BACKGROUND AND MOTIVATION

DETECTING CLANDESTINE SEPARATION OF PLUTONIUM

- Precedents exist for attempts to make plutonium in undeclared facilities
- Concern of “Simple, Quick Processing Plant” (Oak Ridge, 1977)
- Challenge for NPT verification; also relevant for future FMCT verification
- Atmospheric (krypton) sampling appears most promising (“STR-321”)


- The cost of operating a WAES network “could be high and would be strongly dependent on: the type of facility ...; the target region to be covered; and the acceptable probability of detection and false alarm rate”
- Recommended additional work includes: “Refining evaluation of the variability in background levels of target signatures”

BASIC CHALLENGE

AN AIR-SAMPLE IS TAKEN SOMEWHERE ON THE GLOBE:
IS THE MEASURED KR-85 CONCENTRATION FROM A KNOWN OR FROM AN UNKNOWN PLANT?
CHARACTERIZING THE GLOBAL KRYPTON BACKGROUND
CHARACTERIZING THE GLOBAL KRYPTON-85 BACKGROUND

PART 1: HISTORIC BASELINE

70 years of nuclear fuel reprocessing, 10.7-year half life (compare to Xenon-133, 5.2 days)

Background today: ≈1.5 Bq/m³ in the Northern Hemisphere and ≈ 1.3 Bq/m³ in the Southern Hemisphere

Jens Ole Ross, *Simulation of Atmospheric Krypton-85 Transport to Assess the Detectability of Clandestine Nuclear Reprocessing*
PhD Thesis, University of Hamburg, February 2010
CHARACTERIZING THE GLOBAL KRYPTON BACKGROUND

PART 2: EMISSIONS FROM DECLARED REPROCESSING PLANTS

### SIMULATING EMISSIONS FROM KNOWN FACILITIES

LACK OF LIVE STACK EMISSION DATA:
ASSUME CONTINUOUS EMISSIONS FROM TEN REPROCESSING FACILITIES ACTIVE IN 2010

<table>
<thead>
<tr>
<th>Country</th>
<th>Facility</th>
<th>LAT</th>
<th>LON</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Lanzhou</td>
<td>36.2</td>
<td>103.5</td>
<td>2.24E+14 Bq/a</td>
</tr>
<tr>
<td>France</td>
<td>La Hague</td>
<td>49.4</td>
<td>−1.5</td>
<td>2.26E+17 Bq/a</td>
</tr>
<tr>
<td>India</td>
<td>Kalpakkam</td>
<td>12.3</td>
<td>80.1</td>
<td>1.12E+16 Bq/a</td>
</tr>
<tr>
<td>India</td>
<td>Trombay</td>
<td>19.0</td>
<td>72.6</td>
<td>8.00E+15 Bq/a</td>
</tr>
<tr>
<td>Israel</td>
<td>Dimona</td>
<td>31.0</td>
<td>35.1</td>
<td>5.76E+14 Bq/a</td>
</tr>
<tr>
<td>Japan</td>
<td>Tokai</td>
<td>36.3</td>
<td>140.4</td>
<td>1.00E+15 Bq/a</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Nilore</td>
<td>33.4</td>
<td>73.2</td>
<td>1.92E+14 Bq/a</td>
</tr>
<tr>
<td>Russia</td>
<td>Mayak</td>
<td>55.4</td>
<td>60.1</td>
<td>4.86E+16 Bq/a</td>
</tr>
<tr>
<td>Russia</td>
<td>Zheleznogorsk</td>
<td>56.2</td>
<td>93.4</td>
<td>1.00E+16 Bq/a</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Sellafield</td>
<td>54.3</td>
<td>−3.3</td>
<td>4.53E+16 Bq/a</td>
</tr>
</tbody>
</table>

# MODELING APPROACH

## CODE

Flexpart (FLEXible PARTicle dispersion model) v8.2.3

www.flexpart.eu

## DATA

National Centers for Environmental Prediction (NCEP) meteorological data

www.ncep.noaa.gov

| 0.5 degree x 0.5 degree resolution (about 260,000 gridpoints) |
| 2010, day-by-day emissions from ten plants, all tracked for four weeks |
| (At that point, puff effectively disappear in the background) |
RESULTS
GLOBAL KRYPTON-85 VARIABILITY

\[ \mu_1 + \sigma_1 \approx 84.1\% \text{ of local samples are within indicated upper concentration limit above (quasi-constant) baseline } \mu_0 \]
SCENARIOS

RANDOMLY-PLACED UNDECLARED REPROCESSING PLANTS
(IN AREAS WITH LOW, MEDIUM, AND HIGH LOCAL KRYPTON VARIABILITY)
RANDOMLY-PLACED FICTIONAL REPROCESSING PLANTS
(IN AREAS WITH LOW, MEDIUM, AND HIGH LOCAL KRYPTON VARIABILITY)
LOW-VARIABILITY SCENARIO

FICTIONAL PLANT IN SOUTH AMERICA
SEPARATING 8 KG OF PLUTONIUM PER MONTH
LOW-VARIABILITY SCENARIO

FICTIONAL PLANT IN SOUTH AMERICA
SEPARATING 8 KG OF PLUTONIUM PER WEEK

These concentrations above the baseline cannot be measured against a background of 1.3–1.5 Bq/m$^3$. 

**Bq/m$^3$ (above baseline)**
- 5.0E+0
- 1.0E+0
- 5.0E−1
- 1.0E−1
- 5.0E−2
- 1.0E−2
- 5.0E−3
- 1.0E−3
- 5.0E−4
- 1.0E−4
LOW-VARIABILITY SCENARIO

ANALYSIS

PLANT SEPARATING 8 KG PER WEEK (c. 40 tHM/yr)

Earth’s landmass: 149,000,000 km²
Region of detectable emission signature: about 175,000 km²
About 0.1% of landmass

Detection probability for 1000 random samples: $1 - 0.999^{1000} \approx 63\%$
Detection probability for 100 random samples: $1 - 0.999^{100} \approx 10\%$

PLANT SEPARATING 8 KG PER MONTH (c. 10 tHM/yr)

Earth’s landmass: 149,000,000 km²
Region of detectable emission signature: about 25,000 km²
Less than 0.02% of landmass

Detection probability for 1000 random samples: $1 - 0.9998^{1000} \approx 15\%$
Detection probability for 100 random samples: $1 - 0.9998^{100} < 2\%$
RANDOMLY-PLACED FICTIONAL REPROCESSING PLANTS

(IN AREAS WITH LOW, MEDIUM, AND HIGH LOCAL KRYPTON VARIABILITY)

These concentrations above the baseline cannot be measured against a background of 1.3 Bq/m³
SUMMARY AND FINDINGS

WHAT WAS NEW HERE?
Decomposition of krypton background into two components (historic baseline + daily emissions from operational reprocessing plants) allows for new, efficient modeling technique

Updated map of global krypton variability

FINDINGS
Northern Hemisphere: Detectability of clandestine facilities inhibited by variability of background due to ongoing emissions from existing reprocessing plants (not only in Europe!)

Everywhere: Fixed (ground-based) monitoring network most likely impractical due to high krypton-85 baseline; mobile options could be more useful
WHAT COULD BE DONE?

OPTIONS TO IMPROVE THE VALUE OF WIDE-AREA KRYPTON MONITORING

1. DAILY DECLARATIONS OF STACK EMISSION DATA
   
   This would significantly improve the value of atmospheric modeling, especially in the Northern Hemisphere, to correlate detected peaks with declared emissions — and to isolate “unaccounted” peaks.

2. STOP KRYPTON-85 EMISSIONS INTO THE ATMOSPHERE
   
   • Cryogenic removal of krypton-85 prior to emission
     
     Stabilizes krypton-85 inventory; quick die-away of fluctuations in baseline
     Technologies for efficient krypton removal exist, but are expensive
   
   • Ending reprocessing altogether would be equivalent

For illustration purposes only; Source: www.vrv.com