Manipulating the Nuclear Black Market

8.S271
Nuclear Weapons – History and Future Prospects

Michael V. Hynes, Ph.D.
Laboratory for Nuclear Science
MIT
Outline

- Nuclear weapon basics
- Structure of the nuclear black market
- Manipulating the market
- Defeating nuclear aspirants
Corridor of Weaponizable Isotopes

1. Large fission cross section for fast neutrons
2. Multiple neutrons in the final state
3. Long enough half life

Half Life
- **Stable**: > 100,000 yr
- **Very Short**: > 1 min
- **1 hr**: > 1 min
- **> 1 day**: > 1 day
- **> 10 days**: > 10 days
- **> 100 days**: > 100 days
- **> 10 yr**: > 10 yr
- **Stable**

Uranium
- 235U
- 238U

Neptunium
- 237Np
- 239Np
- 241Np

Plutonium
- 232Pu
- 233Pu
- 235Pu
- 236Pu
- 239Pu

Americium
- 232Am
- 233Am
- 234Am

Curium
- 232Cm
- 233Cm
- 234Cm

Mit Physics

LNS
## Weapons and Technologies

<table>
<thead>
<tr>
<th>Assembly Technologies</th>
<th>Gun Assembly</th>
<th>Implosion Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Schematic</strong></td>
<td><img src="image" alt="Schematic" /></td>
<td><img src="image" alt="Schematic" /></td>
</tr>
<tr>
<td><strong>Overview</strong></td>
<td>A sub critical plug of fissile material is fired into a subcritical ring of material to make a supercritical assembly</td>
<td>A subcritical shell of material is uniformly collapsed into a supercritical assembly</td>
</tr>
<tr>
<td><strong>Assembly Technologies</strong></td>
<td>A plug is driven down the inside of metal tube into a series of rings. The propellant in WWII was a cordite derivative, basically very easy technology.</td>
<td>An explosive shell of lenses is uniformly detonated surrounding the shell of fissile material, basically rather difficult technology.</td>
</tr>
<tr>
<td><strong>Separation Technologies</strong></td>
<td>Electromagnetic, gas diffusion, or centrifuge technologies required for HEU – basically very difficult technologies.</td>
<td>Chemical separation required for Plutonium and Neptunium – basically very easy technologies.</td>
</tr>
</tbody>
</table>
Common illustration of a Gun Assembled Weapon

1. Box tail fins
2. Steel gun breech assembly
3. Detonator
4. Cordite (conventional) explosives
5. Uranium-235 "projectile", six rings (26 kg) in a thin can of steel
6. Baro sensing ports and manifold
7. Bomb casing wall
8. Arming and fusing equipment
9. Gun barrel, steel, around 10 cm diameter, 200 cm length
10. Arming wires
11. Tamper assembly, steel
12. Uranium-235 "target", two rings (38 kg)
13. Tamper/reflector assembly, tungsten carbide
14. Neutron initiator
15. Archie fuzing radar antennas
16. Recess for the boron safety plug (not shown) to be ejected into
Common Illustration of an Implosion Weapon

- Fast explosive
- Slow explosive
- Tamper/Pusher
- Neutron initiator
- Plutonium core
- Spherical shockwave compresses core
Fat Man – First Implosion Weapon
Improvised Nuclear Devices
2 Pathways

1. Get working weapon
   - Finance - Facilities - Personnel
     - Acquisition
       - Weaponization
         - Deployment
           - CONOPs
     - Theft
     - Ransom
     - Barter
     - Gift
   - PALs
   - T&F

2. Build from parts (from scratch)
   - Finance - Facilities - Personnel
     - Acquisition
       - Weaponization
         - Deployment
           - CONOPs
     - Education
     - Nuclear Materials
     - Non-Nuclear Materials
     - Nuclear Technologies
     - Nuclear Pit
     - Assembly Technology
     - Ancillary Components
Small quantities of Fissile Material are Involved

Nuclear weapons need only about 1-2 critical masses of weaponizable material

Critical assembly must be supercritical to explode

Chart shows the critical masses for some weapon isotopes

Bare refers to the critical mass of a sphere of material without anything surrounding it

Reflected refers to the critical mass when surrounded by a neutron reflector such as Iron or Tungsten

Using a neutron reflector always reduces the critical mass

Generally a few tens of kilograms or less of material will be involved.
## Modern Day Definition of WGU

**Weapon Grade Uranium**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percent of Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-234</td>
<td>1.00</td>
</tr>
<tr>
<td>U-235</td>
<td>93.30</td>
</tr>
<tr>
<td>U-238</td>
<td>5.50</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The Oxygen content is adjusted to give the measured (alpha,n) spectra.
Modern Day Definition of WGPu

Weapon Grade Plutonium

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percent of Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu-238</td>
<td>0.005</td>
</tr>
<tr>
<td>Pu-239</td>
<td>93.300</td>
</tr>
<tr>
<td>Pu-240</td>
<td>6.000</td>
</tr>
<tr>
<td>Pu-241</td>
<td>0.440</td>
</tr>
<tr>
<td>Pu-242</td>
<td>0.015</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.240</td>
</tr>
</tbody>
</table>

The Oxygen content is adjusted to give the measured (alpha,n) spectra.
Stabilizing Plutonium in the Delta Phase

- Plutonium pits are always stabilized in the delta-phase by alloying with Gallium.
- The delta phase is metallurgically like Aluminum whereas the alpha phase is like glass.
- Other trivalent atoms, like Aluminum, Cerium, Indium, or Scandium, but these other materials have either large (alpha,n) cross sections or do not make the alloy corrosion resistant.
- About 1% Gallium by weight is used in modern weapons.
- Gallium has 2 stable isotopes

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percent of Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu-238</td>
<td>0.005</td>
</tr>
<tr>
<td>Pu-239</td>
<td>92.367</td>
</tr>
<tr>
<td>Pu-240</td>
<td>5.940</td>
</tr>
<tr>
<td>Pu-241</td>
<td>0.436</td>
</tr>
<tr>
<td>Pu-242</td>
<td>0.015</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.238</td>
</tr>
<tr>
<td>Gallium</td>
<td>1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Natural Abundance (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ga-69</td>
<td>60.108</td>
</tr>
<tr>
<td>Ga-71</td>
<td>39.892</td>
</tr>
</tbody>
</table>
Fuels for Nuclear Explosives

Uranium
- Naturally occurring in Earth crust at 0.7% U-235 isotopic abundance
- Weapons grade Uranium (WGU) considered to be 90% or more U-235
- Any enrichment above 20% (HEU) is considered weapons usable
- Cost to produce LEU (3-5% U-235) very substantial fraction of cost to produce HEU or even WGU – very non-linear process.
  - Given LEU or HEU not that much investment in physical plant and equipment to enrich to get to WGU
- Metallic or oxide forms can be turned into weapons
- LEU available for power reactors, HEU available research reactors, WGU in stockpiles in nuclear weapon states.

Plutonium
- Made only in nuclear reactors
- Weapons grade Plutonium (WGP) considered to be 94% or more Pu-239 and less than 6% Pu-240.
- Reactor grade Plutonium at 60% 239 and 24% 240 and MOX grade Plutonium at 40% 239 and 32% 240 considered to weapons usable but predetonation is very likely yielding a fizzle which will still yield at about 0.5 – 1.0 KT (for a Nagasaki-like device). No neutron generator needed.
- Metallic or oxide forms can be turned into weapons
- Reactor and MOX grade Plutonium available for power reactor or at rod-storage facilities, WGP in stockpiles in nuclear weapon states.

Neptunium
- Made only in nuclear reactors
- Only Np-237 stable for long times (2e6 years) and made in quantity in reactors
  - No enrichment needed
  - Chemically separated from other elements in waste stream
- About 50-80 metric tons available world wide from reactor rod reprocessing
- Unregulated as a Strategic nuclear material by IAEA
Outline

- Nuclear weapon basics
- Structure of the nuclear black market
- Manipulating the market
- Defeating nuclear aspirants
Nuclear Marketplace

On the supply side the large number of reactors in global trouble spots could become a rich source for the clandestine nuclear market place

- Many research reactors are in global trouble spots (e.g. Kazakhstan or Ukraine)
- Russian research reactors generally have higher enrichment levels than US reactors
- Even slightly enriched Uranium for reactors requires only slightly more time in the enrichment process to be weaponizable
- IAEA safeguard inspections have significant limitations
- The security of Russian nuclear materials is widely varied, from good to poor

On the demand side of the market for clandestine nuclear material only recently emerged in the 1990s

- Although sellers may have been abundant, buyers were not prior to about 1990
- Shift in global terrorism from political to apocalyptic agendas
- Both true and merely perceived value assessments active in this market place

The clandestine nuclear market has very high transaction costs and is filled with middlemen and asymmetries in information

- Buyers and sellers are not directly able to judge the quality of the nuclear materials
- Both supply and demand sides of this market sought middlemen to close the deal
- In any market middlemen reduce the transaction costs
- Middlemen are also a hedge against asymmetric information

As markets mature the transaction costs decrease

- Buyers and sellers become informed consumers and vendors
- Agents and middlemen become less useful
- Importance of sting operations from both supply and demand side
U.S. Strategy is based on a Multilayered Defense

- First layer is nonproliferation: improve control regimes
  - But always less than perfect

Non-Proliferation

- Improve Control Regimes

Manipulate Black Market

Counter-Proliferation

- Detect Active Phase
  - Project Management
  - Acquisition
  - Weaponization
  - Deployment
## Policies to Improve Control Regimes

**Should Focus on Three Areas**

<table>
<thead>
<tr>
<th>Area</th>
<th>Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modernize Thinking About Special Nuclear Materials</td>
<td>■ Focus on fact that alternative nuclear materials can be weaponized</td>
</tr>
<tr>
<td></td>
<td>■ Focus on difficulty to weaponize uranium enrichment levels</td>
</tr>
<tr>
<td>Address Widespread Nuclear Technologies and Personnel</td>
<td>■ Determine how widely new initiatives like the Proliferation Security and the Container Security Initiatives will be accepted</td>
</tr>
<tr>
<td></td>
<td>■ Determine whether they are strong enough</td>
</tr>
<tr>
<td>Maintain Safety and Security of Nuclear Arsenals</td>
<td>■ Treat newly emerged nuclear powers as matter of fact</td>
</tr>
<tr>
<td></td>
<td>■ Seek Congressional relief from NPT restrictions to share nuclear security technologies with them</td>
</tr>
</tbody>
</table>
U.S. Strategy is based on a Multilayered Defense

Non-Proliferation

- Improve Control Regimes
  - But always less than perfect

Counter-Proliferation

- Manipulate Black Market
  - First layer of counter-proliferation: manipulate nuclear black market
  - But determined adversaries will penetrate this layer

- Detect Active Phase
  - Project Management
  - Acquisition
  - Weaponization
  - Deployment
U.S. Strategy is based on a Multilayered Defense

Non-Proliferation

- Improve Control Regimes
  - First layer is nonproliferation: improve control regimes
    - But always less than perfect

Counter-Proliferation

- Manipulate Black Market
  - First layer of counter-proliferation: manipulate nuclear black market
    - But determined adversaries will penetrate this layer

- Detect Active Phase
  - Next layer of counter-proliferation: detect active phase of weapon development

  - Project Management
    - Opportunities to interdict diminish as you move down the defenses
  - Acquisition
  - Weaponization
  - Deployment
Weapon Development Pathways
Nuclear weapon basics
Structure of the nuclear black market
Manipulating the market
Defeating nuclear aspirants
The Illegitimate Nuclear Market Is Segmented into Two Elements

<table>
<thead>
<tr>
<th>Opportunistic Market</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants</strong></td>
</tr>
<tr>
<td>Low-ranking employees, amateurs</td>
</tr>
<tr>
<td><strong>Typical Materials</strong></td>
</tr>
<tr>
<td>Mostly radioactive junk</td>
</tr>
<tr>
<td><strong>Brokering Mechanisms</strong></td>
</tr>
<tr>
<td>Spontaneous, unstable networks</td>
</tr>
<tr>
<td><strong>Customers</strong></td>
</tr>
<tr>
<td>Subnational groups, middlemen, syndicates</td>
</tr>
<tr>
<td><strong>Impact on Terrorism</strong></td>
</tr>
<tr>
<td>Low to moderate</td>
</tr>
<tr>
<td><strong>Management Technique</strong></td>
</tr>
<tr>
<td>Market forces</td>
</tr>
</tbody>
</table>
The Illegitimate Nuclear Market Is Segmented into Two Elements

<table>
<thead>
<tr>
<th>Participation</th>
<th>Opportunistic Market</th>
<th>Official Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>Low-ranking employees, amateurs</td>
<td>Mid-level and senior government officials</td>
</tr>
<tr>
<td>Typical Materials</td>
<td>Mostly radioactive junk</td>
<td>Some weapon-grade isotopes and weapon know-how</td>
</tr>
<tr>
<td>Brokering Mechanisms</td>
<td>Spontaneous, unstable networks</td>
<td>Criminal syndicates, government officials, visiting scientists</td>
</tr>
<tr>
<td>Customers</td>
<td>Subnational groups, middlemen, syndicates</td>
<td>Nuclear-threshold states, undeclared nuclear states, subnational groups</td>
</tr>
<tr>
<td>Impact on Terrorism</td>
<td>Low to moderate</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Management Technique</td>
<td>Market forces</td>
<td>Incentives</td>
</tr>
</tbody>
</table>
Disrupting the Nuclear Black Market

Convince buyers and sellers that nuclear forensics can reveal source of nuclear materials

Myths about nuclear technologies abound and disinformation can dampen demand

- Drive nuclear aspirants into bad technical decisions that create delays and further opportunities for interdiction
- Drive transaction costs so high that even determined adversaries believe non-nuclear options are less dangerous and more likely to succeed

Buyers and sellers need intermediaries as hedge against risks in transactions

- Use standard techniques used by frauds and con men (e.g., pump and dump, bait and switch, sting operations)

Convince them transferring nuclear weapons and components will have grave consequences

Convince them that transfers will not:

- Provide real advantage over adversaries
- Improve their position in the international system
- Take them closer to their ultimate policy objectives
**Market Forces we can Manipulate**

Nuclear myths abound in this market place
- Only the traditional nuclear materials can be used
- Small batches of fuel rods can make a weapon
- Climbing the learning curve is really tough
- Verifying the quality of nuclear goods is difficult

The perpetuation of these myths can structure the market in ways we want

The strength of these myths can be manipulated to drive actors from the market

These myths can also drive them to eschew easily available nuclear material towards far more secure materials.

Creates the need for expert agents

The need for agents creates opportunities to infiltrate or conduct stings
Red Mercury Scam

- In 1980s Red Mercury was promoted clandestinely as essential to nuclear weapons.
- Actors in the Black Market scurried to get red Mercury.
- Red mercury is not needed in nuclear weapon.
- This delayed the efforts of nuclear aspirants in pursuit of a nuclear weapon.
- Exposed aspirants to detection.
- Wasted resources.

“Red Mercury”
The United States Has the Means to Disrupt the Opportunistic Market

Myths about nuclear technologies abound

The United States can

- perpetuate and manipulate these myths to drive actors from the market and/or lead them to bad technical choices
- increase transaction costs by exploiting the poor assessment capabilities of opportunistic market actors
The United States Can Exert Tremendous Influence on Incentives in the Official Market

Convince both buyers and sellers that

nuclear forensics can reveal the source of nuclear materials

transferring nuclear weapons and components will have grave consequences for them

transfers will not

• provide real advantage over adversaries
• improve their position in the international system
• take them closer to their ultimate policy objectives
Outline

- Nuclear weapon basics
- Structure of the nuclear black market
- Manipulating the market
- Defeating nuclear aspirants
There are Two Pathways to Getting a Nuclear Weapon

1. Acquire a working nuclear weapon
   - Help of a sympathetic nation
   - Bribery or threats, outright theft
   - Simplest and most expedient of pathways

2. Acquire the nuclear and non-nuclear parts to build a weapon
   - Significant investment in expertise, facilities, and special materials
   - Time consuming
Categories for Observables

Passive Physical observables:

- Low to moderate levels of radioactivity
- Special scattering and absorption due to high density and atomic number
- Ionized air cloud near radioactive materials
- Thermal signatures
- EMI from PFN tests
- Special chemicals in the effluent from facilities
- Large industrial facilities using large amounts of electrical power

Active Physical Observables

- Unique spectral response to pulsed neutron sources
- Unique spectral response to moderate energy x-ray sources

Process observables:

- Recruitment and movement of personnel
- Acquisition of knowledge and expertise
- Acquisition and utilization of facilities
- Acquisition of specialized equipment
- Creation and movement of financial resources
It is easier to detect early phases of a program than to locate a finished weapon.
END
Questions