The Probabilistic Risk Assessment of the Abandoned Chemical Weapons in China
Performed for the ACW
Cabinet Office of Japan
2003 - 2007
Background of ACW in China

- 1945: Abandoned
- 1949-55: Buried in Northern China
- 1995-7: CWC Ratification
- 1999: the Abandoned Chemical Weapons (ACW) Office Formed
According to the treaty, the weapons were to be Excavated and Disposed of by 2007; now, perhaps, by 2015.
The number of CWs is believed to be about 500,000.

Mainly concerned with two types of Chemical agents:
- Yellow agent
- Red agent (DC/DA)
5,000 People in 10km; 500,000 in 50km
The Three Questions of Probabilistic Risk Assessment

(1) What can go wrong?
(2) What is the likelihood?
(3) What is the damage?

\[ R \equiv \text{Risk} = \{ < s_i, l_i, x_i > \} \]
What the Japanese Government Wanted to Know

1. What Can Go Wrong?
   - Weapon explosions
   - Release of toxic materials

2. What are the Potential Damages?
   - Worker Injuries
   - Population injuries
   - Facility damages
   - Environmental pollutions (soil, air, water)

3. What is our Financial Exposure?
   - Third party liability
   - Workers compensation
   - Repair/Recovery Cost
What We Needed to Know

1. What can happen during the processes?
2. Under what conditions does a weapon explode?
3. How much of agent is released to air?
4. What are the weather conditions?
5. Blast effect to buildings and equipment?
6. What are the effects to human health? How many people may be injured?
7. Is environment contaminated? Cleanup necessary?
8. Effectiveness of emergency response?
Three Big Questions We Had

1. The ACW in China have been buried underground for *decades* - How can we estimate the conditions, types, and number of buried weapons?

2. There is a **Large amount** of weapons - If a weapon detonates, could it start a domino effect?

3. Weapons contain **toxic materials** – How do we estimate the long term health effects of toxic materials (or even short term)?
Overview of the ACW Hearbaling Site

(source: PMC document)
Excavation

Recovery Robot

AGV

Burial Pit

Conceptual Illustration
Layout Plan

- Gate (Personnel & Material Supply)
- Administration Office, Utility etc.
- 50m Buffer Zone
- Controlled Area
- Sub Wastewater Treatment Building
- Sub Decontamination Building
- Gate (Munitions Transporters)
- Main Yellow Munitions Destruction Building
- Main Red Munitions Destruction Building
- Sub Irregular Munitions Destruction Building

Prevailing Wind
Main Plant (Yellow Munitions)

Process Flow – 1/2

Pre-treatment Process

Treatment Process

Line No.1
- Thermal Detonation Chamber
- Buffer Tank
- Cyclone

Line No.2
- Fragment Thermal Detonation Chamber
- Buffer Tank
- Cyclone

Line No.3
- Fragment Thermal Detonation Chamber
- Buffer Tank
- Cyclone

From temporary storage building at excavation & retrieval area

75mm: 450枚／日 3系列
90mm: 450枚／日 3系列
105mm: 150枚／日 3系列
150mm: 78枚／日 3系列

Munitions Container
Munitions Bucket
Receiving Stacking Inspection Unit

Secondary Combustion Chamber
Car-Bottom Combustion Furnace

Secondary Combustion Chamber
Main Plant (Yellow Munitions) (Cont.)

Process Flow – 2/2
1. What can go wrong?

2. How likely is it?

3. What are the consequences?

**Level 1 PRA: Quantification of Frequencies of Sequences**

- **Agent Leaks**
  - Yes (0.4)
  - Fail (0.6)

- **Air Filter**
  - No (0.6)
  - Work (0.9)

- **Weapon damaged**
  - Fail (0.1)
  - Work (0.9)

<table>
<thead>
<tr>
<th>End State</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>No effect</td>
<td>0.6×0.9=0.54</td>
</tr>
<tr>
<td>No effect</td>
<td>0.6×0.1=0.06</td>
</tr>
<tr>
<td>Onsite dispersion</td>
<td>0.4×0.9=0.36</td>
</tr>
<tr>
<td>Off site dispersion</td>
<td>0.4×0.1=0.04</td>
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</table>

**Level 2 PRA: Development of Source Terms**

- No.1: Leaking of Agent: Inside of the facilities ⇒ 10kg DC
  - 3 workers get minor injury (Frequency = 0.36)

- No.2: Leaking of Agent: Outside of the facilities ⇒ 30kg DC
  - 250 people (general population) get major injury (Frequency = 0.04)

**Level 3 PRA: Consequence Analysis**
Data Gathering

Using Data from Other Weapon Sites

Bayesian 2\textsuperscript{nd} stage update technique was used to create uncertainty distributions for each weapon type, based on:

- Weapon data of other sites,
- Expert opinions, and
- Exploratory excavation at the Haerbaling site.
Sympathetic Detonation

AUTODYN 3 D
(76mm)
Sympathetic Detonation  
(Continued)

AUTODYN 3 D
76mm
Results of SympFD

Number of Total Weapons Reacting

Exceedance Prob

Weapon Count

B2 Garbage Layer Construction
B2 Garbage Layer Excavation
B2 Normal Layer Excavation
B3 Garbage Layer Construction
B3 Garbage Layer Excavation
Event Sequence Model for Disposal

E.g. Weapon Drop

IE
DROP
FORK
FIRE
CRUSH
SPILL
TRUCKACCIDENT
MIGRATE
KILN
WASTEWATER
FURNACE
MISIDENTIFICATION
DRUMEVAPORATE
SEISMIC

LOCATION
IE TYPE
WEAPON1
SUPPORT
ROOMWAC
RELEASE

FRONTLINE Tree
DROP
INTFIRE
CRUSH
SPILL
CARGOFIRE
MIGRATE
KILNMISSFEED
WASTEWATER
FURNACEUPSET
MISIDENTIFICATION
DRUMEVAPORATE
EQRESPONSE

SUCCESS
ENDSTATE
SYMP
DETONATION
DEFLAGRATION
ROOM
FILTER
CONTAMINATED
MATERIAL by C.A.
ARSENIC in LIQUID
TNT in LIQUID
H2S
NODETONATION
EXPOSURE
DAMAGED EQUIPMENT
GAS WITH ARSENIC

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<table>
<thead>
<tr>
<th>Event</th>
<th>Simulation Probability Used</th>
<th>Spill Area</th>
<th>Correlated Fuel</th>
<th>First Truck Simulation</th>
<th>Middle Truck Simulation</th>
<th>Last Truck Simulation</th>
<th>Tank Capacity Full</th>
<th>Tank Filled</th>
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</thead>
<tbody>
<tr>
<td>Car-Truck</td>
<td>0.2177</td>
<td>6</td>
<td>230</td>
<td>0.2177</td>
<td>0</td>
<td>0.1012</td>
<td>Car Tank</td>
<td>Car Tank</td>
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<tr>
<td>Single Truck</td>
<td>0.4675</td>
<td>150</td>
<td>0.657</td>
<td>0.4675</td>
<td>0.343</td>
<td>0.4009</td>
<td>Truck Tank</td>
<td>Truck Tank</td>
</tr>
<tr>
<td>Truck-Truck</td>
<td>0.657</td>
<td>300</td>
<td>0.4978</td>
<td>0.657</td>
<td>0.657</td>
<td>0.4978</td>
<td>Truck Tank</td>
<td>Truck Tank</td>
</tr>
</tbody>
</table>

- Probability of Single Truck Colliding with Object: 0.105
- Probability of Single Truck Rollover/Fire Only Event: 0.895

**Event Scenario:** Single Truck Type: Rollover 0.2941699

- Uniform Random Number for Event Type
- Car Tank

**Combustion Rate:** 0.16 inches/min

- Burn Time: 150 liters × 1000 cm³/liter
  - 6 ft² × 920 cm³/ft² × 0.16 inches/min × 2.54 cm/inch
  - Unmitigated Burn Time: 66.22 min
  - Upper Limit of Fuel for Escort Fire Fighting: 225 liters
  - Pr Escort Takes Action: 0.75
  - Escort Would Fight Fire: Yes
  - Time for FD to Arrive: 3 Minutes
  - Pr FD Takes Action: 0.8
  - FD Would Fight Fire: Yes

- Escort Adjusted Burn Time: 31.60858344
- Final Adjusted Burn Time: 6.321716688
MIDAS
Agent Dispersion & Transportation Model
(Particle Tracking Model)
Health Effect Analysis

Health Damage Curve

<table>
<thead>
<tr>
<th>Explosive (kg)</th>
<th>General Public</th>
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<tbody>
<tr>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>1,000</td>
<td>174</td>
</tr>
<tr>
<td>5,000</td>
<td>14,095</td>
</tr>
<tr>
<td>50,000</td>
<td>54,819</td>
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Dispersion

Population Data
Spatial Database of Rooms

Room Attributes

Fire Frequency

Weapon Inventory
Fire Propagation Simulation

• Monte Carlo Simulation
• Modeled all Rooms
  – With and Without Weapons
  – Localized or Propagation throughout the room, to floor, or Entire Building
• Time Step Simulation
• Propagation of Fire Due to Detonation/Deflagration
Past Seismic Events
Simulation of Seismic Consequences

- Monte Carlo Simulation
- Considered all Buildings and Rooms Simultaneously
- Structure Fragility Design Specific
- Time Step Simulation
- Propagation of Damage Due to Detonation/ Deflagration
Integrating the Models

Batches of End States Grouped by Project Phase

[Diagram and interface of a software tool for model integration]

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Sample Risk Curve Uncertainties

Operation Loss (Total)

Loss

Exceedance Probability

5th 95th Mean 50th

Loss (in Thousand Yen)
Loss Exceedance Curve (LEC)

• Represents the probability that a certain level of monetary loss will be exceeded during 2.5-year project.
• LEC incorporates uncertainty in event occurrence probability and
The PML is that place on the exceedence curve where a lower probability of loss will NOT translate into a relatively higher monetary loss. For example here is the PML for the median loss.
Components of Loss

Exceedence Curve

Excavation Loss Curve (Mean)

JP Worker
CN Worker
Property
Onsite Cleanup
Offsite Cleanup
General People
Total

Exceedance Prob

1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10

Thousand Yen

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But Caveat Consulters! Some important things to remember about PRA
Much is learned in the process of creating and quantifying the PRA. The act of trying to measure the risk involved is the source of knowledge. The acts of trying to assign values, combining them, questioning their verisimilitude, building the model are the great treasure of PRA: the key to the treasure is the treasure itself.
Uncertainty is not some noisy variation around a mean value that represents the true situation. Variation itself is nature's only irreducible essence. Variation is the hard reality, not a set of imperfect measures for a central tendency. Means and medians are the abstractions.

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Too often risk is defined as $\text{risk} = \text{likelihood} \times \text{consequence}$ and $\text{safety} = 1 - \text{risk}$.

This can misinform: acceptable risk is a consideration of likelihood AND consequence, not a simple multiplication with safety as the additive inverse of risk.

Acceptable risk and safety are normative notions, changing with situations and expectations, and must be assessed accordingly.
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