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SAB200132340000

Tunnel Damage from Ground Shock (U)

Jon Rogers

Dept. 5412

June, 1997

M Burkhard 10/23/00

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~~Classified by R. G. Easterling Org. 5412~~
~~Title Systems Modeling & Analysis Dept. Date 12/1/97~~

JDR:5412:6/6/97:tnldmg.ppt

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW

1ST REVIEW-DATE: 2/23/98	DETERMINATION [CIRCLE NUMBER(S)]
AUTHORITY: ☒ DC ☐ DD	1. CLASSIFICATION RETAINED
NAME: [illegible]	2. CLASSIFICATION CHANGED TO:
	3. CONTAINS NO DOE CLASSIFIED INFO
2ND REVIEW-DATE: 12/1/00	4. COORDINATE WITH: DOD
AUTHORITY: DD	5. CLASSIFICATION CANCELED
NAME: [illegible]	6. CLASSIFIED INFO BRACKETED
	7. OTHER (SPECIFY): DOE ING CFRD

(DOE info in black)

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SNL-(97-180-J)-C-5400-1-2

98SA20B000107

Issue: Hard Target Defeat (U)

- **Briefing Outline**
  - Motivation
  - Previous Analyses
  - Example
  - Areas of Concern
  - Proposed Further Analyses

Why look at Tunnel Vulnerability? (U)

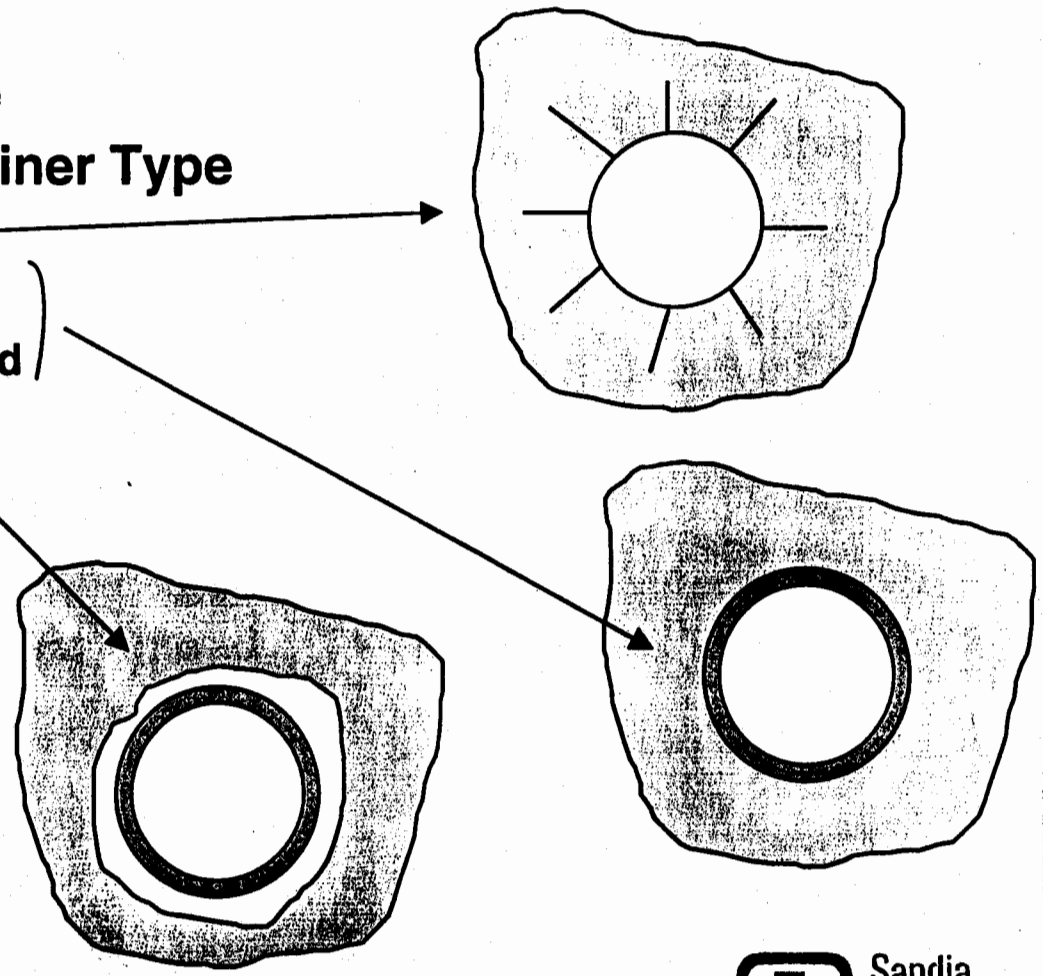
[redacted]

Attack Tunnels Using Nuclear Weapons (U)

DOE b (3)

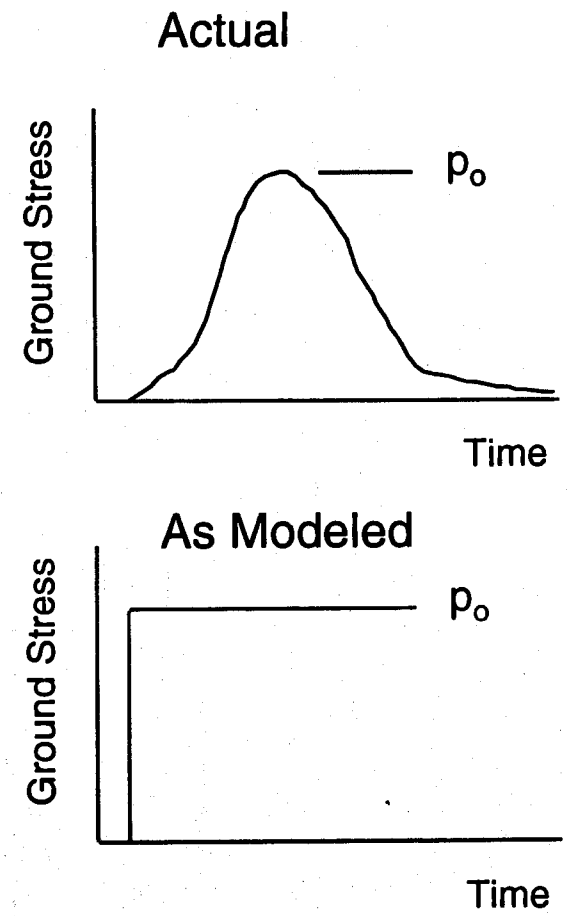
First Define the Tunnel (U)

- **Geology**
  - local to the site
- **Construction/Liner Type**
  - Rockbolted
  - Concrete lined
  - Composite lined
  - Backpacked



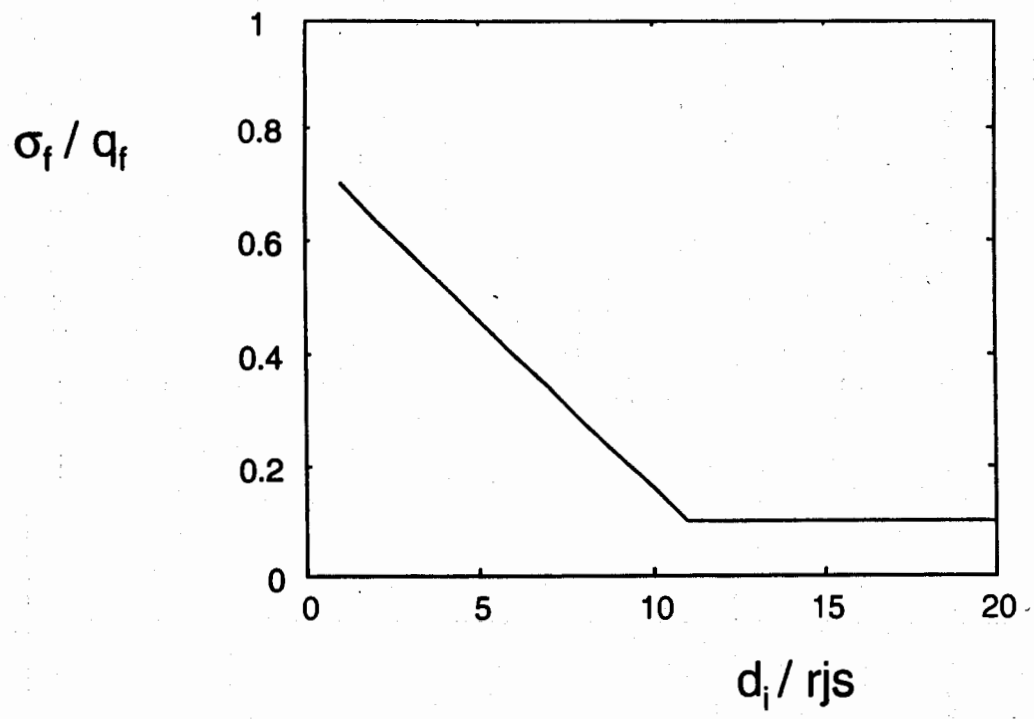
Hendron and Aiyer Analysis (U)

- **Published by Corps of Engineers in 1972**
  - **Extension of work by Newmark (1969)**
  - **These are "Big Names" in Rock Mechanics**
- **Assumes static loading**
  - **Uniform external pressure, p_o**
  - **p_o is the maximum ground stress**
  - **Elastic/Plastic analysis with dilatency**
  - **Uses Coulomb-Navier failure criteria**
- **Calculate Hoop Strain for a given external pressure**



Hendron and Aiyer Analysis - Cont'd (U)

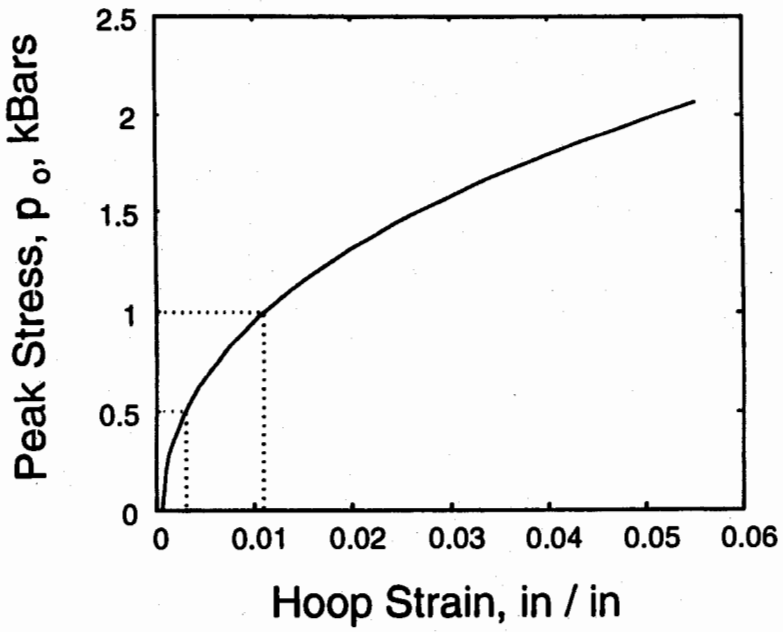
Use a Rock Strength Reduction Factor (SRF)



σ_f = in-situ rock strength
q_f = unconfined laboratory rock strength
rjs = rock joint spacing
d_i = rock opening diameter

Hendron and Aiyer Analysis Results (U)

Stress - Strain Curve for Tunnel



- Curve Depends on:
  - Liner
  - Rock Properties
  - Tunnel Size
- Similar / Identical sections in different locations have different peak stresses (p_o) but the same curve.
  - Different hoop strains
  - Identify failure/survival strain
- Many issues to consider

Issues to Consider (U)

- Dynamic loading effects
  - Rock tends to be a lot stronger under dynamic loads than under static loads
  - Impulse versus peak load analysis
- Liner/Rock interface not well modeled
- Test data come from 2 geologies
  - Granite
  - Tuff
- What are the inherent biases of the analysis?

"Calibration" of Hendron and Aiyer Results (U)

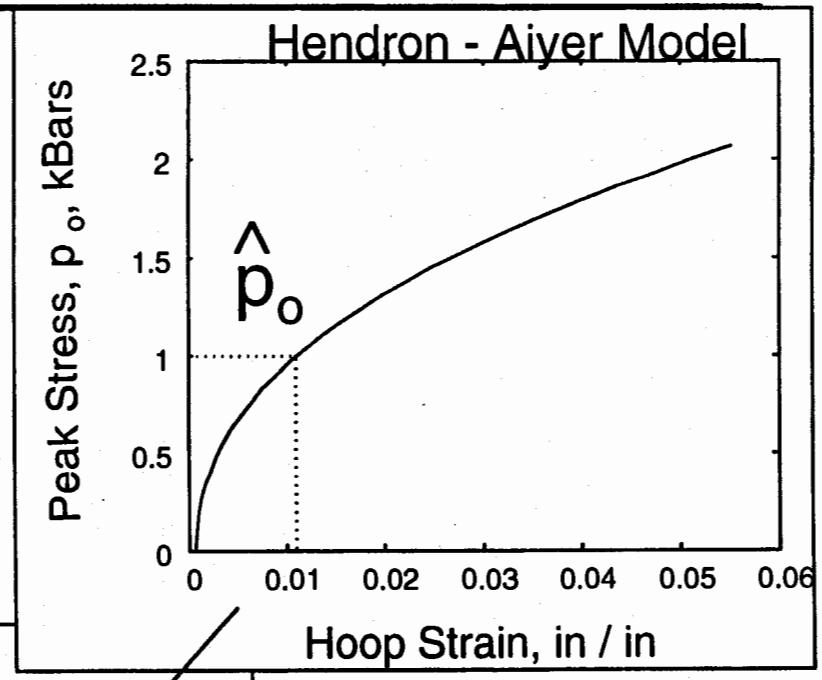
- "Calibrated" for various construction types
  - Much of data from 3 UGTs
    - Piledriver and Hard Hat - tests in Granite
    - Mighty Epic - test in Tuff
  - Lots of tunnel sections and liner types, few large sections
    - Most sections 6 - 7 feet in diameter
    - Most sections loaded side-on
- Work was in support of Deep Basing (1983)
  - Goal was protection of U.S. assets
  - Focus was on "Sure Safe" design
    - Choose to err on the side of "defender conservative"

"Calibration" Continued (U)

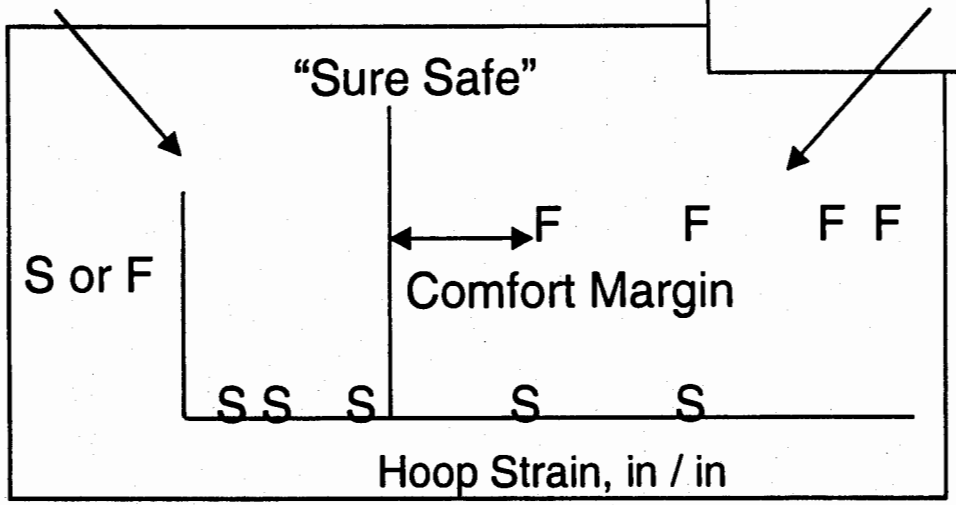
- The project officer made a post-test damage assessment
  - Severe Damage: Requires Remining
  - Moderate Damage: Major Repairs
  - Light Damage: Minor Repairs
  - Undamaged
- These categories were further reduced to
  - Survived
  - Failed

The "Calibration Trail" (U)

{Instrumentation} → $\hat{p}_o$ →



{Survive / Fail Assessment}



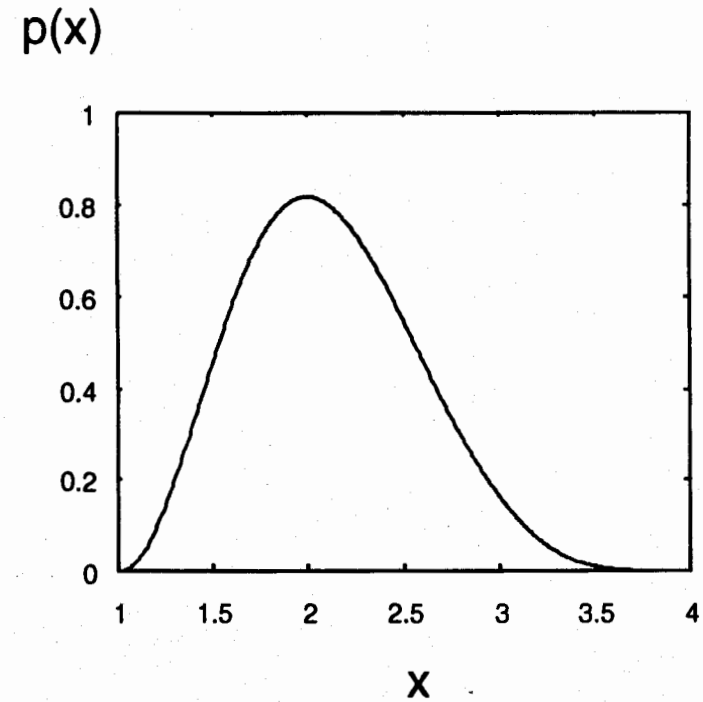
Ground Shock Vulnerability Calculation (U)

- **1990 DIA Report Describes Method**
  - Uses Hendron and Aiyer Method for p_o - hoop strain relationship
  - Converts "Sure Safe" hoop strains to "Failure Strains"
  - Large Monte Carlo simulation representing uncertainty in target parameters
- **Results in a distribution of failure stresses, p_o**
  - Failure values for p_o are fit to a Beta-distribution
  - Published tables give min, max, mode, and t-value
  - These values are used for GVN determination
    - See later chart for more details
  - GVNs are used in PDCALC 6.2

What is the Beta distribution? (U)

- **The Beta distribution has several convenient characteristics.**
  - **Bounded**
  - **Can take on almost any shape**
  - **Described by 4 parameters**
    - **minimum value**
    - **maximum value**
    - **mode**
    - **t - peakedness**
- **Uniform distribution**
  - **t = 2**

Beta distributed variable, x
min = 1, max = 4, mode = 2, t = 9



Calculating "Failure" Strains (U)

Calculating Tunnel Vulnerability (U)

- Select minimum and maximum values for all important parameters, for the target of interest
  - Geological characteristics
  - Liner characteristics
  - Size
  - "Sure Safe" strains (from earlier table)
- Select Beta distribution characteristics for each parameter
  - Peakedness, (t), and mode
- Run Monte Carlo simulation
  - Example has 10,000 draws from 13 distributions

Tunnel Vulnerability Example (U)

DOD 6(1)

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Rock and Liner Properties (U)

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Tunnel Hardness Results (U)

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Observations and Issues (U)

- The distributions represent uncertainty about the site parameters, not within site variability
  - E.g., Sure safe hoop strain
    - Assumed Beta Distribution ranges from:
      - 0.004 to 0.025 (Unreinforced concrete to very heavily reinforced)
      - The tunnel liner itself does not vary
- Choosing the resulting p_o mode is approximately the same as running a nominal case analysis - uncertainty is nearly irrelevant
- Uncertainty distributions have weak supporting rationale
  - Ranges, peakedness, independence

Hendron and Aiyer Analysis Issues (U)

- Hendron and Aiyer Method assumes static loads
  - Rock is much stronger under dynamic loads than static loads - strain rate effects
    - Tunnel is stronger than static load predicts
    - Conservative assumption for tunnel designer
  - Requires full engulfment of structure in ground shock wave
    - Probably OK for nuclear - not even close for conventional weapons effects
  - When failure occurs - loading or unloading - may be important but is not included in analysis

Tunnel Vulnerability Analysis Issues (U)

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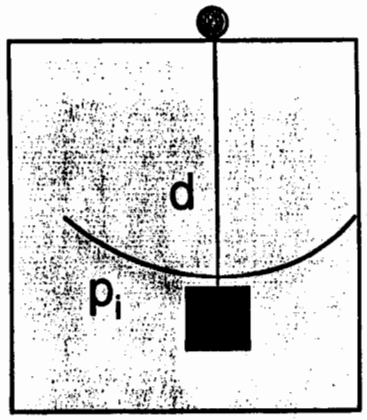
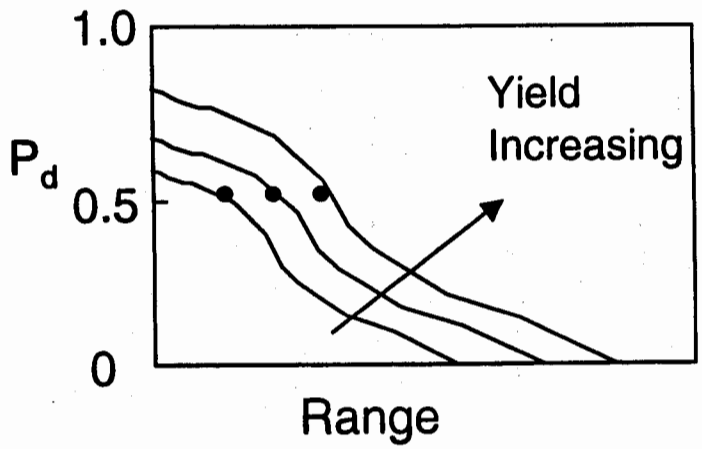
Where do GVNs come from? (2) (U)

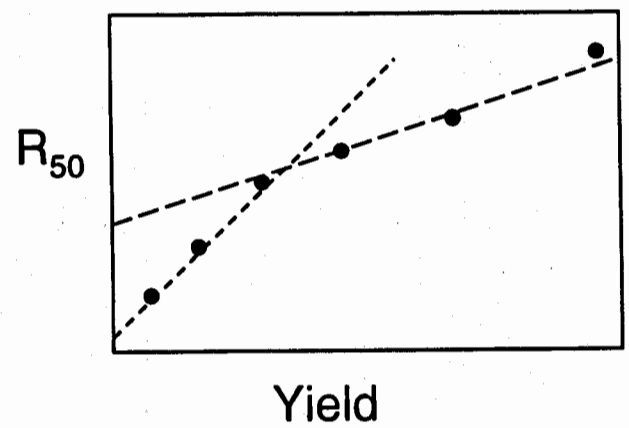
- **Step 3: Pick many weapon yields**
  - Evenly spaced on log scale from min to max
  - HOB is 0.5 meters
- **Step 4: Monte Carlo simulation drawing from distributions on:**
  - Facility depth (assumes weapon directly above facility)
  - Geology parameters
  - Result: p_i, the peak ground stress at the facility
  - Compare to the chart in Step 2 to get P_d for that trial
  - Save P_d and depth for that trial associated with the yield.



Where do GVNs come from? (3) (U)

- **Step 5: Repeat the process for many yields**
  - Fit P_d vs. Range to lognormal for each yield
  - Select R_{50} for each yield from fitted curve





- **Step 6: Fit 2 straight lines to 50 % P_d values**
  - Determine GVN (parameters of curve fit)

Further Analyses of Tunnel Vulnerability (U)

- Review tunnel vulnerability assessment methodology
  - More sophisticated techniques are available
  - Include dynamic loading effects
- Look again at failure models and test data
  - Identify where conservatism exists and quantify
  - Reanalyze for "Sure Kill" levels
- Consider other treatments of uncertainty
  - Run selected cases
  - Evaluate parameter effects on p_o

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CINC Priorities for Counterproliferation Capabilities (U)

CINC Priority	CINC's Counterproliferation Capabilities
1	Detection/characterization of BW/CW Agents
2	Intercept cruise missiles
3	Defeat underground targets
4	Characterize and identify underground targets
5	Collect and analyze intelligence
6	Passive defense enabling operations
7	Support for operations in NBC environment
8	Biological vaccines
9	Planning and targeting for above ground infrastructure
10	BW/CW agent defeat
11	Detection and tracking of shipments
12	Prompt mobile target kill
13	Support for Special Operations Forces
14	Locate, detect, and disarm WMD in CONUS/OCONUS

External Interactions

- *Defense Intelligence Agency*
- *Waterways Experiment Station*
- *University of Dayton*
- *Eglin Air Force Base - Wright Lab*
- *USSTRATCOM*
- *Defense Nuclear Agency*

Uniqueness

- Team Approach: Nationally Recognized Members
  - 30 Years of EPW Experience
  - Large Scale Computational and Modeling Capability
  - Unique SNL/USSTRATCOM Analysts
- Success Oriented
  - Technically Credible Approach
  - Target Assessment/Mission Analysis

    Low Risk
  - Design Methodology/Analytical Tool Development

    Medium-High Risk

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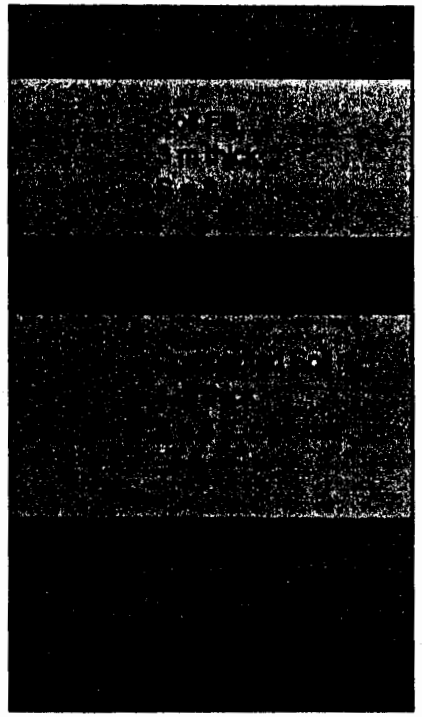
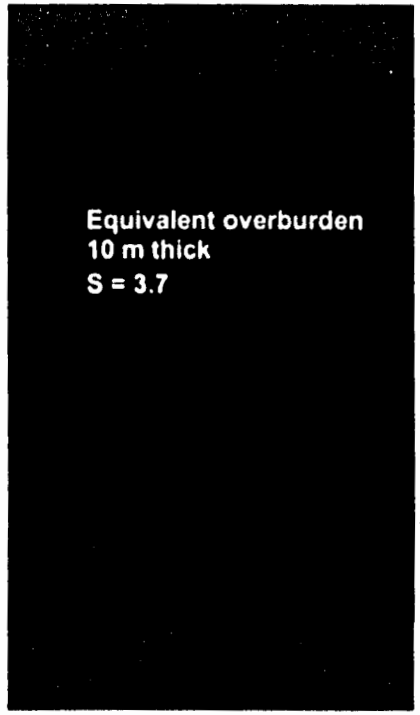
Illustration of Equivalent S-number Process (U)

Actual Facility with Layered Geology or Construction



Facility modeled with uniform geology/construction and equivalent S-number



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LDRD Project: Unexplored Penetrator Regime Against Super-Hard Underground Facilities

Part 2: Review of Tech Base Activities

Technical goal

- Develop basic understanding computational models to predict unique features of earth penetration at high velocity:
  - Penetrator abrasion, plastic deformation, and failure

End product is a tool to predict:

- **Survivability**:
  - Predict loads, peak stresses on the penetrator case and warhead.
- **Lethality**:
  - Predict depth of penetration.

EPW LDRD

Modeling Regimes/Capabilities

Velocity

Low (V < 3000 fps) ← *Intermediate* → **High (V > 10000 fps)**

Material Response

Elastic/Plastic → **Hydrodynamic**

Data

Good → **Extensive**

Codes

Lagrangian/Hybrid → **Eulerian/Hybrid**

-UNEXPLORED-

Technical challenges

- Overcome lack of understanding of physical processes.
  - Abrasion, friction, other interface phenomena.
  - Material failure: cracking, plastic flow.
- Overcome difficulty in modeling interface numerically
  - Allow gross changes in penetrator shape.
  - Develop ability to remove penetrator material from Lagrangian mesh.
  - Predict structural response while the above are occurring.
- Contribute to penetrator design process in this velocity regime.
  - Materials science basis.
  - Computational tools.

Major Technical R&D Activities

- **Physics model development**
  - Metal penetrator wear/erosion/abrasion
- **Micrographic analysis**
  - Investigate/discover erosion phenomenology
  - Guide model development
- **Ballistic testing**
  - Samples for micrographic analysis
  - Validation data for computational models
- **Production code implementation of penetrator erosion model**
  - Platform for validation of computational models
  - Model-based tool for routine EPW engineering design & analysis

Technical accomplishments: Abrasion model

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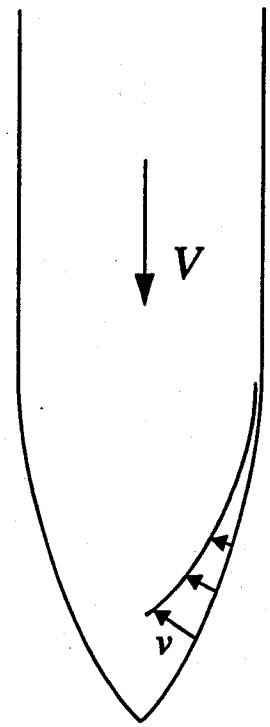
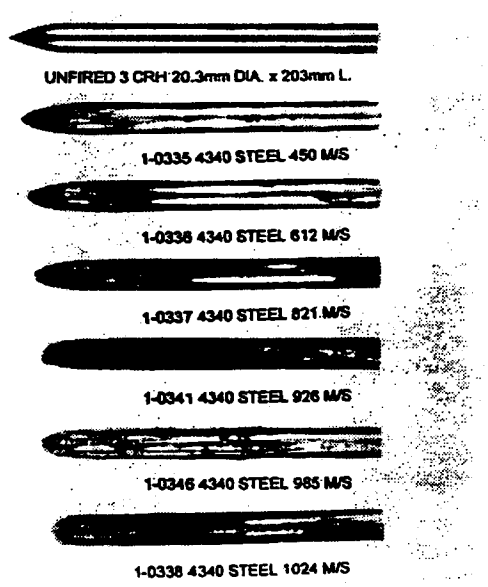
Computational Physics & Mechanics Department

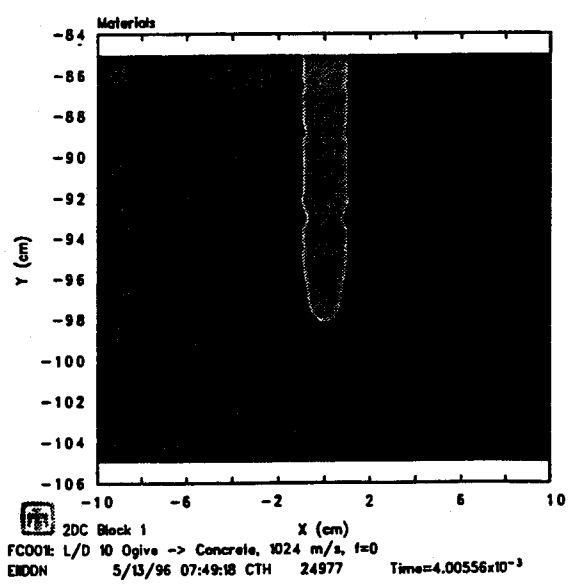
- CTH model removes mass from the surface according to local conditions.
- Data show mass lost is proportional to initial KE. This suggests model shown at right:
- Results agree well with experimental data by Forrestal on mass loss and penetration depth.

$$v = \frac{CVp}{\rho}$$

C=constant

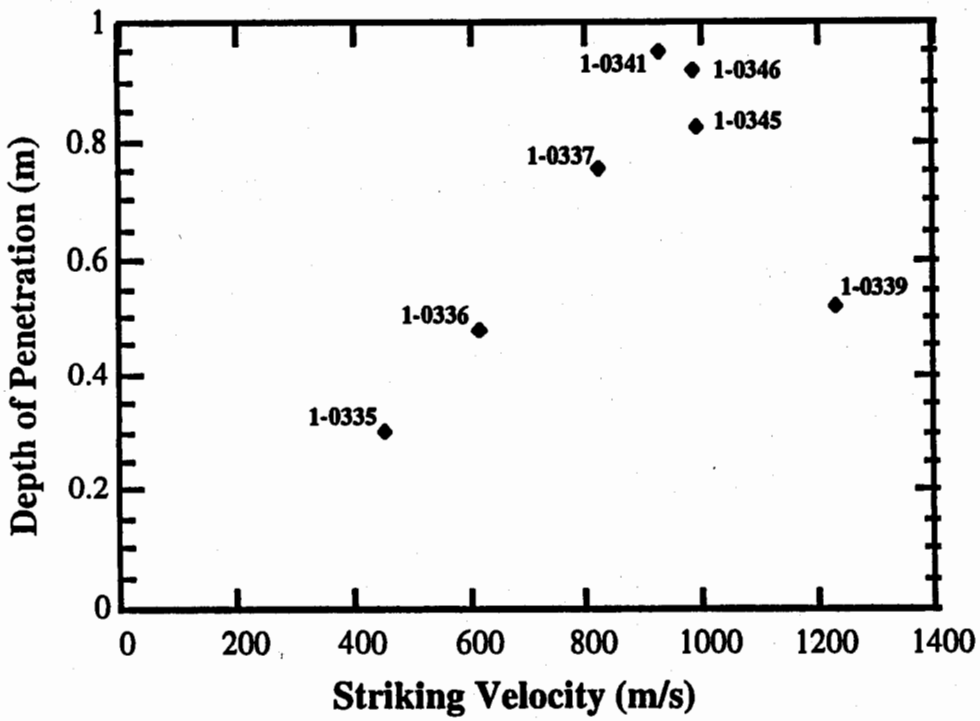


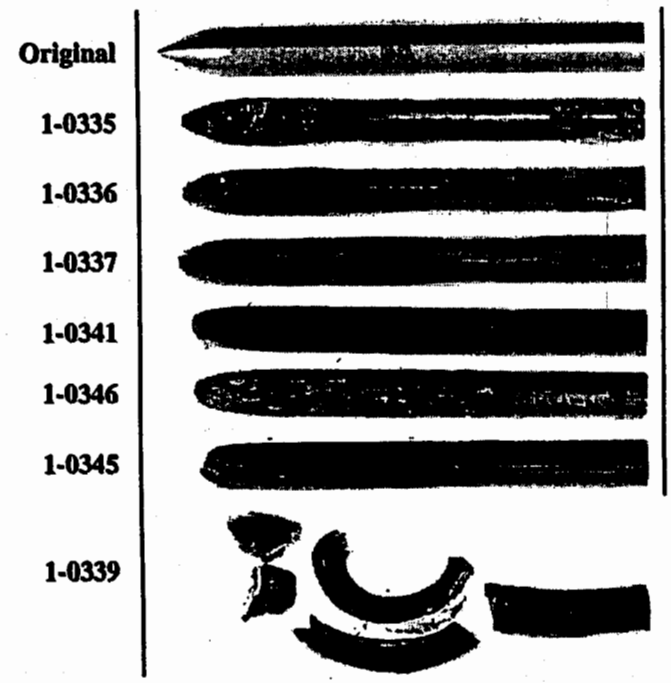




EPW Technology

AISI E4340 SAQ Steel Projectiles into SAC-5 Concrete





Technical accomplishments: Experimental data up to 3 km/s

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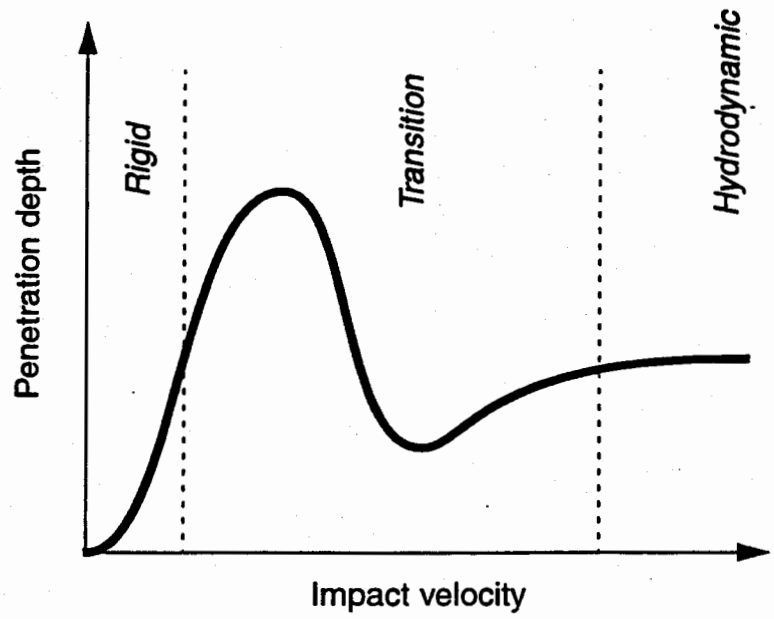
Computational Physics & Mechanics Department

- Existing data on high velocity penetration is fragmentary.
- Obtain a consistent set of data over a wide range of velocity.
  - Steel rods into aluminum blocks, 1-3 km/s.
  - For use in model validation.
    - Can we predict the expected maximum and minimum in the penetration depth curve as a function of velocity?
  - To be completed in FY96.



(Expected results)

FY96-97 planned work

- Improve and validate penetrator-target coupling algorithm, implement in ALEGRA.
- Get data for and thoroughly understand penetrator depth curve in transition region (steel -> aluminum).
  - Reproduce computationally.
- Incorporate into models what is learned from micrographic analysis and penetration data.
  - Physical models can be incorporated into any applicable code.

Resource Utilization

FY96		*5400 (Rogers)*	*9200 (Yarrington)*	*2100 (Hansen)*
		186,354	*233,478*	*223,839*
	Labor	*165,000*	*164,000*	*150,000*
	DC	*9,000 Travel*	*34,000 Contract*	*34,000 Tests*
	SC	*0*	*20,000 Computer*	*25,000 Shop*
				($30,000 Kelley)
				($80,000 Forrestal)
FY97		*230,000*	*225,000*	*221,000*
		45K Additional	*same*	*same*
		for test & travel		

LDRD Products - End FY97

1. *SNL/DIA Publication on Hard Target Characterization*
2. *Report on Military Mission Considerations for EPW Use*
3. *Report on Nose-Tip Enhancements for Increased Penetration*
4. *Summary of Scale Model Test Results*
5. *An Abrasion/Erosion Model that can be incorporated in Hybrid Numerical Codes for Penetration Analysis*

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Response to MAWG Questions

EXISTING NUCLEAR STOCKPILE OPTIONS
VARIABLE YIELD NUCLEAR EPW WEAPON

- **Design Information**
- **Weapons Output Information**
- **Effects/Effectivness**
  - **Fireball Effects**
  - **Groundshock**
  - **Fallout**
- **Collateral Damage**

DOE
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Fireball Effects/Effectivness

- Within some fraction of the radius of a fireball, all C/B agents will be destroyed
  - Steve Schaefer Presentation
- Proposed Fireball Kill Radius

$$R = 145(kt)^{0.4}$$

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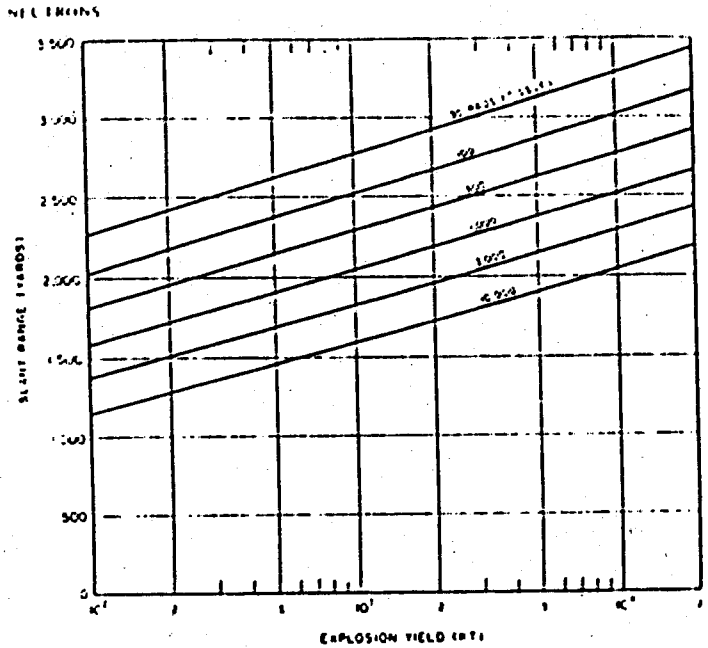
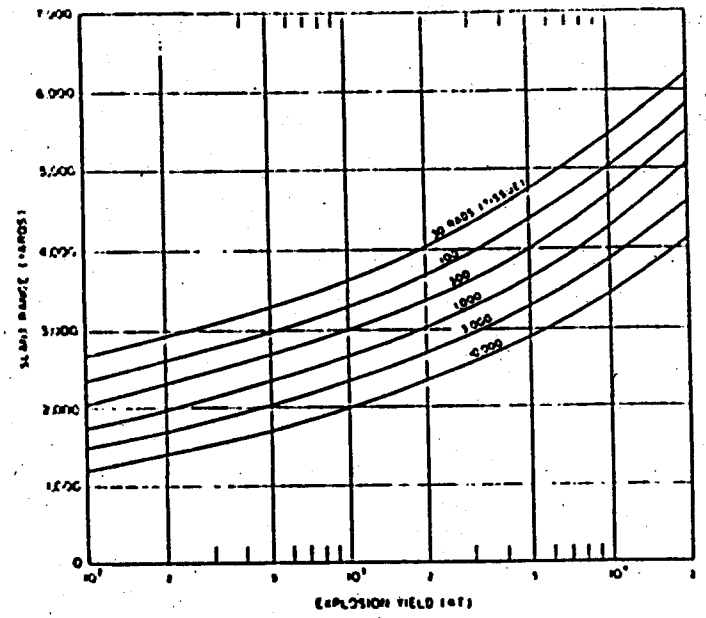


Slant ranges for specified neutron doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons based on 0.9 sea level air density. (Reliability factor 0.25 to 1.5 for most thermonuclear weapons.)



Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons with 50 percent fission yield, based on 0.9 sea-level air density. (Reliability factor from 0.25 to 1.5 for most thermonuclear weapons.)

Characteristics of Expected Radiation Field

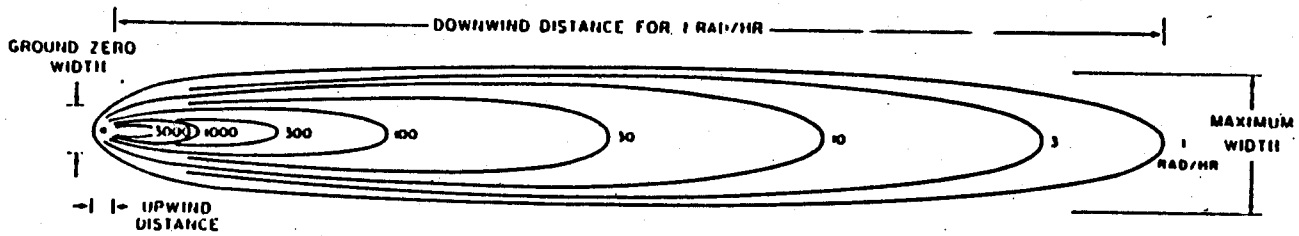


Illustration of idealized unit-time dose-rate pattern for early fallout from a surface burst (The contour dimensions are indicated for a dose rate of 1 rad/hr)

SCALING RELATIONSHIPS FOR UNIT-TIME REFERENCE DOSE-RATE CONTOURS FOR A CONTACT SURFACE BURST WITH A YIELD OF *W* KILOTONS AND A 15 MPH WIND

Reference dose rate (rad/hr)	Downwind distance (statute miles)	Maximum width (statute miles)	Ground zero width (statute miles)
3,000	0.95 $W^{0.40}$	0.0076 $W^{0.40}$	0.026 $W^{0.40}$
1,000	1.8 $W^{0.40}$	0.036 $W^{0.40}$	0.060 $W^{0.40}$
300	4.5 $W^{0.40}$	0.13 $W^{0.40}$	0.20 $W^{0.40}$
100	8.9 $W^{0.40}$	0.38 $W^{0.40}$	0.39 $W^{0.40}$
30	16 $W^{0.40}$	0.76 $W^{0.40}$	0.53 $W^{0.40}$
10	24 $W^{0.40}$	1.4 $W^{0.40}$	0.68 $W^{0.40}$
3	30 $W^{0.40}$	2.2 $W^{0.40}$	0.89 $W^{0.40}$
1	40 $W^{0.40}$	3.3 $W^{0.40}$	1.5 $W^{0.40}$

Fallout Criteria and Data

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DOE
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Impact Velocity (ft/sec)

Sandia National Laboratory

B61-11 Flight Characteristics

Los Alamos National Laboratory

DLM 7/1/96

SECRET

SECRET

WELD ON HP 9-4-20

OPTION 3 SECRET SMALL PARACHUTE/BALLUTE REPLACES CURRENT RETARDATION SYSTEM

RNE 9/28/94

Do 1
6/3

SECRET-FRD

Ground Shock Propagation (U)

DOE
(b)(3)

SECRET

SECRET

DoD 6(1)

Summary

- **On These Two Concepts Groups**
  - Design data are well developed, available
  - Weapon outputs, effects documented, modeled
    - Temperature history
    - Radiation outputs and spectra
    - Shock production
  - Major effort required is in area of
    - Estimating collateral damage/agent release
    - What is required for denial
    - What are consequences of agent release

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Agent Defeat Weapon Nuclear Baseline Assessment (U)

John St. Ledger
Steve Schafer
Chris Cunningham

November 19, 1996

M Burkwald 10/23/00

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TSA-3 Group Leader
Derived From: See References
TSA-3:9[illegible]-96

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CONCEPT EXPLORATION AGENT DEFEAT WEAPON

This page is unclassified.

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SNL-(97-180-J)-C-2100-1-2

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Baseline Analysis Roadmap

- Targets with additions
- Baseline weapons
- Codes
  - PDCALC6
  - CORES
  - SAMPLL & DUG 1C
  - KDFOC & NEMESIS
  - Agent release
  - SCIPUFF
  - QUICKSTRIKE & CTEM
- Target damage and collateral damage

[redacted] SNL-(97-180-J)-C-2100-1-4
SAB2001 32410000

FY 97 PROPOSED ACTIVITIES FOR AGENT DEFEAT WARHEAD STUDY (u)

[redacted] At this point we don't know which or how many of them will be selected for further development. DOE (b)(3)

For the concepts selected, calculations of the performance and collateral effects of the nuclear candidates against the Agent Defeat Weapon target set will be required. A few of the nuclear concepts will also require additional weaponization effort. This would consist of preliminary concept layouts and packaging studies.

[redacted] What would be required for those proposals is presented in more detail on the next page. DOE (b)(3)

Mel Buchwald 10/23/00
MB

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Sources: [illegible]-W[illegible] Class. [illegible] Guide, 1984

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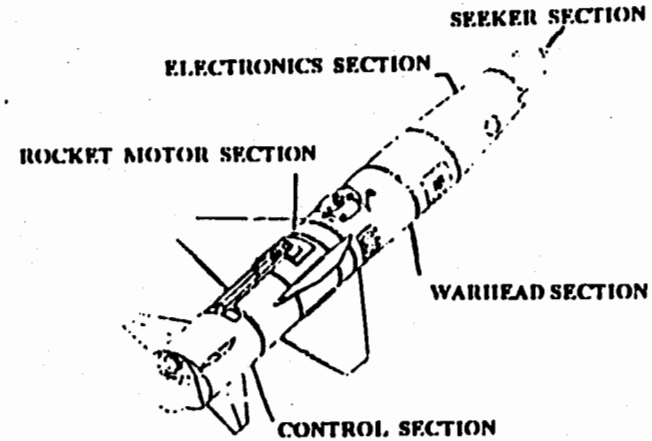
PLYWD TYPE

Concept Description

- Low-yield nuclear weapon
- Precision guidance
- Standoff capability
- AB/SB/EPW capability



AGM-142-Like Concept

Technical Issues

- pit production/use
- nuclear material production
- warhead certification
- nuclear tests

Benefits

- Neutralization of Bio/Chem agents
- facility and weapon destruction
- Long-term denial
- can defeat area targets
- mitigates target/critical element location uncertainty
- potential collateral damage reduction
- high confidence BDA
- compatible with current and proposed AF weapon systems
- can engage weapons in all stages from manufacture to deployment on delivery platforms

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Steven, A. Wright, March 12, 1996

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DEPARTMENT OF THE AIR FORCE
AIR FORCE MATERIEL COMMAND (AFMC)
NUCLEAR WEAPONS INTEGRATION DIVISION

28 June 1996

MEMORANDUM FOR SEE DISTRIBUTION

FROM: SA-ALC/NWIE
1651 First Street SE, B-20360
Kirtland AFB NM 87117-5617

SUBJECT: Agent Defeat Weapon (ADW) Concepts Working Group (CWG) Action Items CWG-6 and CWG-7

1. CWG #6 was held at Eglin AFB, FL on 7 May 96. At this meeting Action Items CWG-6 and CWG-7 were generated. CWG-6 tasks the Mission Analysis Working Group (MAWG) to review the ADW concepts and provide specific questions. The MAWG reviewed the concepts during 17-20 Jun 96. The specific questions from this review are included in the attachment. Response is requested by 31 Jul 96. Although some of the concept questions are unclassified, many of the responses will be classified. Please classify response accordingly with the ADW Concept Exploration Security Classification Guide.

2. Action Item CWG-7 tasks the CWG and MAWG Chairs to schedule a joint meeting to discuss the results from the effort identified in paragraph 1. Concept providers will be required to brief their responses to the questions during this meeting. The joint meeting is scheduled for 6-7 Aug 96 with an ADW Program Review scheduled on 8 Aug 96. Details for these meetings are forthcoming.

3. If you have additional questions please contact Don Erdmann, (505) 846-4001 x206, DSN: 246-4001 x206, FAX: (505) 846-4618.

(S) R K

DONALD R. ERDMANN
ADW CWG Chairperson

Attachment:
Specific Concept Questions (S)

M Bulwood 10/23/00

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ADW CONCEPT QUESTIONS
CONCEPT 27
Existing Nuclear Stockpile Options.

1. (U) QUESTIONS REGARDING PHYSICAL CHARACTERISTICS:

   a. (U) What are the external dimensions?

   b. (U) What is the case thickness?

   c. (U) What are quantity & characteristics of ADW materials?

   d. (U) What is the toxicity of the by-products?

   e. (U) What are the mass moments of inertia?

   f. (U) How much HE, if any, and what type?

   g. (U) What type of propellant is used?

   h. (U) What is the overall weight?

2. (U) QUESTIONS REGARDING FUNCTIONAL CHARACTERISTICS:

   a. (U) What volume or area is effected by the weapon?

   b. (U) How will dust, debris and other contaminants effect the system?

   c. (U) What weapon outputs should be associated with each weapon and yield combination?

   d. (U) What are the CEP's for each weapon?

   e. (U) What are the available fuse settings for each weapon?

3. (U) QUESTIONS REGARDING LOGISTICAL CHARACTERISTICS:

   a. (U) What restrictions will different weather conditions pose upon the concept?

   b. (U) What intelligence dependencies does the concept need (agent type, target structure, BDA)?

   c. (U) Does the concept need any special handling?

ADW CONCEPT QUESTIONS
CONCEPT 27
Existing Nuclear Stockpile Options.

d. (U) What is the shelf life of the system?

e. (U) What is the time needed to prepare the concept for a launch?

f. (U) What are the VN and GVN numbers for the targets?

4. (U) QUESTIONS REGARDING COST:

a. (U) What is the life cycle cost?

b. (U) What is the average unit cost?

c. (U) What is the disposal cost?

5. (U) QUESTIONS REGARDING PROGRAM MANAGEMENT:

6. (U) GENERAL COMMENTS:

a. (U) What type of testing has been completed?

b. (U) What is the availability of defeat mechanism raw material?

c. (U) Is there any reference material available?

d. (U) What is the impact of missing the target on weapon function?

e. (U) What are the characteristics of the expected radiation field?

f. (U) What delivery accuracy will be required?

g. (U) For any system or subsystem performance specifics, justify or substantiate how these claims were arrived at. Was it due to a system level test, subsystem level test, or was it simulated or analysis performed (i.e. DARPA, contracted, in-house).

ADW CONCEPT QUESTIONS
CONCEPT 27
Existing Nuclear Stockpile Options.

i. (U) Please relate a concepts effectiveness to the ADW consolidated target list? For the ADW consolidated target list, how many sorts of a given concept are needed to defeat or deny access to that target?

j. (U) Can you provide energy spectra that should be used for transport calculations in bunkers with shielding? Or will you do the calculations or the threat scenarios? (radiation concepts only)

k. (U) Quantify collateral effects. Estimate effects - are containers vaporized, ruptured, thrown about, etc? Give some specific examples.

l. (U) We need more data to substantiate the kill mechanisms from these concepts. The radiation contours can be assessed in a straight forward manner - but thermal kill is a very difficult area. Provide the details that lead you to state the fireball will kill all agents. Since heat kill is a time and temperature criteria, how much dispersed agent is pushed out by the shock wave before the fireball temperature kills it. The lethality estimates call for about 2000 degrees for several milliseconds. Can you detail how the material is entrained and show that a conservative analysis kills most agent.

m. (U) Vaporization is certainly a kill criteria. But if you loft globs of spore the heat will kill spore on the outside but given the low thermal diffusivity of spore, the agent in the center may still be viable.

n. (U) Provide some sure-thermal-kill radius based on hydrocode calculations of the shock wave from weapon detonation and fireball temperature.

o. (U) Need to address agent in containers that may be ruptured outside of this sure-kill zone. Please estimate the probability of container rupture.

p. (U) Please provide detailed fallout data on this concept to use as a measure of collateral damage.

ADW CONCEPT ANSWERS
CONCEPT 27 (U)
Existing Nuclear Stockpile Options
J. F. Cuderman, Steve Schafer, Al Baker—Sandia National Laboratories

1. (U) PHYSICAL CHARACTERISTICS

   a. (U) External Dimensions:
   B61-7: 142"long, 13.3" OD; B83: 145"long, 18"OD;
   W80 CM Warhead: 31.5 "long, 12.75" OD.

   b. (U) Case Thickness:
   Not Applicable to non-penetrator systems

   c. (U) Quantity and characteristics of ADW materials:
   Nuclear Package

   d. (U) What is toxicity of the by-products:
   Radiation

   e. (U) What are moments of inertia:
   B61-7: Pitch and Yaw: 819 lb-in^2; Spin: 15,000 lb-in^2
   B83: See Fig. 1

   f. (U) How much HE, if any, and what type:
   Not applicable to nuclear systems since it is not significant part of the ADW material

   g. (U What type of propellant is used:
   Not applicable to these nuclear systems

   h. (U) Overall weight:
   B61-7: 765 lb
   B83: 2467
   W80 CM Payload: 300 lb

2. (U) FUNCTIONAL CHARACTERISTICS

   a (U) Volume or area affected by weapon:
   Depends on yield, height of burst

   b. (U) Effect of dust, debris, and other contaminants:
   Little or none

   c. (U) Weapon outputs associated with each weapon and yield combination:

DERIVATIVE CLASSIFIER:
R. B. COX 2161, Adv. Sys. Development
Date: 8/1/96
Sources: SAND 79 - 2452, 7/81
SAND 77 - 0173, 2/78
CGW-5 Class. Pol. Guide 11/8

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Radiation, heat, blast , shock—will be provided in effects calculations

[redacted]

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a. (U) Restrictions imposed by different weather conditions:
Only those which affect delivery system.

b. (U) Required intelligence:
Target structure, BDA

c. (U) Special handling requirements
Approval by National Command Authority, Nuclear weapon handling procedures.

d. (U) Shelf life of the system :
Indefinite—intent is to maintain stockpile as long as necessary

e. (U) Time required to prepare for launch:
Depends on approval time, state of readiness of weapons and delivery systems.

f. (S) VN and GVN numbers for targets:
See **Attachment 1**

4. (U) Questions Regarding Cost:
These systems are already in stockpile. Therefore there are no development costs involved. In any event, costing is a DOE, not a laboratory, function.

5. (U) Questions Regarding Program Management
There are no questions regarding program management since the weapons are already in stockpile. Any program management issues are handled by the appropriate POG.

6. (U) GENERAL COMMENTS
a. (U) Weapons Testing Completed:
All tests required for certification of the weapons "pre-Test Ban".
b. (U) Availability of defeat mechanism raw material:
In stockpile

m. (U) Vaporization is a criteria, but spores heat resistant.....
See answer to 6-k., above.

n. (U) Provide some sure-thermal-kill radius based on the shock wave from weapon detonation and fireball temperature.
See 6-h.

o. ([redacted]) Estimated probability of container rupture outside of "sure kill zone":
Unity

p. (U) Detailed fallout data as a measure of collateral damage:
See Attachment 3 and Cris Cunningham's presentation.

ATTACHMENT3: Fallout Data

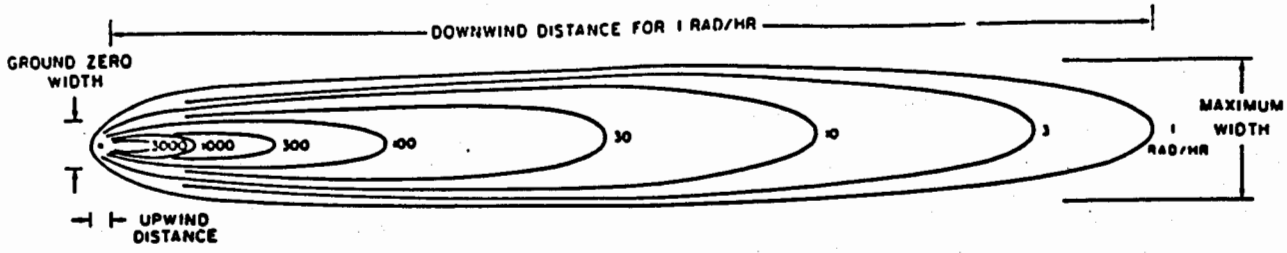

Illustration of idealized unit-time dose-rate pattern for early fallout from a surface burst (The contour dimensions are indicated for a dose rate of 1 rad/hr.)

SCALING RELATIONSHIPS FOR UNIT-TIME REFERENCE DOSE-RATE CONTOURS FOR A CONTACT SURFACE BURST WITH A YIELD OF W KILOTONS AND A 15 MPH WIND

Reference dose rate (rad/hr)	Downwind distance (statute miles)	Maximum width (statute miles)	Ground zero width (statute miles)
3,000	0.95 W[illegible]	0.0076 W[illegible]	0.026 W[illegible]
1,000	1.8 W[illegible]	0.036 W[illegible]	0.060 W[illegible]
300	4.5 W[illegible]	0.13 W[illegible]	0.20 W[illegible]
100	8.9 W[illegible]	0.38 W[illegible]	0.39 W[illegible]
30	16 W[illegible]	0.76 W[illegible]	0.53 W[illegible]
10	24 W[illegible]	1.4 W[illegible]	0.68 W[illegible]
3	30 W[illegible]	2.2 W[illegible]	0.89 W[illegible]
1	40 W[illegible]	3.3 W[illegible]	1.5 W[illegible]

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(U) INTRODUCTION

(U) Desert Storm experience alerted U.S. theater commanders to the fact that major deficiencies exist in our ability to detect and locate critical mobile targets on the tactical battlefield. Possible ways to reduce these deficiencies include the use of sensors of various types to detect and identify SCUDs (or other missiles) with enough timeliness and precision to cue effective counter-attacks before the missiles are launched. Issues pertaining to sensor capabilities and deployment in this situation were analyzed in Reference 1. Another possible defense is to use sensors to detect missile launch and communicate launch time and location information to missile defense systems that can intercept and destroy the missile in-flight. The effectiveness of this defense will depend on sensor and interceptor performance and deployment parameters. The path from concept to a fielded, effective system is arduous, but a simulation analysis, such as is reported here, can provide ballpark figures that will be useful to system designers and operational planners.

(U) This report, as indicated, describes the results of a simulation analysis to evaluate a sensor-to-shooter architecture designed to detect and destroy tactical ballistic missiles (TBMs) during their boost phase. To perform the analysis, the previously-developed SENsor Evaluation Model (SENSEM) code[2], which was written to simulate the detection and identification of critical mobile targets, such as SCUD launchers in transit, was ~~extended to simulate~~ launch detection and boost-phase intercept. DOD b(1)

nterceptor ability was estimated as a function of the time delay from missile-launch to interceptor cue.

(U) SCENARIO DEVELOPMENT

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(U) SENSOR DEPLOYMENT STRATEGY

(U) Seismic sensors that have been used in the past to detect and locate Lance missile launches at White Sands Missile Range (WSMR) typically use accelerometers and geophones to measure the low frequency signature of the acoustically-coupled seismic energy associated with the first burn of the rocket motor. Although propagation times are a function of terrain type, detection ranges of 8-10 kilometers have been demonstrated[4]

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in some of the tests conducted at WSMR. Based upon discussions with sensor hardware experts, a detection probability of 0.9 was assumed for launches within the maximum detection range of the sensor. Launches outside this range were given a detection probability of 0. A value of 10 km was used as the base case maximum detection range but was varied in subsequent cases in order to evaluate the sensitivity of sensor array performance to detection range.

though, that while coverage may be enhanced by closely spaced sensors, such spacing could degrade launch location estimation. This is an area for future study.

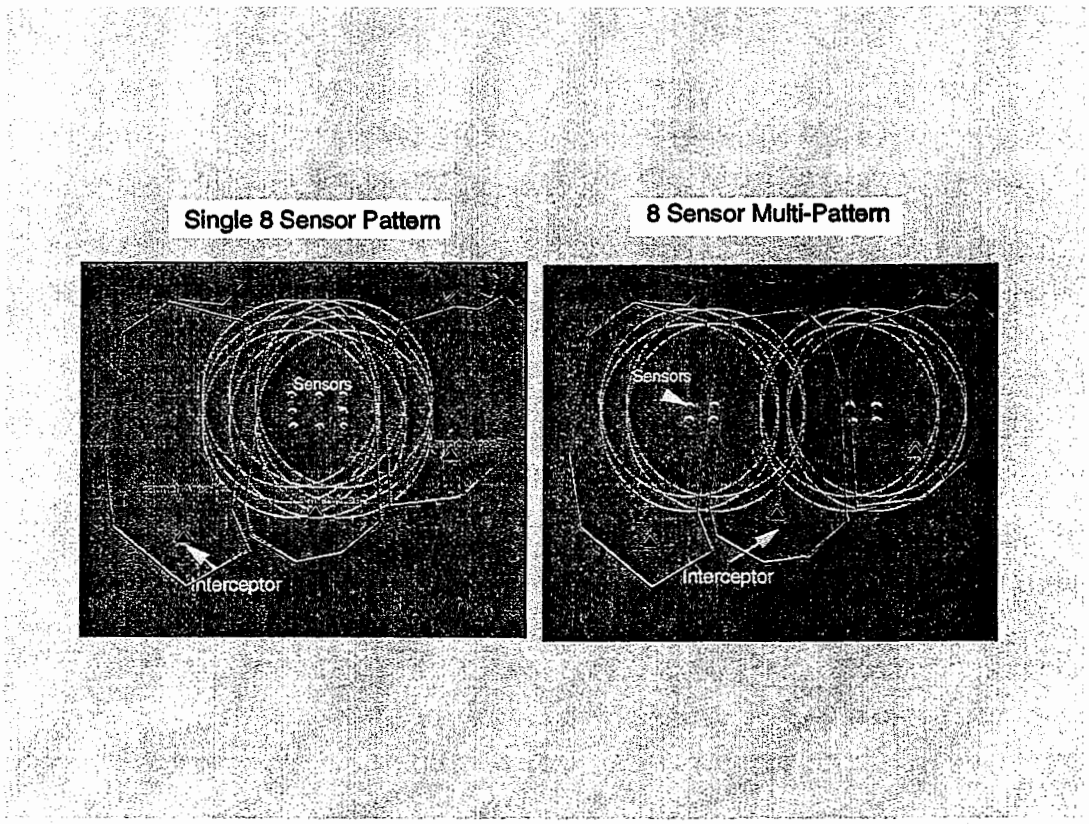

Figure 3. Deployment Patterns for 8 Sensor Array (U)

(U) SENSOR REQUIREMENTS FOR LAUNCH DETECTION AND LOCATION

(U) Sensor arrays were deployed across the three launch areas using the patterns discussed above and SCUD launcher tracks were generated using the SENSEM simulation. Multiple replications (50) were performed for a total of 200 launches and the percent of launches detected by 1,2,3,4,...., or 8 sensors was calculated. The base case results are shown in Figure 4 for a sensor maximum detection range of 10 km. No location solution is possible with less than 3 sensor detections, therefore the bar values for 0 (no detections) and 1 or 2 sensor reports represent detections only. The bars for 3,4,...., or 8 sensor reports represent the percent of launches for which detection <u>and</u> location estimates were made for the indicated array size. For example, for the 16 sensor array case, 19% percent of the launches were detected by only 2 sensors (no location solution) while 28% of the launches were detected by exactly 3 sensors and located after post-processing of the individual sensor data. The solid lines accompanying the bar charts sum the total percent of launches for which 3 or more and 4 or more sensors both detect and estimate launch location. As expected, the percent of launches for which position estimates are made increase as the number of sensors in the sensor array grows, e.g.

(U) Increasing the number of sensors in the array has the beneficial effect of improving the accuracy of the launch location estimate. In Figure 5, for all the cases where a location estimate was made, the conditional cumulative distribution of position errors is shown for the different size arrays. The results show, e.g., that the median estimation error is 400 m for 4 sensors, 100 m for 8 sensors, and about 30 m for 16 sensors and 24 sensors. It should be noted that large position errors can occur, e.g., in excess of 3000 meters. These situations almost always occurred when only three sensors detected the launch and the launch point estimation algorithm failed to find a local minimum (see Appendix).

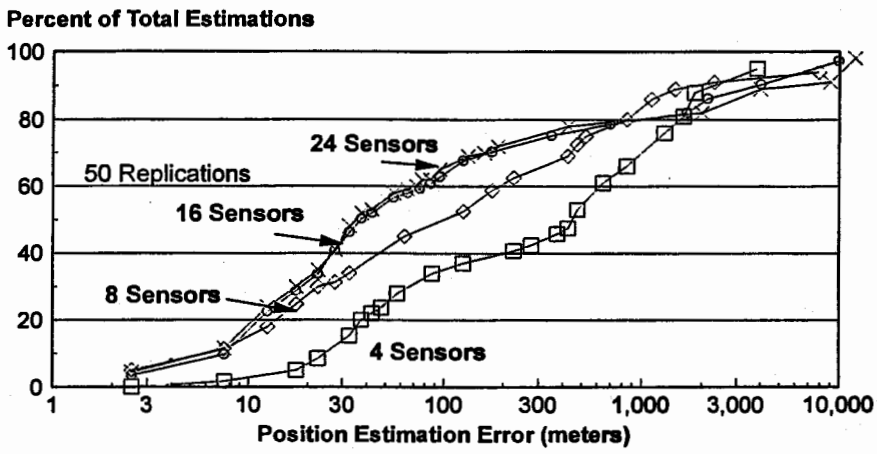

Figure 5. Distribution of Position Estimation Errors (U)

(U) SENSITIVITY OF SENSOR REQUIREMENTS TO DETECTION RANGE

(U) Additional calculations were made to assess the degradation in sensor array performance associated with smaller detection ranges. Although detection ranges of 8-10 km have been observed during test series, the base cases were rerun with a maximum detection range of only 5 km. The sensor deployment locations chosen for the base case (10 km detection range) were clearly not optimum for the 5 km case; therefore the off-line analysis was rerun for the latter case in order to determine more favorable sensor locations for use in the SENSEM model. The results of those calculations indicated that a deployment pattern similar to the base case was optimal for maximizing area covered by 3 or more sensors but modified by closer spacing between sensors.

(U) A comparison of sensor array effectiveness is shown in Figure 6 for both detection ranges. Sensor detection range is obviously a big driver in the performance of boost-phase sensor arrays. For example, with a detection range of 10 km, the 16 sensor array was able to detect and locate over 75% of the launches. However, when the sensor detection range was reduced to 5 km, only 20% of the launches were detected and located. Note that the area covered by a sensor is reduced by a factor of 4 when the detection range is halved, so, at least in the parameter region in which these calculations were done, there is a corresponding approximate factor of four decrease in the detect/locate probabilities.

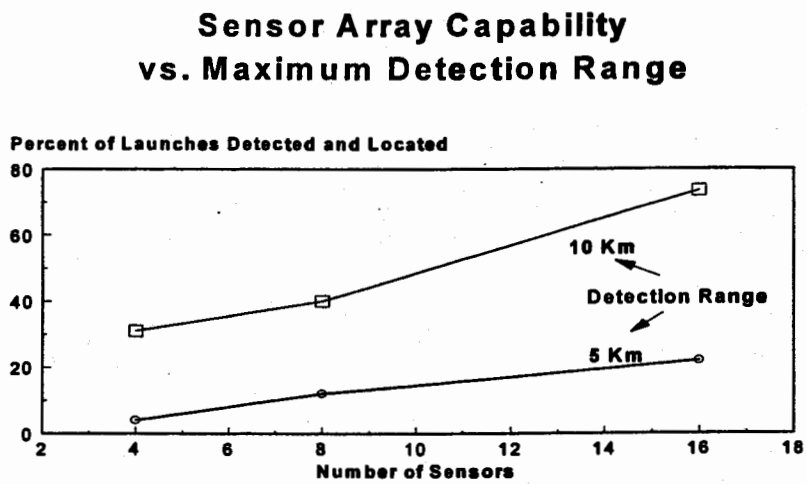

Figure 6. Maximum Detection Range Sensitivity (U)

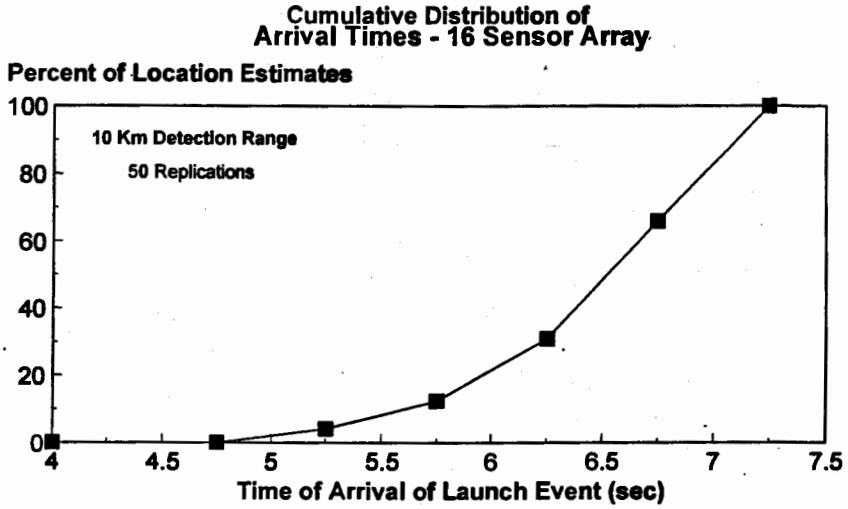

Figure 8. Maximum Arrival Times - 16 Sensor Array (U)

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(U) Detailed Command, Control and Communication (C3) architecture requirements for data transmission between sensors and interceptor platform were not considered in this study. Rather, it was assumed that a seismic sensor array could receive the launch signal

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(U) Air-to-Air Interceptor

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(U) CONCLUSIONS

(U) The results of this study indicate that a moderately small number of capable, reliable, well-placed seismic sensors could successfully detect and locate enemy TBM launches.

(U) The key assumptions underlying this conclusion area:

a. sensors can be suitably emplaced in the launch region and will be operational at the time of launch.
b. sensors will be able to identify TBM launches over the detection range and with the reliability modeled in the simulations.
c. the geology of the launch area is well-represented by the model used in estimating launch location.
d. there are no ambiguous signatures when near-simultaneous launches occur.

(U) In the baseline case, sensors with 10 km detection range and .9 reliability each covered about 25% of the launch area and a 16 sensor array was able to detect and locate ~75% of all launches. If the detection range is only 5 km, then only about 25% of the launches in the scenario studied can be detected and located. In general, launch detection

by four or more sensors is required to provide accurate location estimates, so the density and overlapping patterns of the sensors are important determinants of array performance. In this study, for 16 sensors the density is 16/(25*50)=1 sensor per 78 km^2, and this figure might be used to provide a rough estimate of sensor requirements in other launch scenarios. Neither the launches nor the sensors were uniformly distributed throughout the launch area in this study, so 'results may vary' in other applications.

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(U) In summary, two components of this proposed boost-phase sensor-to-shooter architecture were analyzed. The detection and location phase seems promising although some risks are inherent, such as geology uncertainty, and a variety of issues pertaining to sensor emplacement, performance, and data processing would need to be resolved. On

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DCD
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5. Ballistic Missile Threat Specification (U), BMDO, June 1994, Secret.

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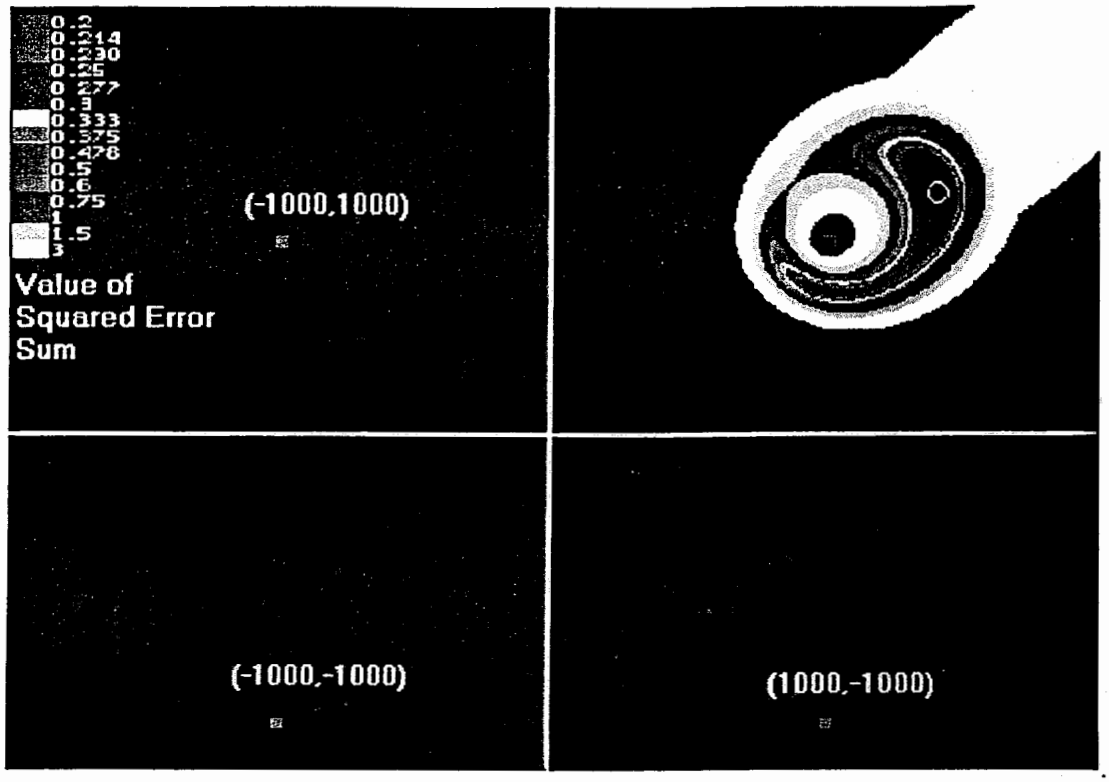

Figure A3. Multiple Minima on Cost Function

Launch Point Estimation for a Three Layer Model

Truth Model TOA:

The "actual" time of arrival (TOA) of the seismic signal at a sensor located a distance r from the source location is

$$\text{TOA} = t_{oa} = \frac{2d_1}{c_1 \cos\theta_1} + \frac{2d_2}{c_2 \cos\theta_2} + \frac{1}{c_3}\left[r - 2(d_1 \tan\theta_1 + d_2 \tan\theta_2)\right] \qquad (1)$$

where d is the thickness, c is the sound speed, and θ is the refraction angle at the respective layers.

Let θ_{1m} and θ_{2m} be the refraction angles in layers 1 and 2 which minimize t_{oa}. Then

$$\sin\theta_{1m} = \frac{c_1}{c_3}$$
$$\sin\theta_{2m} = \frac{c_2}{c_3} \qquad (2)$$

If c_1 or c_2 is greater than c_3, the minimum time path will never be through layer 3. Also,

acoustic time of arrival = r/c_0 (3)

surface wave time of arrival = r/c_1 (4)

1st refracted wave TOA = $\frac{2d_1}{c_1 \cos\theta_{1m}} + \frac{1}{c_2}\left[r - 2d_1 \tan\theta_{1m}\right]$ (5)

2nd refracted wave TOA =

$$t_{oa} = \frac{2d_1}{c_1 \cos\theta_{1m}} + \frac{2d_2}{c_2 \cos\theta_{2m}} + \frac{1}{c_3}\left[r - 2(d_1 \tan\theta_{1m} + d_2 \tan\theta_{2m})\right] \quad (6)$$

If more than three layers are included in the model,

nth refracted wave TOA =

$$t_{oa} = \sum_{i=1}^{n-1} \frac{2d_i}{c_i \cos\theta_{im}} + \frac{1}{c_n}\left[r - 2\sum_{j=1}^{n-1} d_j \tan\theta_{jm}\right] \quad (7)$$

The actual TOA will be the minimum of the above TOAs.

Measured TOA:

The "measured" TOA, t_{oam}, is obtained for each of the sensors by taking the corresponding t_{oa} and adding a random measurement error (standard deviation input by user) that represents the accuracy of the sensor. The smallest of the measured TOAs is taken to be a reference and a relative measured TOA, rt_{oam}, is obtained. Corresponding to these relative measured TOAs there are relative actual TOAs, rt_{oa}. The sum of the squared differences between these two values will be used to determine a launch point estimate.

Launch Point Estimate (LPE):

Let $rt_{oa}(x,y)$ be the actual relative TOA obtained when the source is located at (x,y). Then a two dimensional search is performed over a region determined by the maximum range of the sensors looking for the local minima of the function

$$L(x,y) = \sum_{k=1}^{n_s} \left[rt_{oak}(x,y) - rt_{oamk}\right]^2 \quad (8)$$

where n_S is the number of sensors within range of the source. An error is issued if n_S is less than three.

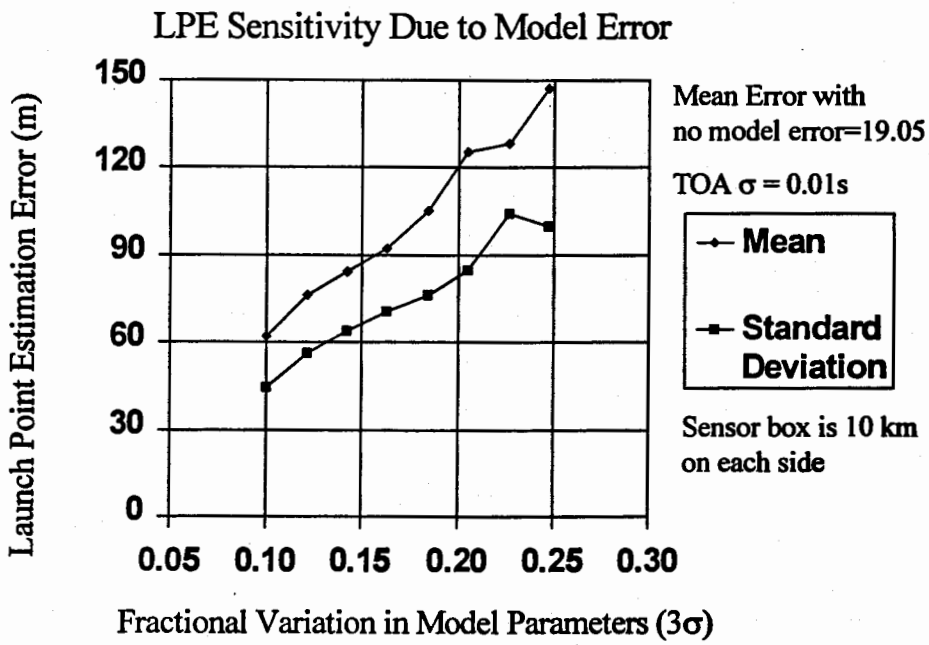

Figure A4. LPE Sensitivity - 10 km Case

A second case, with the sensors in a 2 km box, is provided in Figure A5 to illustrate the reduced sensitivity of the LPE when the sensors are more closely spaced.

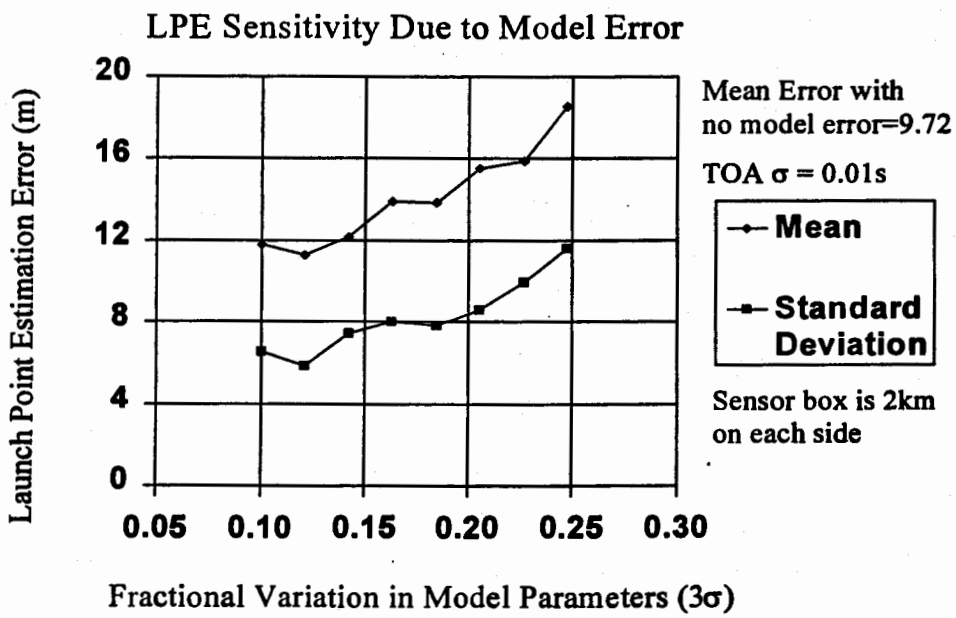

Figure A5. LPE Sensitivity - 2 km Case

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Sandia POC: Jon Rogers, MS 0419, Dept. 5412, (505)844-3872

[redacted]

DoD
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1. What initiatives are currently underway?

A. Tactical Unattended Ground Sensors (TUGS)

The TUGS program objective is to develop seismic, acoustic, and magnetic sensors for monitoring and characterizing underground facilities. Specific TUGS tasks are indications and warnings (detection of activity), equipment identification and location within the facility, and battle damage assessment. Hand emplaced sensor units will be developed for the Counterproliferation Advanced Concept Technology Demonstration (ACTD) in FY98. An air delivery capability will be developed in late FY98 and FY99.

Sponsor: Defense Nuclear Agency

POC: Brad Parks, (505)844-6883

B. Sensor Evaluation Model (SENSEM)

Sandia's SENSEM computer simulation model provides a means to investigate several important aspects of underground facilities. [redacted] Users also deploy packages of various types of ground-based sensors to collect intelligence on vehicle movements.

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Classified by: R. C. Eastering, Mgr., New Initiatives Dept. 5412, 4/10/96, Derived from: TCG/UC-1 Declassify on: 4/09/2006

Using SENSEM, users can represent operational activities of critical systems such as Multiple Rocket Launchers and tactical missiles as they move from underground hide sites to firing positions and return to hide sites. The utility of ground-based sensors can be evaluated in identifying and initiating the engagement of these targets during windows of vulnerability.

SENSEM can also be used to represent military and civilian traffic on the road network to include traffic patterns that might be characteristic of critical underground facilities. From these representations, investigations can be conducted of our ability to identify the location and operational status of important facilities through analysis of traffic patterns.

POC: Jim Crowther, (505)844-1206

C. Remote Induction of Signals into Power and Communication Lines

DOE-supported technology presently being developed addresses close-in survey to detect and characterize underground facilities. The present survey capability is very limited for covert operations. However, a closely associated capability has been demonstrated to be technically viable in the course of detecting and characterizing underground structures. This capability is remote signature coupling for two-way communication into and out of underground structures. The latter capability can support such intelligence needs as: (1) remote location of previously intercepted equipment acquired by a hostile operation and placed in service on the power grid at an unknown location; (2) covert transmission of operative messages or information from clandestinely installed sensors inside a facility; (3) intra-facility/sensor communication; (4) remote interrogation of a suspect power grid to estimate its linear extent to unknown termination points; and (5) (not yet demonstrated) remote imaging of the physical location and distribution of the power grid through induction of highly unique signals onto the suspect grid to facilitate remote tracking of segments of high interest.

POC: Dan Cress, (505)844-7182

D. Coherent Change Detection (CCD)

CCD is a technique that uses 2 complex radar images in a way that permits the detection of extremely subtle changes in the earth, e.g., vehicles traveling on dirt roads. This technique is currently being used to detect evidence of activity around sites such as chemical and biological facilities.

POC: Tom Prevender, (505)844-8768

E. Airborne Multisensor Pod System (AMPS)

AMPS consists of three pods carried on a P-3 Orion aircraft. AMPS Pod 1 contains a Synthetic Aperture Radar (SAR), AMPS Pod 2 contains a Multisensor Imaging system (MSI), and AMPS Pod 3 (in development) contains Effluent Species Identification (EFI) sensors. The data from the AMPS Pods can be used for Coherent Change Detection (CCD), or multisensor data fusion. The SAR Pod is being upgraded to an Interferometic SAR (IFSAR) using two antennas which will result in high-quality terrain elevation maps (3-D). AMPS has been used to observe underground facilities at the Nevada Test Site (NTS) through characterization of surface features such as ground subsidence, adit identification, and muck pile changes.

POC: Bob Huelskamp, (505)844-0496

F. Gravity Gradiometry

Variations in the local gravity field can be used as indicators of voids or structures underground. Measurement of the gravity field and its gradient can locate underground structures. Recent work has been directed toward both the improvement of the gravimeters used to measure the gravity field and the signal processing algorithms used to analyze the data.

POC: Bob Asher, (505)844-5900

2. What enhancements are needed?

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3. What special collection efforts need to be maintained/established/enhanced?

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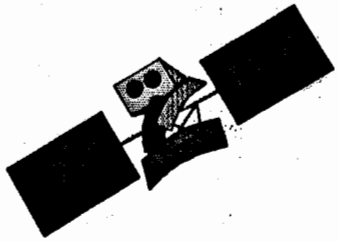
Micro Sensor Capabilities

- Imaging
- Seismic
- Acoustic
- Chemical
- Biological
- RF Tags
- Electromagnetic Field
- Radar
- Nuclear
- Accelerometer



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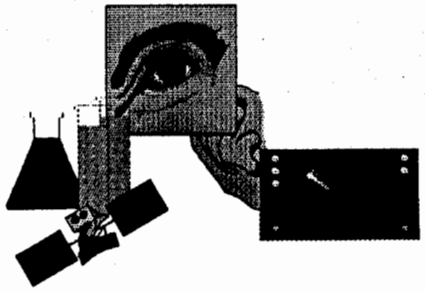
Sensor Fusion Process

Estimate Target Site Characteristics
Knowledge of Appropriate Sensor Measurands

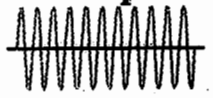
Risk Assessment
Sensor Data Acquisition Plan
(Sample Rate, Patterns, Filters, etc.)

New Estimates



New Paths/
Sensing Locations

Interpretation of Raw Data Using:



- Expert Systems
- Physical Models
- Statistics
- Learning Algorithms

(Neural Nets, Genetics, etc.)

Microbot Paths/Sensing Locations
Sensor Data Acquisition Control

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