Lecture and colloquium 1.3 Nonproliferation challenges associated with the use of nuclear technology

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Classification and categorization of nuclear and other radioactive materials

Safe radioactive waste and spent fuel management: possible solutions

“Narrow” (sensitive) technological operations of NFC from nonproliferation point of view

Radioactive sources: proliferation risks

Colloquium’s questions
What are the materials?

Nuclear materials
(uranium, plutonium and thorium in different forms)

Radioactive sources

Radioactive waste and radioactively contaminated materials
Nuclear Materials Classification

IAEA STATUTE  ARTICLE XX: Definitions

1. The term "special fissionable material" means plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233, but the term "special fissionable material" does not include source material.

2. The term "uranium enriched in the isotopes 235 or 233" means uranium containing the isotopes 235 or 233 or both in an amount such that the abundance ratio of the sum of these isotopes to the isotope 238 is greater than the ratio of the isotope 235 to the isotope 238 occurring in nature.

3. The term "source material" means uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound, or concentrate; any other material containing one or more of the foregoing in such concentration as the Board of Governors shall from time to time determine.
### TABLE 1. CATEGORIZATION OF NUCLEAR MATERIAL

<table>
<thead>
<tr>
<th>Material</th>
<th>Form</th>
<th>Category I</th>
<th>Category II</th>
<th>Category III&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plutonium&lt;sup&gt;*&lt;/sup&gt;</td>
<td>Unirradiated&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2 kg or more</td>
<td>Less than 2 kg but more than 500 g</td>
<td>500 g or less but more than 15 g</td>
</tr>
<tr>
<td>2. Uranium-235 (235U)</td>
<td>Unirradiated&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5 kg or more</td>
<td>Less than 5 kg but more than 1 kg</td>
<td>1 kg or less but more than 15 g</td>
</tr>
<tr>
<td></td>
<td>– Uranium enriched to 20% 235U or more</td>
<td></td>
<td>10 kg or more</td>
<td>Less than 10 kg but more than 1 kg</td>
</tr>
<tr>
<td></td>
<td>– Uranium enriched to 10% 235U</td>
<td></td>
<td></td>
<td>10 kg or more</td>
</tr>
<tr>
<td></td>
<td>– Uranium enriched above natural, but less than 10% 235U</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Uranium-233 (233U)</td>
<td>Unirradiated&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2 kg or more</td>
<td>Less than 2 kg but more than 500 g</td>
<td>500 g or less but more than 15 g</td>
</tr>
<tr>
<td>4. Irradiated fuel</td>
<td></td>
<td></td>
<td>Depleted or natural uranium, thorium or low enriched fuel (less than 10% fissile content)&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> All plutonium except that with isotopic concentration exceeding 80% in plutonium-238.

<sup>b</sup> Material not irradiated in a reactor or material irradiated in a reactor but with a radiation level equal to or less than 1 Gy/h (100 rad/h) at 1 m unshielded.

<sup>c</sup> Quantities not falling in Category III and natural uranium, depleted uranium and thorium should be protected at least in accordance with prudent management practice.

<sup>d</sup> Although this level of protection is recommended, it would be open to States, upon evaluation of the specific circumstances, to assign a different category of physical protection.

<sup>e</sup> Other fuel which by virtue of its original fissile material content is classified as Category I or II before irradiation may be reduced one category level while the radiation level from the fuel exceeds 1 Gy/h (100 rad/h) at one metre unshielded.

**Note:** This table is not to be used or interpreted independently of the text of the entire publication.
Radioactive waste and SNF management

Types of radioactive waste:

- **Low-level waste (LLW)** is generated from hospitals and industry, as well as the nuclear fuel cycle (paper, rags, tools, clothing, filters etc.). It comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste;

- **Intermediate-level waste (ILW)** contains higher amounts of radioactivity and some requires shielding. It makes up some 7% of the volume and has 4% of the radioactivity of all RW (resins, chemical sludges and metal fuel cladding);

- **High-level waste (HLW)** arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and transuranic elements generated in the reactor core. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW: spent nuclear fuel itself* and separated waste from reprocessing the SNF. (TRU)

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* SNF from light water reactors contains approximately:
  95.6% uranium (less than 1% of which is U-235), 2.9% stable fission products, 0.9% plutonium, 0.3% cesium & strontium (fission products), 0.1% iodine and technetium (fission products), 0.1% other long-lived fission products, 0.1% minor actinides (Americium, curium, neptunium)
Radioactive waste and SNF management, cont’d

✓ Each year, nuclear power generation facilities worldwide produce about 200,000 m³ of low- and intermediate-level radioactive waste, and about 10,000 m³ / 12,000 tonnes of high-level waste.

✓ A typical 1000 MWe light water reactor will generate (directly and indirectly) 200-350 m³ low- and intermediate-level waste per year. It will also discharge about 20 m³ (27 tonnes) of spent fuel per year. (This compares with an average 400,000 tonnes of ash produced from a coal-fired plant of the same power capacity.)
Radioactive waste and SNF management, cont’d

Spent fuel is subject to international safeguards due to its uranium and plutonium content. Separated (and vitrified) HLW is not subject to safeguards, which is another factor in easier handling.

After 40-50 years the heat and radioactivity have fallen to one thousandth of the level at removal.

The cost of managing and disposing of nuclear power plant wastes represents about 5% of the total cost of the electricity generated, but decommissioning...

SNF represents high risk for nuclear nonproliferation due to its high radioactivity, but...(sabotage more dangerous than theft)
SNF management policy in the Russian Federation

Remains at the Bilibino NPP

(SNF reprocessing)

(SNF storage at GKhK)
The continued buildup of fissile material stockpiles, the spread of uranium enrichment and spent fuel reprocessing facilities, and the lack of will or capacity to dispose of spent nuclear fuel all pose long-term risks for proliferation and nuclear security. Once a State has produced enough LEU enriched to roughly 3-5 percent in U-235, it has already completed about three-quarters of the enrichment effort required to produce weapons-grade uranium.

Reprocessing plants and associated storage and fuel fabrication facilities pose proliferation and security risks because they usually have substantial stocks of separated plutonium. Reactor-grade plutonium also has been and could be used in nuclear explosive devices.

Proliferation and security risks inherent in NFC are not just technical in nature, but have political aspects as well.

IAEA safeguards system, NSG, multinational approaches to the NFC and other initiatives as possible solutions for nonproliferation regime
THE NUCLEAR AND RADIOLOGICAL THREAT

- Theft of nuclear weapon
- Theft of nuclear material to make improvised nuclear explosive device IND
- Theft of other radioactive material for RDD or RED
- Sabotage of facility or transport
France Nuclear Power Plant Drones: Mysterious Illegal Flyovers Have Officials Puzzled

Y-12 protesters allegedly enter high-security area, spray paint, splash blood
July 28, 2012 By John Huotari 3 Comments

Nuclear smuggling deals 'thwarted' in Moldova
7 October 2015
Media caption Richard Galpin reports on the attempts by smugglers to sell nuclear material to extremist groups
Moldovan police working with the FBI are reported to have stopped four attempts by smugglers to sell nuclear material to extremists in the Middle East over the past five years.

Is ISIL a Radioactive Threat?
Posted on Nov.07, 2014 in ISIL, Radiological Terrorism by George M. Moore

Al Qaeda In Pursuit Of Nuclear Weapons/Radiological Material – Analysis
Written by: Muhammad Jawad Hashmi, ScienceBlog, 24 April 2012

Stuxnet: UK and US nuclear plants at risk as malware spreads outside Russia
by Alastair Stevenson, 11 Nov 2013
Inventories – facilities and materials potential targets

> 20,000 nuclear weapons
> 3,000 tons civil and military HEU and Pu

> Around 700 research reactors (>100 with HEU)
> 100 fuel cycle facilities

➢ 450 operating nuclear power plants

> 100,000 Cat I and II radioactive sources
> 1,000,000 Cat III radioactive sources
Radioactive sources in Nonproliferation context

✓ Upwards of 3,000 radioisotopes have been identified, although only a small subset of these is of relevance to nuclear and radiological terrorism.
✓ Many radioisotopes have half-lives of less than a second and so decay too quickly for use in a radiological attack.
✓ Conversely, radioisotopes with long half-lives (greater than several thousand years) do not decay quickly enough to emit sufficient radiation to induce negative health effects.
✓ Radioisotopes of relevance must be both accessible in sufficient amounts and emit a significant fraction of their radiation over the lifetime of an individual source.
High Risk Isotopes

All of the Category I radioactive sources pose the greatest security risk for a RDD

- Americium-241
- Californium-252
- Cesium-137
- Cobalt-60

- Iridium-192
- Plutonium-238 and -239
- Radium-226
- Strontium-90 and others

Risk assessment:
- How much energy does it produce?
- What type of radiation does it produce?
- What is its half-life (high vs. low radioactivity)?
- How much of the radioactive material is available?
- How prevalent is the radioactive material (and where is it found)?
- What is the radioactive material’s shape, size and portability? and
- How easy is it to disperse the material over a wide area?
Some examples of Radioactive sources
Category I

<table>
<thead>
<tr>
<th>Element</th>
<th>Half-life</th>
<th>Used in</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strong Gamma and Beta emitters:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt 60</td>
<td>5.3 years</td>
<td>Radiotherapy; irradiating bacteria in spices and other food products</td>
</tr>
<tr>
<td>Cesium 137</td>
<td>30 years</td>
<td>Radiation devices to treat cancers; equipment to monitor wells for oil</td>
</tr>
<tr>
<td>Iridium-192</td>
<td>74 days</td>
<td>Treating prostate cancer; detecting faults below the surface of certain materials</td>
</tr>
<tr>
<td><strong>Strong Beta emitter:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strontium 90</td>
<td>29 years</td>
<td>Medical and agricultural research; provides a long-lived source of electricity, and has often been used to power remote locations such as lighthouses and weather stations</td>
</tr>
</tbody>
</table>
Radiological Weapons:

RDD: any means used to **disperse** radioactive material. can use conventional explosives, an aerial sprayer, or other means. Could be a backpack, truck, boat, etc. A conventional high explosive bomb placed near a radioactive source. So-called **“dirty bomb”**

RED: using materials to emit **radiation**. a highly **radioactive source** is placed somewhere while unshielded. Likely target: locations where many people would be exposed (subways, airports, office buildings, indoor stadiums, etc.). Not really a “bomb” at all.
# EFFECTS OF “DIRTY BOMB”

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medical/Health</strong></td>
<td>Other than the injury from the explosion, the principle health risk at expected dose levels is the possible increased risk of cancer. At 100 mSv the lifetime risk of fatal cancer is believed to be increased about 20%</td>
</tr>
<tr>
<td><strong>Psychosocial</strong></td>
<td>Fear/Panic, Transportation paralysis Demand for medical evaluation Emotional, physical, and cognitive effects</td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td>Clean up costs, Impact on commerce</td>
</tr>
</tbody>
</table>
Questions for colloquium

➢ Types of nuclear and radioactive materials, classification;
➢ Radioactive waste and SNF management: threats and possible solutions;
➢ What are the most vulnerable parts of NFC and why?
➢ Four types of nuclear and radiological terrorism;
➢ Threat of radiological terrorism: high risk radioisotopes and “dirty” bomb
Summary:

✓ Nuclear materials classification is done by IAEA Statute and CPPNM definition
✓ Radioactive waste and spent fuel management could create nonproliferation concerns. “Postponed solution” for next generations
✓ Uranium enrichment, reprocessing of SNF and stockpiles of separated plutonium are the most sensitive and vulnerable parts of NFC
✓ Threat of the use of radiological weapons is real and merits the immediate and adequate response
Thank you for your attention!

Questions?