Nuclear Weapons Accidents
Lessons Learned

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*Speakers
Overview

- U.S. Nuclear Weapons Accident History
  - Summary of Types, Years, Circumstances
  - Politics Events & Military Operations of Time
  - Key Accidents
- Evolution of Accident Preparedness in DoD & DOE
  - Equipment
  - Plans
  - Procedures
- Recent Restoration Activities at a few Continental U.S. Sites

Integrity - Service - Excellence
U.S. Nuclear Weapon Accident History

Definition

Accidental event that involves nuclear weapons or components, but which does not create the risk of nuclear war, and includes: accidental or unexplained nuclear detonation, non-nuclear detonation or burning of a nuclear weapon, radioactive contamination, jettisoning of a nuclear weapon or nuclear component, public hazard actual or implied
U.S. Nuclear Weapon Accident History (Summary)

- U.S. Experienced (32) Nuclear Weapon Accidents
  - 28 USAF, 3 USN, 1 Atomic Energy Commission
  - Timeframe: 13 Feb 50 to 19 Sep 80
- Locations:
  - (12) Overseas
  - (9) On-Base CONUS
  - (10) Off-Base CONUS
  - (1) Both On-/Off-Base CONUS (Medina Base)
U.S. Nuclear Weapon Accident History (Summary)

- Circumstances:
  - High-Explosives Detonations & Dispersal of Radioactive Materials
  - Fires Involving Dispersal of Radioactive Material
  - Weapon Damage, but no Release of Contamination
  - Lost Components
  - None with a Nuclear Yield
Radiological/Environmental Consequences for Releases:
- Fire vs. Explosion
- Radioactive Materials Involved

<table>
<thead>
<tr>
<th>Radioactive Material</th>
<th>Specific Activity (Ci/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weapons Grade Plutonium (excluding Am-241)</td>
<td>7.3E-02</td>
</tr>
<tr>
<td>Highly Enriched Uranium</td>
<td>5.8E-05</td>
</tr>
<tr>
<td>Moderately Depleted Uranium</td>
<td>4.0E-07</td>
</tr>
</tbody>
</table>

Radioactive Material
The Cold War 1

- June 22, 1948 – USSR blocks access to West Berlin
- June 24, 1948 – Berlin Airlift begins
- July 1948 – USSR threatened to interfere with airlift
- July/August 1948 – Truman orders B-29 “atomic bombers” to England
- August 29, 1949 – USSR explodes its 1st A-bomb
- May 12, 1949 – Berlin Airlift ends
The Cold War 2

- June 25, 1950 – N. Korea invades S. Korea
- October 14, 1962 – Cuban Missile Crisis
  - USAF U-2 photographs Soviet missile in Cuba
  - SAC on full alert. (70) B-52s airborne & fully armed.
Early Designs

- Early nuclear weapon designs were “open pit” type
  - Weapon case and capsule
  - Separated, nuclear yield not possible
  - Capsule carried apart from the weapon in special container called a “bird cage”
Later Designs

Later nuclear weapon designs had “sealed pits”
- Nuclear material surrounded by high explosives
- Weapons designed as “one-point safe,” accidental high explosives detonation will not produce nuclear yield

Before Firing

Subcritical mass

Compressed Supercritical mass

High explosive

After Firing

Implosion
U.S. Nuclear Weapon Accident History (Politics & Operations)

The graph shows the number of nuclear weapon accidents from 1945 to 1990. Key accidents include:
- **BOMARC**
- **Palomares**
- **Thule**
- **Damascus**

The graph indicates that the number of accidents increased significantly in the 1960s and 1970s.
Strategic Air Command (SAC) Airborne Alerts - Operation Reflex Action (initiated 1950)

- B-47’s: 90-day rotations to England, Spain, and North Africa – mid-air refueling in from the Azores

Accidents:

- Mar 56 (Mediterranean)
- Jul 56 (OCONUS SAC)
- Oct 57 (Homestead AFB)
- Jan 58 (OCONUS SAC)
- Mar 58 (Florence SC)
- Nov 58 (Dyess AFB)
Strategic Air Command (SAC) Airborne Alerts - Operation Chrome Dome

- B-52’s: 1961 – 1968, up to 24 hour missions
- Mission Routes:
  - Northern (Central U.S. to Novaya Zemlya)
  - Southern (Eastern U.S. to Mediterranean)
  - Western (Western U.S. to Aleutian Chain)
Strategic Air Command (SAC) Airborne Alerts - Operation Chrome Dome

Accidents:
- Oct 59 (Hardinsburg KY)
- Jan 61 (Goldsboro SC)
- Mar 61 (Yuba City CA)
- Jan 66 (Palomares Spain)
- Jan 68 (Thule Greenland)
Key Accidents

- Boeing Michigan Aeronautical Research Center Missile (BOMARC), McGuire AFB, N.J., 7 June 1960
- Palomares, Spain, 17 January 1966
- Thule, Greenland, 21 January 1968
- Damascus, AR, 19 September 1980
BOMARC Missile Site, McGuire AFB/Fort Dix

- Site construction began 1958, operational 1960
- Deployed to counter Soviet bomber threat
- Operational until 1972
- US had (11) similar sites
- Missile w/non-nuclear warheads at some sites
Accident Details

- 7 June 1960: helium tank explosion initiated fire in liquid rocket propellant and nuclear warhead
- Fire suppression-related water caused migration of weapons-grade plutonium, weapons-grade uranium, and depleted uranium
- Estimated 300 g plutonium not recovered (~ 22 Ci, α-emitters)
U.S. Nuclear Weapon Accident History (BOMARC)

- **Follow-on Actions**
  - Concrete & asphalt covers added to contaminated areas
  - Shelter 204 interior surfaces coated with paint to limit migration
  - Monitoring limited to delineation of contaminated areas (α-radiation-only)
■ **Palomares, Spain**
- Mid-air collision with KC-135 tanker during re-fueling
- All four KC-135 crewmen of killed
- Four of seven crewmen of B-52 killed
- All four nuclear weapons fell from B-52
U.S. Nuclear Weapon Accident History (Palomares)

- Palomares, Spain
  1. Parachute deployed, slightly damaged by impact.
  2/3. Parachutes partially deployed, high-explosives detonation.
  4. Parachute deployed, landed in sea, recovered 81 days later.
U.S. Nuclear Weapon Accident History (Palomares)

Integrity - Service - Excellence
### Personnel and Function

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Function</th>
<th>Numbers</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>Ground search</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>Detection, decontamination, harvesting</td>
<td>41</td>
<td>Air police</td>
</tr>
<tr>
<td>23</td>
<td>Accident investigation board</td>
<td>7</td>
<td>Information and public relations</td>
</tr>
<tr>
<td>23</td>
<td>Civil engineering</td>
<td>19</td>
<td>Navy ordnance disposal</td>
</tr>
<tr>
<td>30</td>
<td>Camp support</td>
<td>4</td>
<td>Technical representatives</td>
</tr>
<tr>
<td>6</td>
<td>Legal claims</td>
<td>7</td>
<td>Army engineers</td>
</tr>
<tr>
<td>5</td>
<td>Medical</td>
<td>36</td>
<td>Transportation</td>
</tr>
<tr>
<td>58</td>
<td>Communications</td>
<td>20</td>
<td>Command and staff</td>
</tr>
</tbody>
</table>

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*Integrity - Service - Excellence*
## Radiological emissions Weapons Grade Plutonium

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>α-Particle Energies (MeV) &amp; Frequency</th>
<th>β-Particle Energies (MeV) &amp; Frequency</th>
<th>Photon Energies (MeV) &amp; Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu-239 (~ 93 %)</td>
<td>5.155 (0.733) 5.143 (0.151) 5.105 (0.115)</td>
<td>None</td>
<td>0.113 (0.0005) 0.014 (0.044)</td>
</tr>
<tr>
<td>Pu-240 (~ 6.5 %)</td>
<td>5.168 (0.735) 5.123 (0.264)</td>
<td>None</td>
<td>0.054 (0.0005) 0.014 (0.11)</td>
</tr>
<tr>
<td>Pu-241</td>
<td>None</td>
<td>0.021 (1.00)</td>
<td>None</td>
</tr>
<tr>
<td>Am-241</td>
<td>5.486 (0.852) 5.443 (0.128) 5.388 (0.014)</td>
<td>None</td>
<td>0.014 (0.427) 0.0595 (0.359) 0.026 (0.024)</td>
</tr>
</tbody>
</table>
Radiological emissions Weapons Grade Plutonium

“Weapons Grade Plutonium Detection in Field Conditions is Technically Challenging”
Lessons Learned (focused to audience interest)

- Logistics key response function – a military expertise
- \(\alpha\)-scintillation detection only available field instrument available to monitor terrain, equipment, persons, etc.
- High failure rate in mylar, no field repair capability
- Monitoring skills of personnel directly related to experience level (maturity/rank)
- Correlation: Pu and portable instrument count rate
  - Assumed \(\sim 2X\) factor
    - Self-absorption
    - Terrain shielding

High Uncertainty: Risk of Underestimating Residuals
Lessons Learned

- Personnel Monitoring
  - Air Samples – suggest personnel exposures below 500 mrem
  - Urine Samples (1,370)
    - Few personnel with high results
    - Cross-contamination interference suspected
    - Sensitivity of bioassay & laboratory methods had limited sensitivity
  - Re-evaluated by AF in 1968 & 2002
### Lessons Learned

#### Remediation

<table>
<thead>
<tr>
<th>Concentration (μg/m²)</th>
<th>Action</th>
<th>Area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 462</td>
<td>Scraped (U.S.)</td>
<td>5.5</td>
</tr>
<tr>
<td>5.4 – 462</td>
<td>Water &amp; Plowed</td>
<td>285</td>
</tr>
<tr>
<td>&lt; 5.4</td>
<td>Water</td>
<td>285</td>
</tr>
</tbody>
</table>

- Ongoing surveillance program (Spain/U.S.)

1,088 yd³ from 5.5 acres
Thule AB, Greenland

- In-flight fire on B-52
- Six of seven aircrew successfully ejected and rescued on Thule AB
- High-explosives detonation in all four nuclear weapons upon impact on the ice (scattered Pu)
- Aircraft and weapons debris scattered over 3 mi²
- Accident occurred in total darkness . . . -24 °F
# U.S. Nuclear Weapon Accident History (Thule)

## Contaminated Areas

<table>
<thead>
<tr>
<th>Concentration (mg/m²)</th>
<th>Pu (g)</th>
<th>Area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>380</td>
<td>845</td>
<td>0.5</td>
</tr>
<tr>
<td>112</td>
<td>2816</td>
<td>2.7</td>
</tr>
<tr>
<td>8</td>
<td>3014</td>
<td>6.2</td>
</tr>
<tr>
<td>2.4</td>
<td>3079</td>
<td>9.6</td>
</tr>
<tr>
<td>0.9</td>
<td>3109</td>
<td>15</td>
</tr>
<tr>
<td>0.26</td>
<td>3135</td>
<td>27</td>
</tr>
<tr>
<td>0.19</td>
<td>3140</td>
<td>33</td>
</tr>
<tr>
<td>0.06</td>
<td>3151</td>
<td>55</td>
</tr>
</tbody>
</table>

*Area Blackened by Fuel Fire*
Contamination Characteristics

- PuO₂
- Calculated PuO₂ mass-median diameter ~ 4 μm (assuming log-norm)
- PuO₂ associated with inert material of much higher particle size
Snow/Ice Removal

- (67) 25k gallon containers
- ~15 acres, mean depth four inches
- Transported 17 February to U.S.
Lessons Learned

- Radiation detection
  - Deployable equipment repair capability aided operations
  - Environment too cold for field instrument batteries, required placement inside survey personnel clothing
  - New $\gamma$-radiation detection instrumentation superior for terrain surveys over $\alpha$-radiation scintillators (Palomares)

- Bioassay samples
  - Urine samples for Pu assessment delayed until personnel returned to States, eliminated cross-contamination
Lessons Learned

- Personnel Monitoring
  - Air Samples
    - 179 analyzed
    - High 23 nCi/m³, questionable result
  - Urine Samples (~ 800)
    - All considered free of Pu
    - Highest $^3$H: 200 nCi/L
- Environmental
  - Extensive post accident
  - Continues today
U.S. Nuclear Weapon Accident History (Damascus)

- Damascus, Arkansas
  - Maintenance-related damage to skin of nuclear-tipped Titan II Intercontinental Ballistic Missile caused rocket fuel leak
  - After 8.5 hours of accident, ignition of fuel vapors caused explosion. Force of explosion blew 740-ton steel/concrete door 650 ft and warhead 500 ft, respectively from silo
U.S. Nuclear Weapon Accident History (Damascus)

- Damascus, Arkansas
  - No high-explosives detonation, no radiological contamination
  - Precautionary radiography conducted by DOE & Air Force Explosives Ordnance Disposal revealed no major damage
  - Warhead disassembled and shipped to Pantex Plant, TX
Transition
Recent Restoration Activities at a few CONUS Sites (Bunker Hill)

- **Bunker Hill (5 December 1964)**
  - Two impacted sites: surface soils near flightline accident site & debris burial site
  - **Flightline Remediation**
    - September 2000
    - ~ 70 yd³ DU contaminated soil
  - **Burial Site**
    - November 2000
    - ~ 431 yd³ DU, HEU, MagThor contaminated soil & debris

*HEU mixed with MgO*
Recent Restoration Activities at a few CONUS Sites (Bunker Hill)
Recent Restoration Activities at a few CONUS Sites (Bunker Hill)

- Barksdale (6 July 1959)
  - Impacted site: accident debris burial
  - Remedial action initiated January 2008
  - HEU- and DU-contaminated soils
  - Anticipated disposal volume ~ 250 yd³
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- (1972) Site Closed
- (1972 – 1989) Periodic monitoring to verify integrity of engineering controls/site security, depth distribution of contaminant
- (1989 – 1991) Remedial Investigation/Feasibility Study (RI/FS)
- (1992) Record of Decision
  - $^{239}+^{240}$Pu remediation: 8 pCi/g
  - If disposal site available & cost-effective
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- (2002 - 2004) Site remediation
  - Shelter demolition
  - Soil removal
  - Utility demolition
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- (2002 - 2004) Site remediation
  - Volumes
    - Soil – 21,667 yd³
    - Rubble – 331 yd³
  - Disposal – Envirocare (UT)
  - Final Status Surveys
    - 9.5 acres (~37,000 m²)
    - Average depth: ~ 2 feet
    - Maximum depth: 16 feet
    - MARSSIM survey design
      - > 1,200 soil samples
      - 100 % FIDLER scans
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- (2005 - 2007) Outlying Areas
  - Contamination discovered outside primary (water) transport route
  - Concerns that discrete particle form not adequately addressed by RI/FS (RESRAD models)
  - Adequate detection sensitivity of survey instrumentation
  - Removal completed 2007
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- Lessons Learned
  - Plutonium predominantly in discrete particle form
    - Discrete Particle Characteristics (SEM imaging, Radiochemistry Group, UNLV)

![Images showing SEM imaging results for BOMARC]

- 31.4 μCi
- $^{239+240}$Pu
- D (min): 415 μm
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- Lessons Learned
  - Discrete particle character exists at remedial action criterion

Soil Sample Analyses
(Cabrera Services, 2007, Larry Pawlus)
Recent Restoration Activities at a few CONUS Sites (BOMARC)

- Lessons Learned
  - Discrete particle character exists at remedial action criterion
  - Substantial fraction of Pu contamination aerodynamically too large for respiratory intake
  - Inhalation pathway predominant exposure pathway for residual future use scenarios
  - Risks over-estimated – assumptions of models
  - 42+ year period between accident and restoration increased soil volume requiring removal
  - ~0.1 % of residual plutonium translocated by vehicle/foot traffic mechanism
Questions