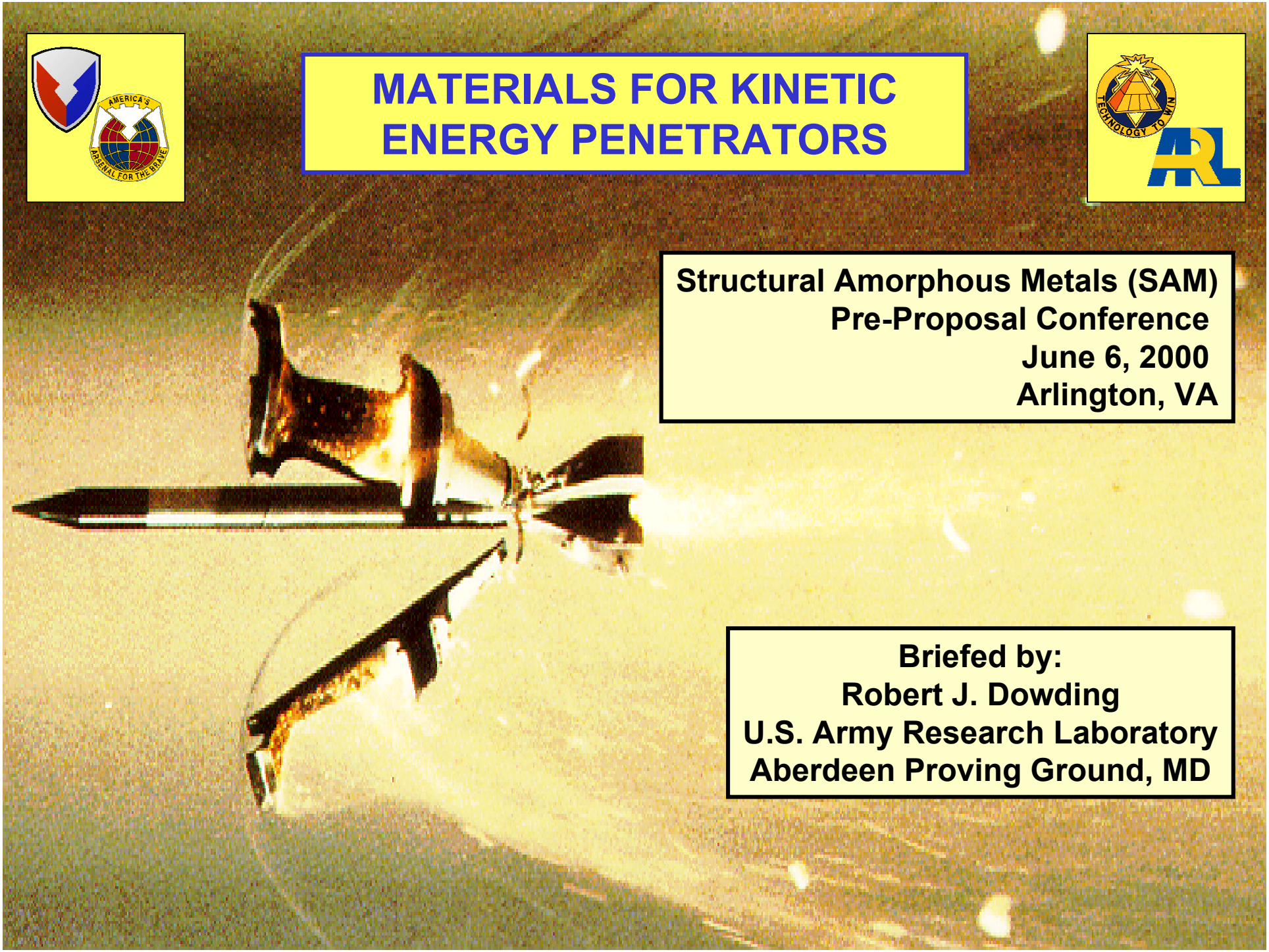

MATERIALS FOR KINETIC
ENERGY PENETRATORS
Structural Amorphous Metals (SAM)
Pre-Proposal Conference
June 6, 2000
Arlington, VA
Briefed by:
Robert J. Dowding
U.S. Army Research Laboratory
Aberdeen Proving Ground, MD

PURPOSE OF BRIEFING

Information, Awareness, Technical Background

Introduction
- The Kinetic Energy Application
- Material

Development of Alternatives
- Historical Perspective

Opportunities

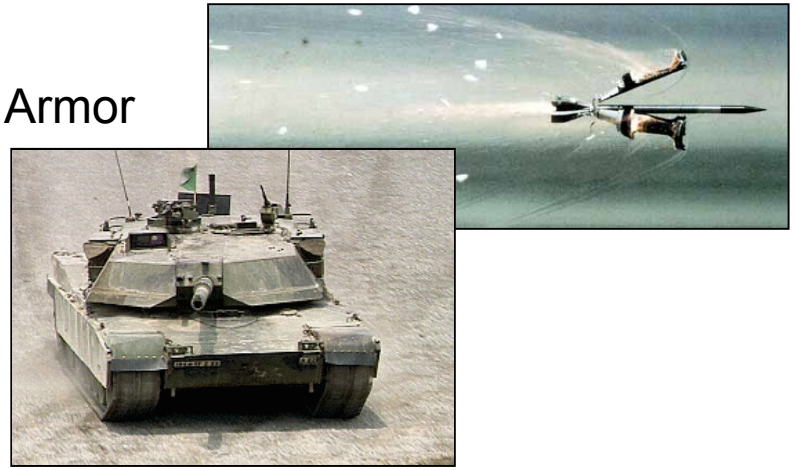
KINETIC ENERGY PENETRATORS

APPLICATION OF TUNGSTEN HEAVY ALLOYS

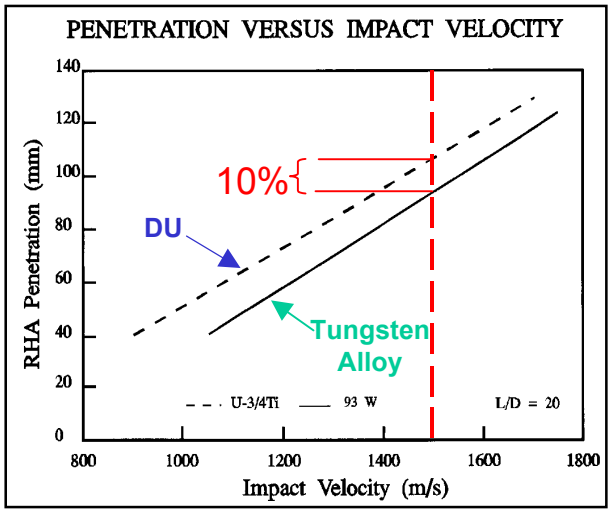
Kinetic Energy Penetrators
Fired from M-1 Tank Cannon

THE KINETIC ENERGY PENETRATOR APPLICATION

Application:
Kinetic Energy Penetrators for Defeat of Armor
Examples: M829, M919, GAU-8



Benefit: Depleted uranium alloys out perform tungsten alloys by 10% at ordnance velocities.



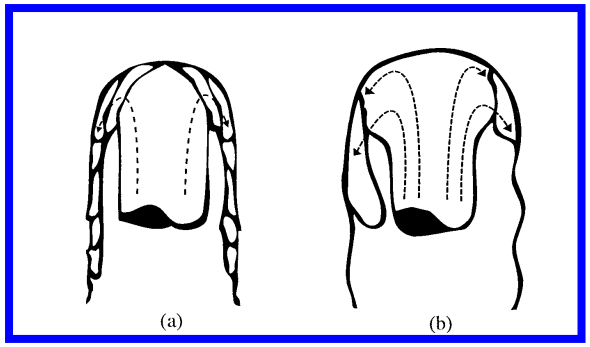
Drawbacks:

Health & Safety
Cost of Clean-up
Environmental Impact
Political

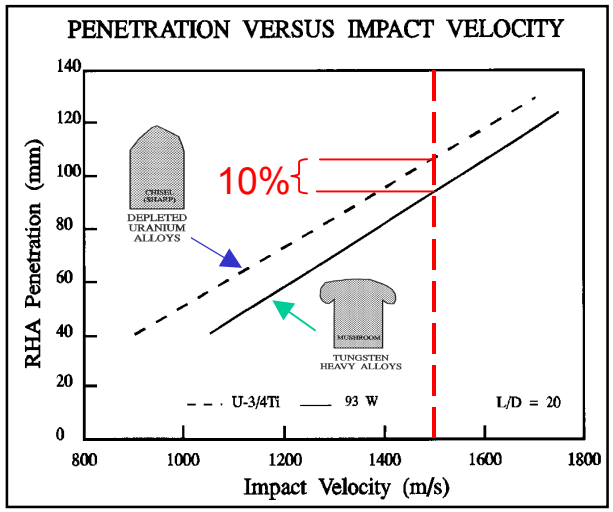
DEPLETED URANIUM vs. TUNGSTEN

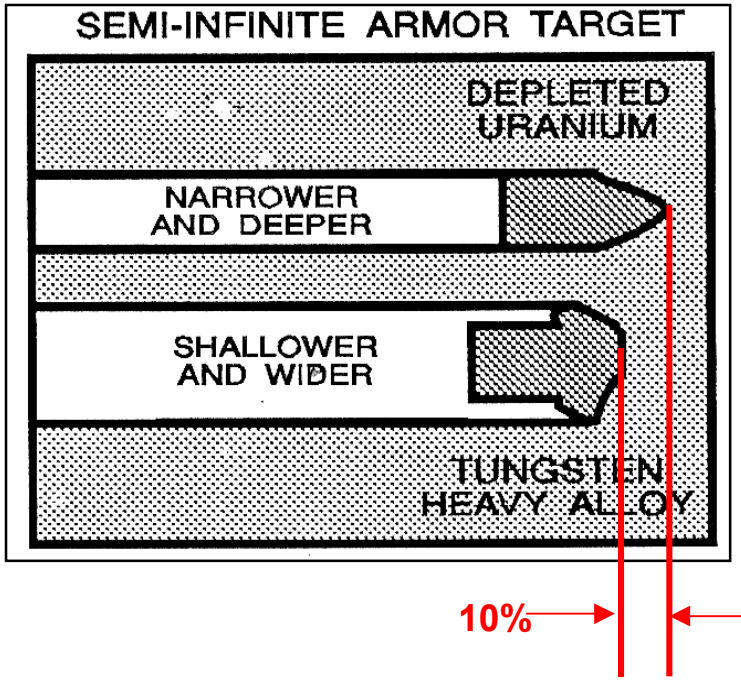
CURRENT MATERIAL AND DEFORMATION BEHAVIOR

- DU SHEARS
  - REMAINS SHARP
  - NARROW CHANNEL
  - DEEP CAVITY
- WHA MUSHROOMS
  - BLUNT NOSE
  - WIDE CHANNEL
  - SHALLOW DEPTH



Depleted Uranium (DU) | Tungsten Heavy Alloy





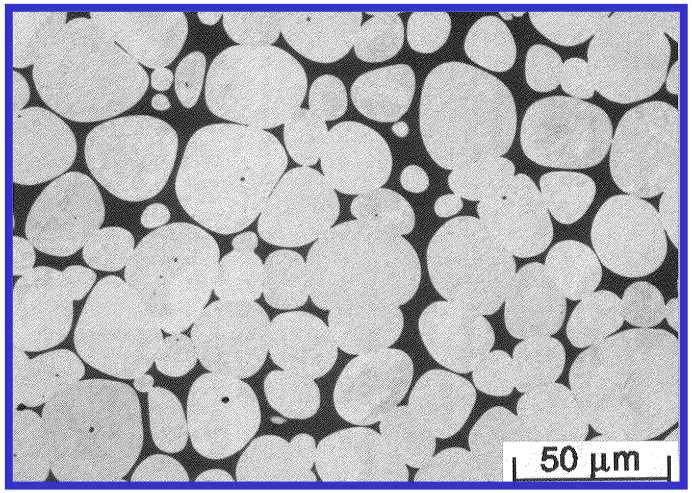
Tungsten Heavy Alloys

Alloys typically based on tungsten, nickel and iron.

- Two-phase composite structure.
- Primary phase: tungsten.
- Matrix can contain Ni, Fe, Co, Cu, Cr, Ag in various combinations.
- One common alloy 90W-7Ni-3Fe.

Primary phase: Essentially pure tungsten.

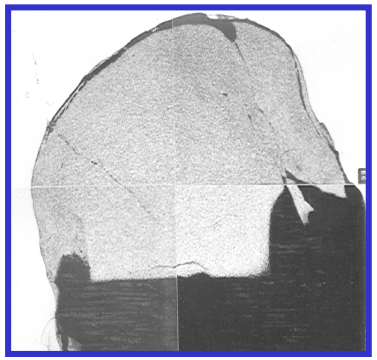
Matrix phase: 50% Ni, 25% Fe, 25% W

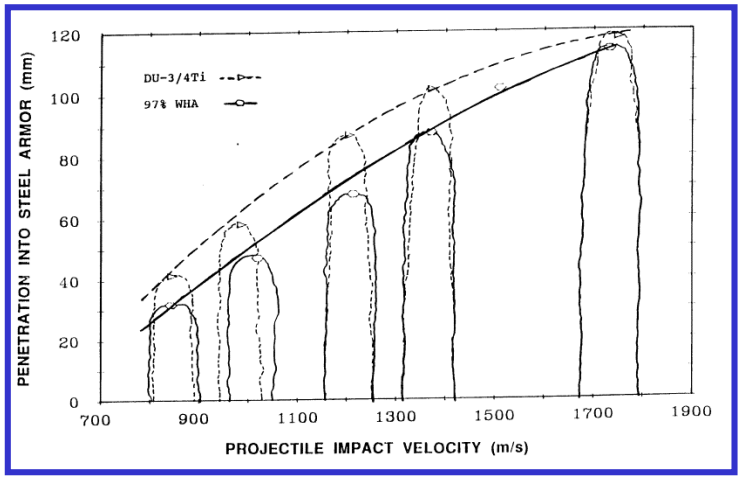


Typical Tungsten Heavy Alloy Microstructure, as-sintered

WHY ARE URANIUM ALLOYS PREFERRED?

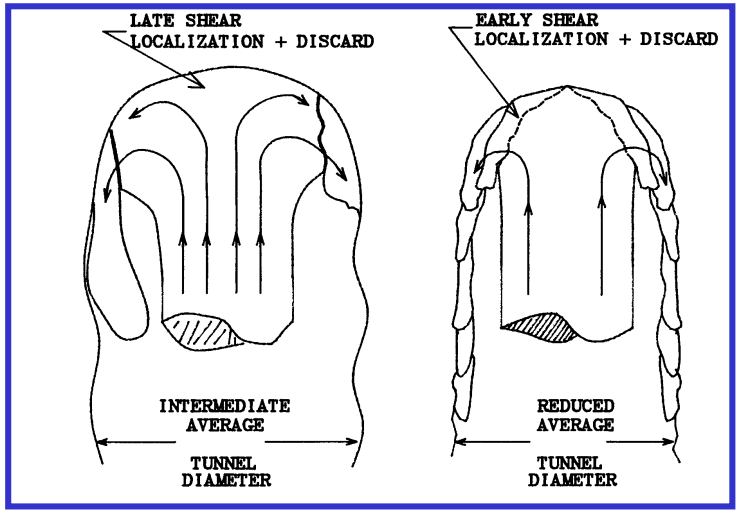
Flow and Failure of High Density Penetrator Materials





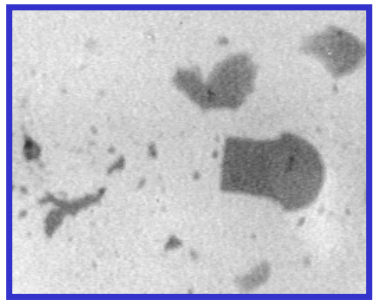
TUNGSTEN HEAVY ALLOY

- BLUNT NOSE
- WIDE CHANNEL
- SHALLOW DEPTH

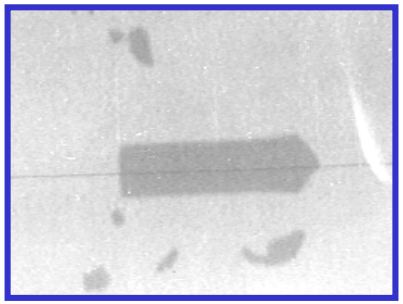


DEPLETED URANIUM ALLOY

- REMAINS SHARP
- NARROW CHANNEL
- DEEP CAVITY



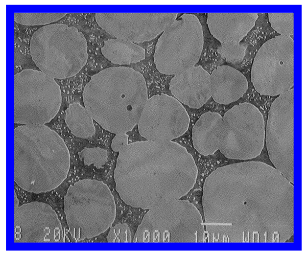
W-Ni-Fe



U-8Mo

TUNGSTEN HEAVY ALLOYS AND TUNGSTEN BASED COMPOSITES

Change Flow & Failure Behavior of W-Composites Through Alternative Matrices



TUNGSTEN HEAVY ALLOYS

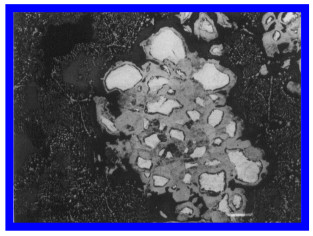
TUNGSTEN BASED COMPOSITES

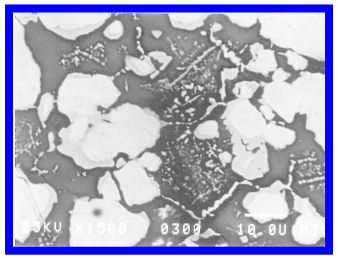
- Replace matrix with materials that deform like DU.
- Proof-of Principle (WHA-DU composite).

Candidate materials have physical properties similar to DU.

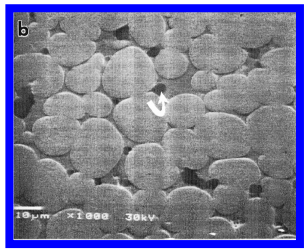
- Titanium and its alloys.
- Hafnium containing alloys.
- High strength steel.

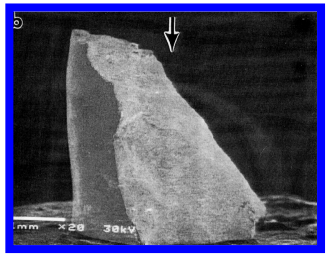
Materials known to undergo adiabatic shear in other applications.





W-Hf-Ti

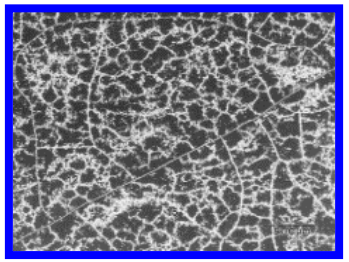




W-Ni-Fe-Al

Single crystals aligned [100] on axis.

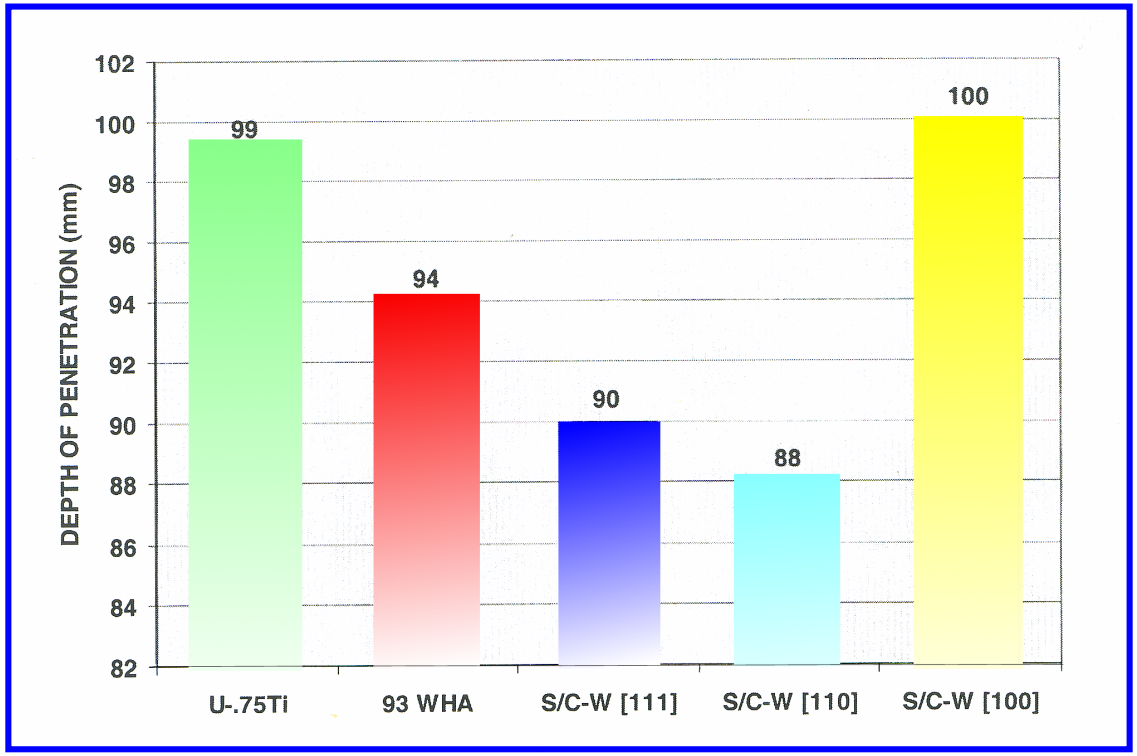
- Flow Anisotropy



S.C. W-[100]

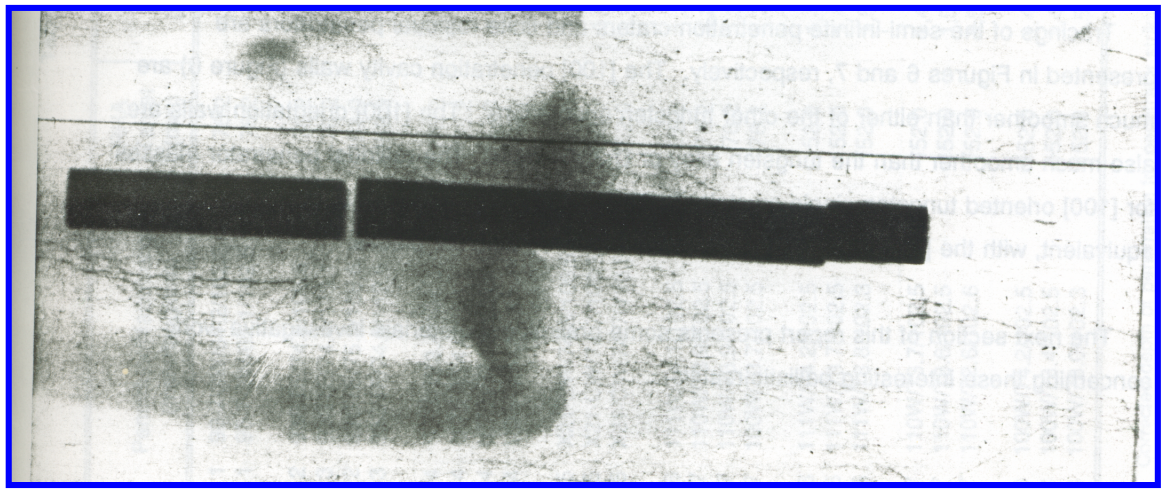
Ballistic performance testing, to date, indicates insufficient improvement in deformation behavior for any tungsten based penetrator.

BALLISTIC RESULTS
DEPTH OF PENETRATION (DOP)
VARIOUS HIGH DENSITY MATERIALS



Tungsten single crystal performance in depth of penetration studies is on a par with depleted uranium.

LAUNCH FAILURE OF [100] TUNGSTEN SINGLE CRYSTAL



Mechanical properties of tungsten single crystals are generally insufficient for ballistic launch and interaction with complex targets

QUARTER-SCALE BALLISTIC TESTS

Conventional and Experimental Alloys

65g, L/D=15 rods vs. 76.2mm RHA

Penetrator Type	Composition	Density (g/cc)	Limit Velocity (m/s)
Baseline WHA	90W-9Ni-1Co	17.15	1390
Alternate Hf. Alloy Matrix	80W-20HB3	17.0	1350
Alternate Matrix	NIST W-Cu-Ni-Al (mech. alloyed)	15.2	1347
U-3/4Ti		18.6	1260
U-8Mo		17.2	1300

TUNGSTEN BASED K.E. PENETRATOR DEVELOPMENT

The Army needs to develop an environmentally “green” kinetic energy penetrator material because external forces may seek to remove depleted uranium (DU) as a material available for this application for the following reasons:

- Health
- Safety
- Life Cycle Cost
- Environmental
- Political

It is our intention, through a thorough research and development program, to place tungsten based materials in the technological position to replace depleted uranium in future systems.

ARL ACTIVITIES IN K.E. PENETRATOR MATERIALS DEVELOPMENT

- Depleted Uranium-Vanadium Alloys.
- Equi-Channel Angular Extrusion (ECAE).
- Bulk Amorphous Alloys
- Nanocrystalline Materials
- Jacketed Penetrators

Materials For Ballistic Testing in FY00

Single Crystal Tungsten Alloy; W-6Ta

Bulk Amorphous Alloy & Composite

Deformation Processed; ECAE WHA

Non-Beryllium Bulk Amorphous Alloy

Novel Process; U-3/4Ti

ARL Alloy; U-V

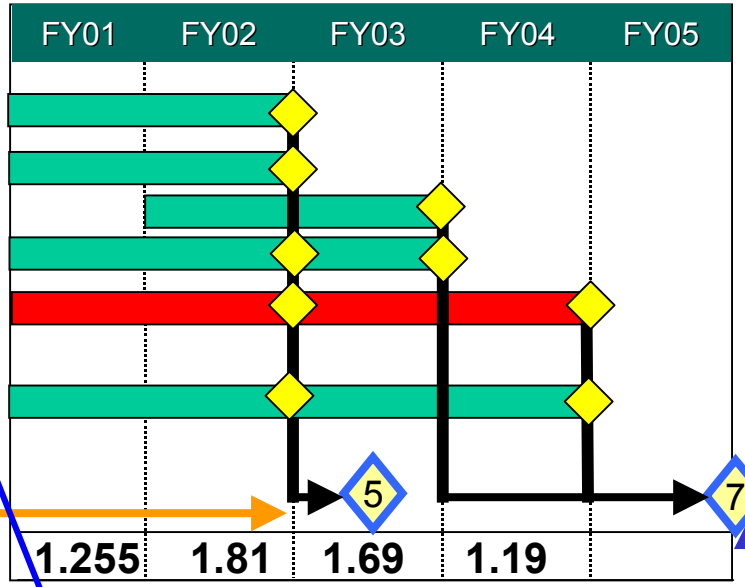
FY01 Direction will be Based on Test Results

Enabling Lethal Mechanism Technology for Target Defeat

ARDEC STO III.G.17: Ammunition Suite for Multi-Role Cannon
AMRDEC STO III.G.18: Compact KE Missile Technology

Activities

- WHPR02A Novel LM's for KE Missiles**
- WHPR02B Jacketed Penetrator
- WHPR02C Enh. Behind Armor Effects
- WHPR02E Initiation of Expl. Armor
- WHPR04A, B, C Improved High Density Material (Tungsten & DU)
- WHPR04F Simulation/Modeling for Optimum Properties
- ARDEC FCS Munitions STO Milestones



Funding Current Program

** Funds are part of CKEM STO.

Lethal Mechanism Demo - TRL5

Integrated Cartridge Demo -TRL 7

Improved Alloy Development Meets FCS Timelines

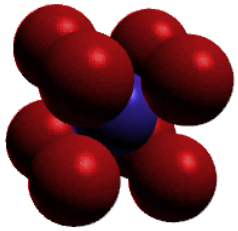
ARDEC Will Wait Until FY04 for New Material to "Drop-In" Their System

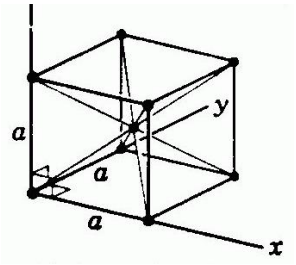
TUNGSTEN PENETRATOR MATERIALS DEVELOPMENT

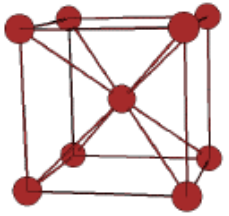
- The Army has conducted extensive conventional materials development over the last 25 years.
- DU is still better than tungsten.
- ARL is currently pursuing several non-conventional materials development programs to improve the ballistic performance of tungsten-based materials.

AMORPHOUS ALLOYS ARE DIFFERENT

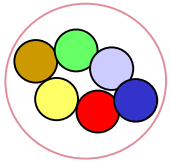
Crystalline Solids Have Periodic Arrays of Atoms

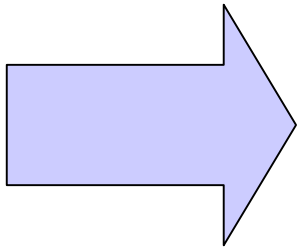


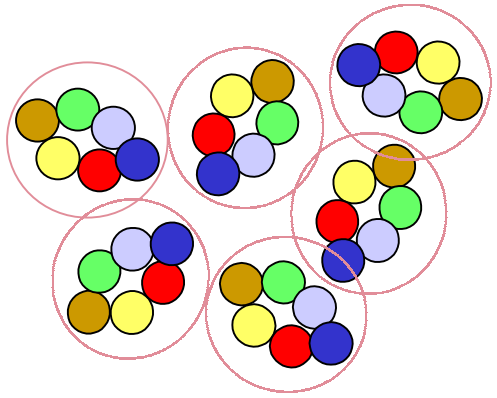




Amorphous Alloys Have non-Periodic Arrays of Atoms

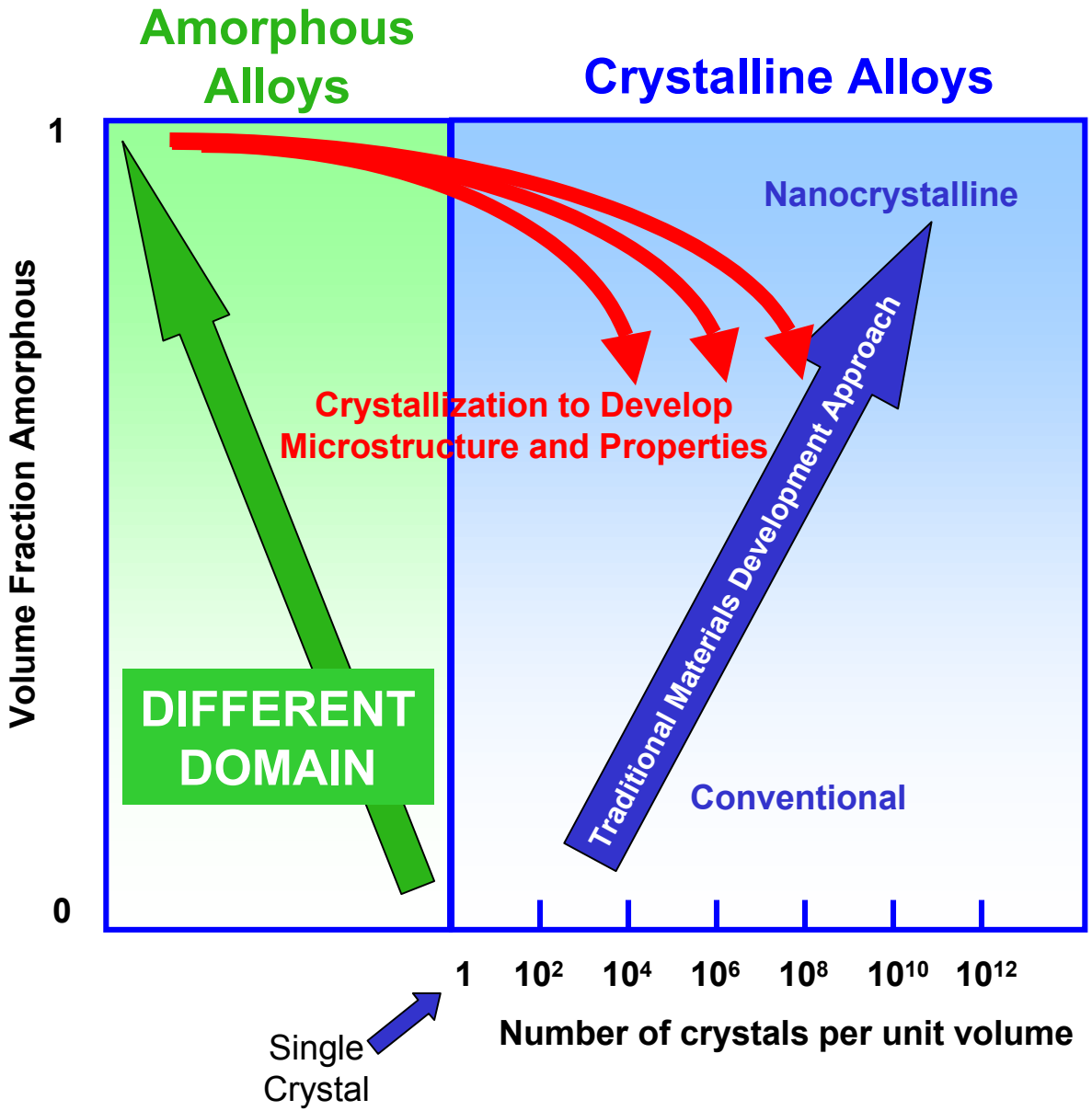






6 component system

PROPERTY AND MICROSTRUCTURE SELECTION

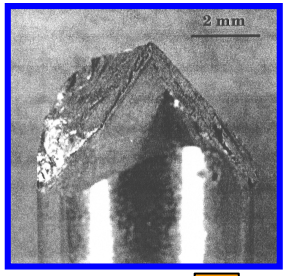


Adapted from Chart by
Leo Christodoulou, DARPA

BULK AMORPHOUS ALLOYS

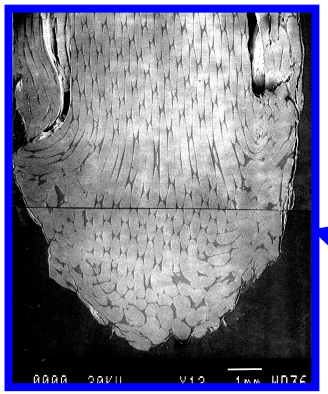
Amorphous matrix tungsten based composites.

Uranium-Like Behavior
I.e., Self-Sharpening



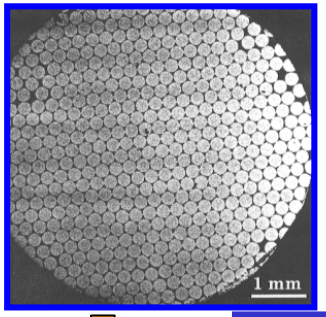
Chisel nose on bulk Amorphous alloy

- Higher density
- Improved Mechanical Properties



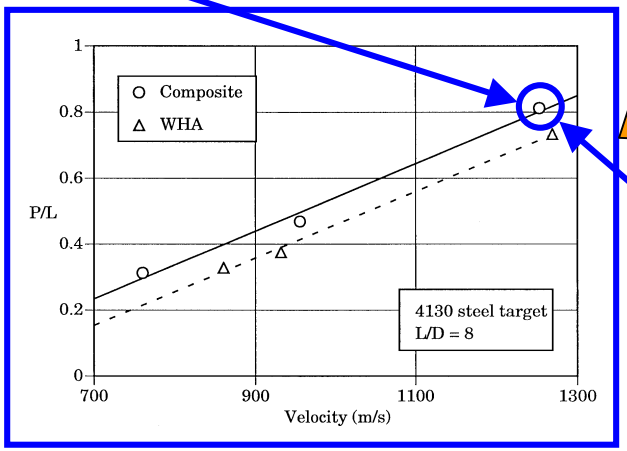
- ARO funded, CalTech development.

Zr-Ti-Cu-Ni-Be bulk castable amorphous alloy.

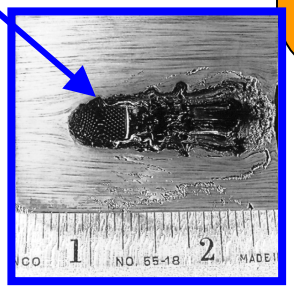


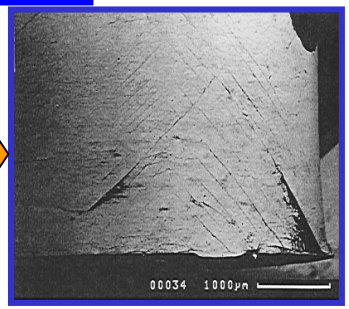
Tungsten wire/ amorphous alloy composite.

80% wire reinforced.



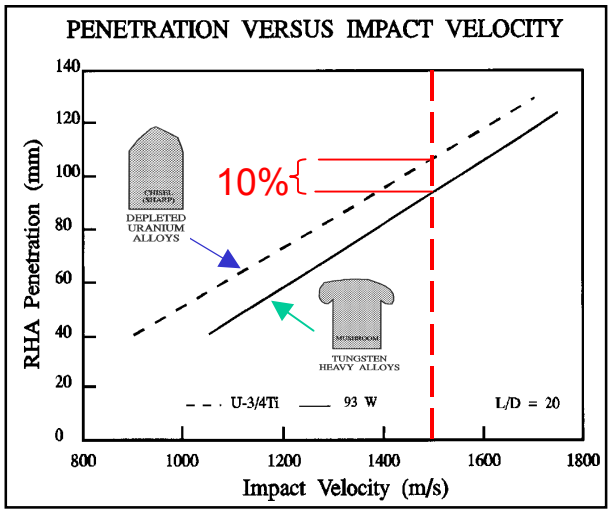
Depth of penetration performance testing results. From ARO grant to CalTech (W. Johnson)





40% W wire – Vitreloy

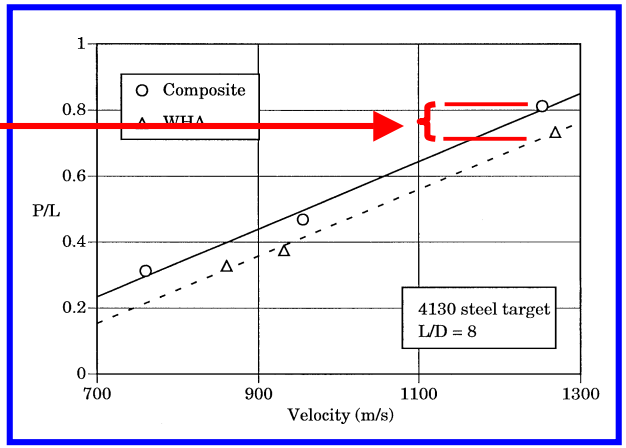
We can reproduce uranium-like behavior with a non-uranium material.



Tungsten versus Uranium

Is this the 10% Gain We Are Seeking?

MAYBE!!



BULK AMORPHOUS ALLOY ISSUES

- Beryllium Content of Current Compositions
- Density of Bulk Amorphous Alloy
- Materials Cost
- Critical Cooling Rate
- Mechanical Properties for Ballistic Performance
  - Quasi-static and high strain rate
  - Launch and terminal ballistic properties
- Compatibility with Reinforcement Materials

ALTERNATE AMORPHOUS ALLOY COMPOSITIONS

- There are numerous amorphous compositions previously discovered.
- It is highly likely that there are other compositions
- Wide range of mechanical property combinations.

IT IS PROBABLE THAT A NEW ALLOY WITH THE DESIRED FEATURES CAN BE IDENTIFIED.