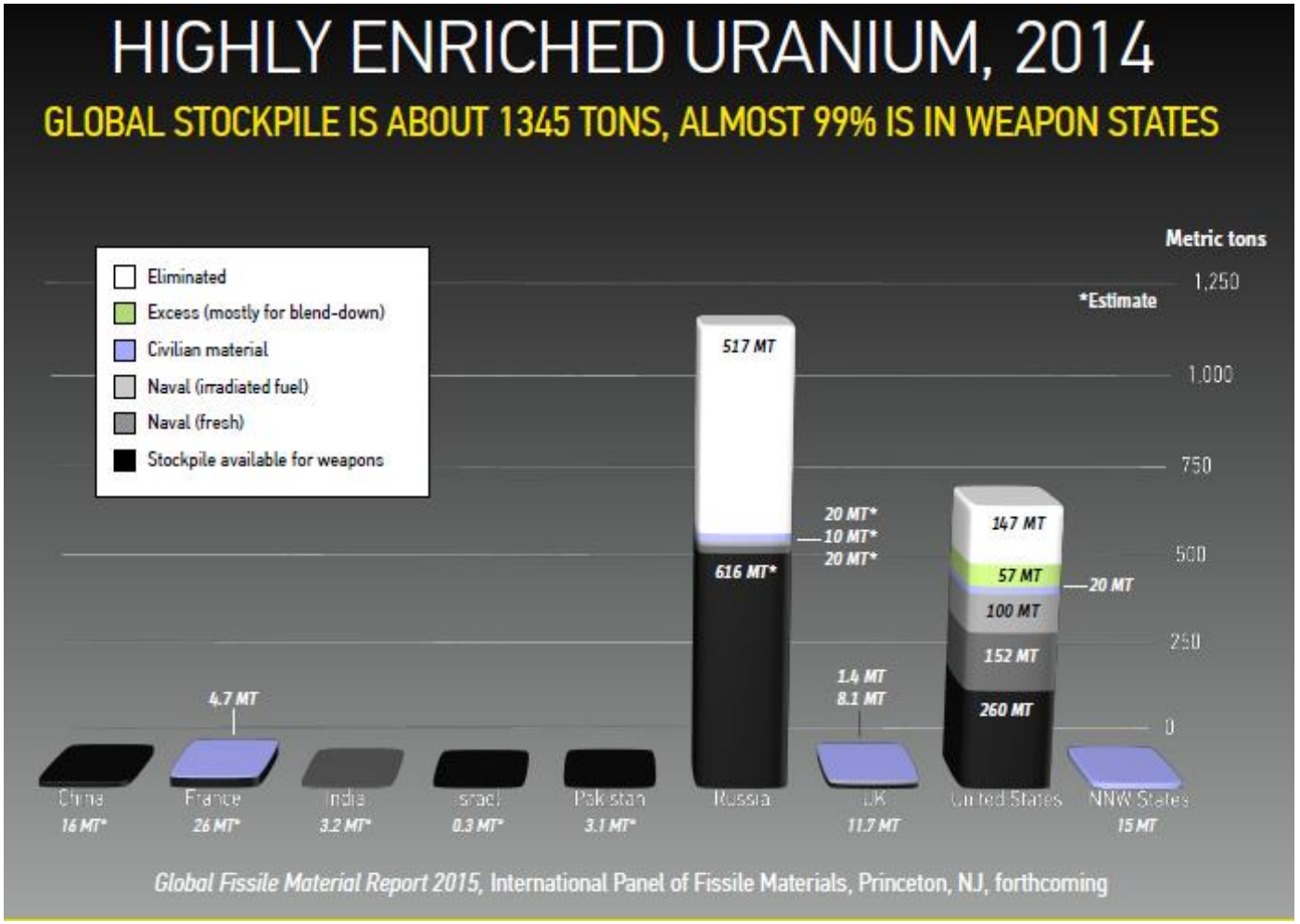
- DOE “Category I” quantities (requiring the highest physical protection):
  - 5 kg or more of HEU metal
  - 20 kg or more of HEU contained in alloys
- LEU is DOE Category IV
- Kilopower fuel: HEU-7%Mo alloy
- Category I security and material accountancy requirements for HEU affect the entire fuel cycle in addition to the mission itself
  - Requires immediate recovery if lost during failed launch
  - Requires Presidential launch authorization (8/20/19 memorandum)
- To date, DOE has subsidized the additional security costs associated with NASA’s Kilopower program, but taxpayers ultimately pay them
- Private enterprises without access to government subsidy may choose to purchase HEU from and establish facilities in countries with more permissive security environments



United Arab Emirates Mars 2117 Project

Stimulating HEU demand

- Mars mission with 4-6 astronaut crew would require 5 x 10-MWe Kilopower reactors (including one spare); 12-year reactor life
  - 44 kg U-235 (roughly two nuclear weapons' worth) per person
- United Arab Emirates wants to establish a city of 600,000 on Mars; Elon Musk wants 1 million settlers
  - Existing worldwide HEU supply grossly insufficient
  - 28,000-47,000 metric tons of HEU every 12 years at steady-state
- Annual HEU production requirements at steady-state:
  - 700,000 metric tons of natural uranium (compare 60,000 MT today)
  - 630 million SWU (compare 60 million SWU today)
  - The proliferation implications of the vast uranium enrichment and processing infrastructure required would be unfathomable


HIGHLY ENRICHED URANIUM, 2014
GLOBAL STOCKPILE IS ABOUT 1345 TONS, ALMOST 99% IS IN WEAPON STATES
Eliminated
Excess (mostly for blend-down)
Civilian material
Naval (irradiated fuel)
Naval (fresh)
Stockpile available for weapons
Metric tons
*Estimate
1,250
1,000
750
500
250
0
517 MT
20 MT*
10 MT*
20 MT*
616 MT*
147 MT
57 MT
20 MT
100 MT
152 MT
260 MT
1.4 MT
8.1 MT
4.7 MT
China
16 MT*
France
26 MT*
India
3.2 MT*
Israel
0.3 MT*
Pakistan
3.1 MT*
Russia
UK
11.7 MT
United States
NNW States
15 MT
Global Fissile Material Report 2015, International Panel of Fissile Materials, Princeton, NJ, forthcoming

IAEA safeguards on Mars?

- Outer Space Treaty bans nuclear weapons in space: but what about weapon-usable materials in space?
- How would it be verified on the Moon? On Mars?
- IAEA inspection frequencies for
  - HEU:
    - 1 month unirradiated
    - 3 months irradiated
  - LEU
    - 1 year
- Although yearly inspections wouldn't be significantly more feasible than monthly inspections, one could make a reasonable case that in the absence of enrichment facilities, inspections would not be necessary for LEU

Fostering opposition in nonproliferation community

- Continued use of HEU for space reactors could result in entrenched opposition to space reactor programs from members of the nonproliferation community who might otherwise support them
- UCS is neutral on nuclear power provided it meets high safety and security standards
  - Uranium-fueled space reactors do not pose the same safety risks to Earth as radioisotope thermoelectric generators
  - UCS likely would not oppose LEU-fueled space reactor programs (provided ground-based testing is done with robust containment)
  - UCS will continue to oppose HEU-fueled space reactors