

Comprehensive Environmental Assessment of Engineered Aluminum Nanoparticles in DoD Materiel: Evaluation before Acquisition

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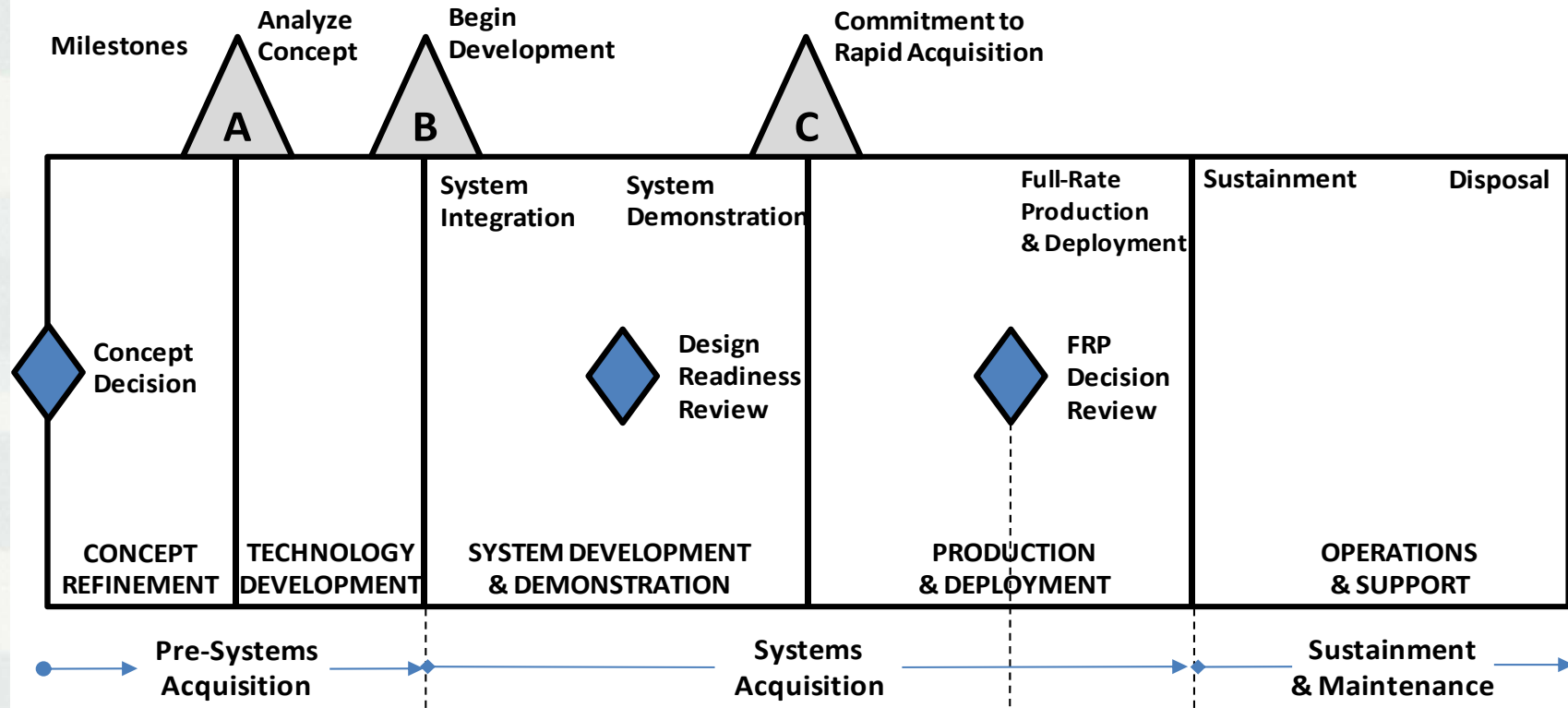


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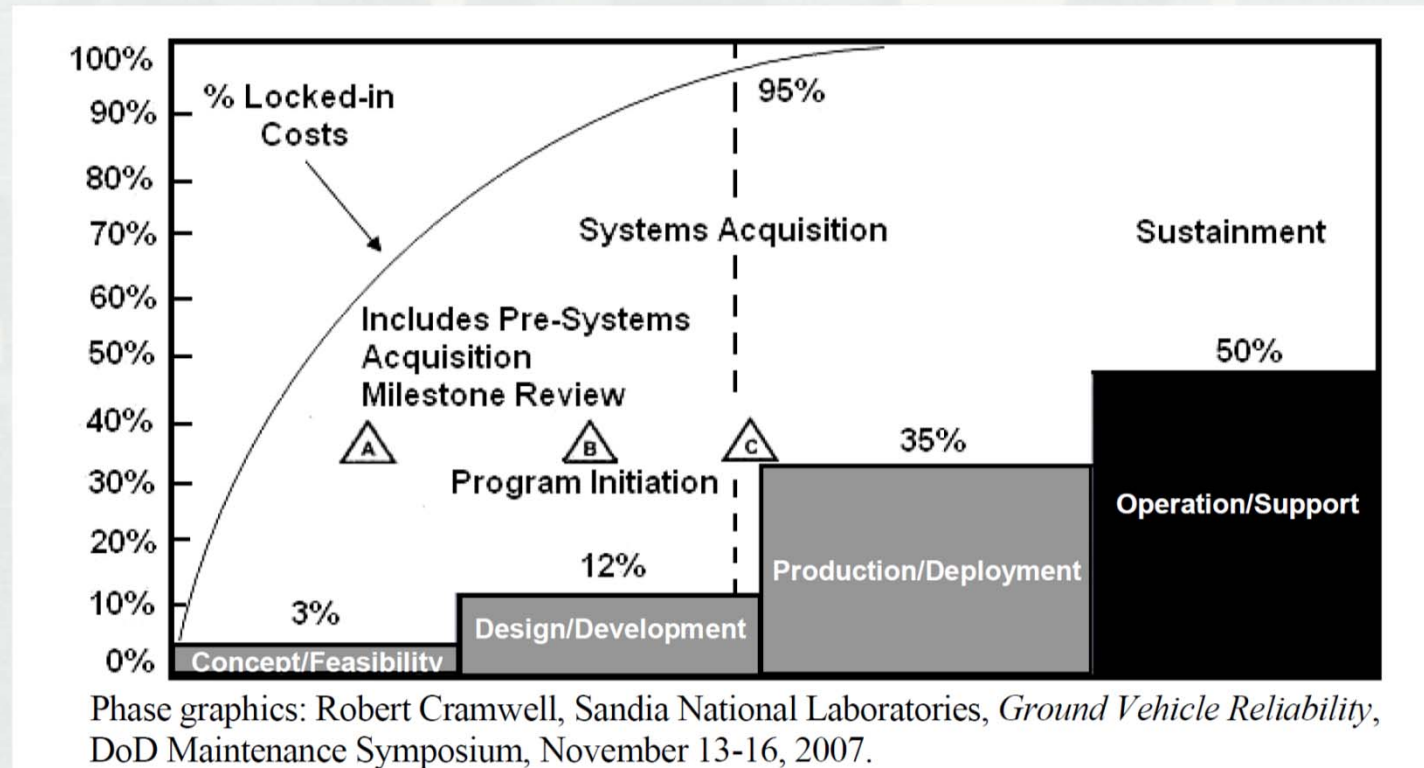
Stages of Acquisition Process Benefiting from Environmental Hazard Assessment



Technology development and acquisitions process. Adapted from Mike McDevitt, Installations Management Command



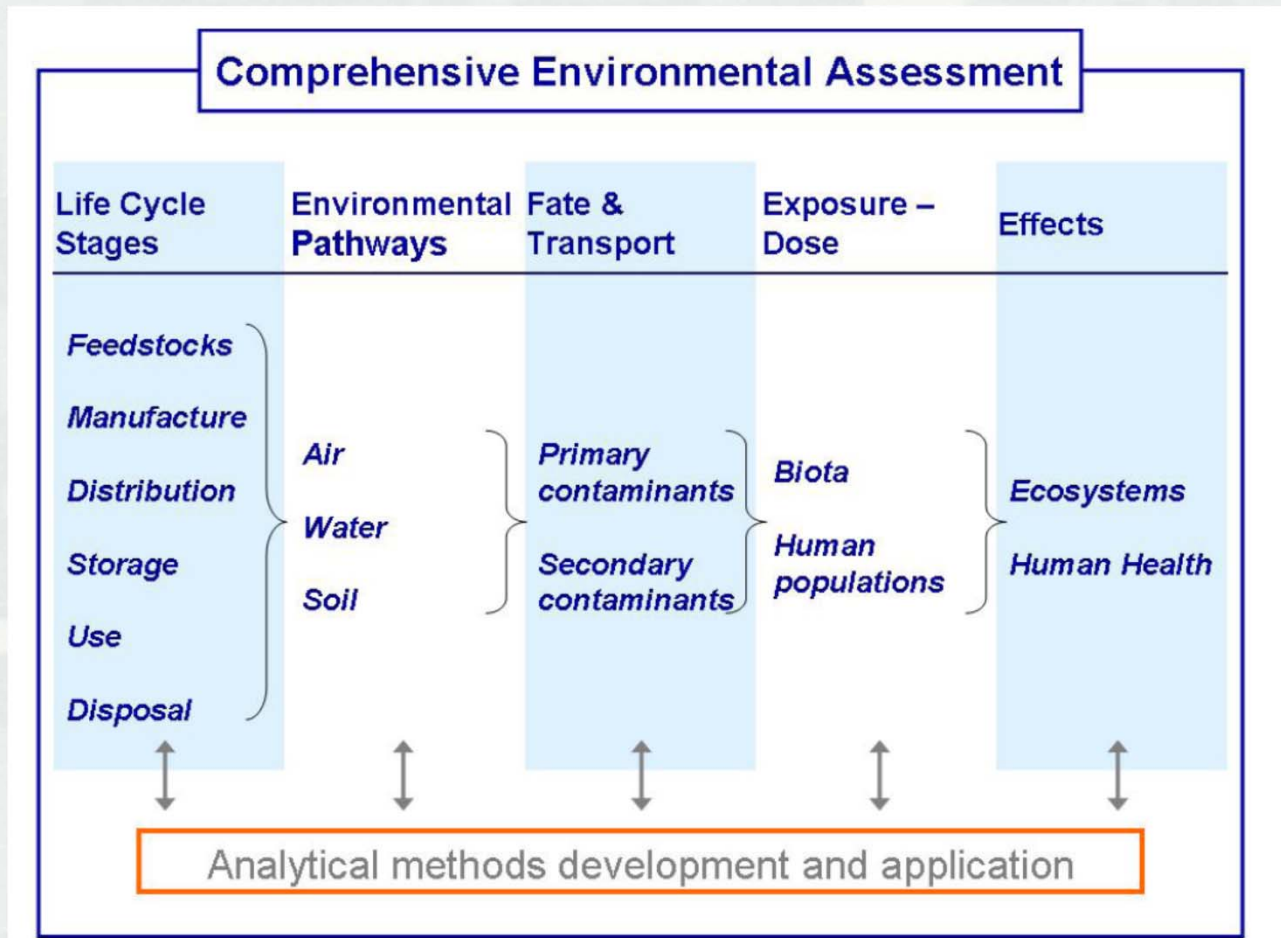
DoD Materiel Development and Costs



- It is estimated that over 85% of the costs of technology occur after systems acquisition



Comprehensive Environmental Assessment (CEA)



Adapted from Davis, 2007



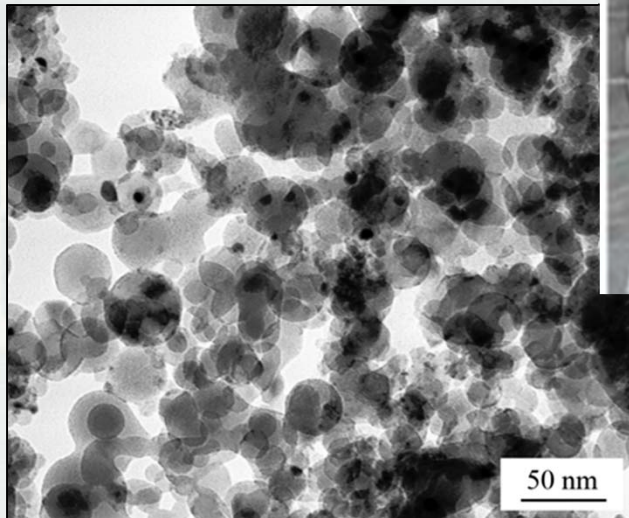
CEA Process

- **Identify the question(s)**
 - ▶ Sources
 - ▶ Life cycle stages, fate & transport, matrices, exposure, effects
 - ▶ Developed methods and standardized protocols
- **Obtain diverse perspectives**
 - ▶ **ODUSD** Chemical & Material Risk Management
 - ▶ **NNCO** National Nanotechnology Coordination Office
 - ▶ **ARMY** - ARDEC , Army Institute of Public Health, ERDC
 - ▶ **Navy** - NSWC-IHD
 - ▶ **Air Force** - Air Force Laboratory Human Effectiveness Directorate
- **Use collective judgment method**

Adapted from Davis, 2007



ERDC CEA Case Study: Engineered Aluminum Nanoparticles

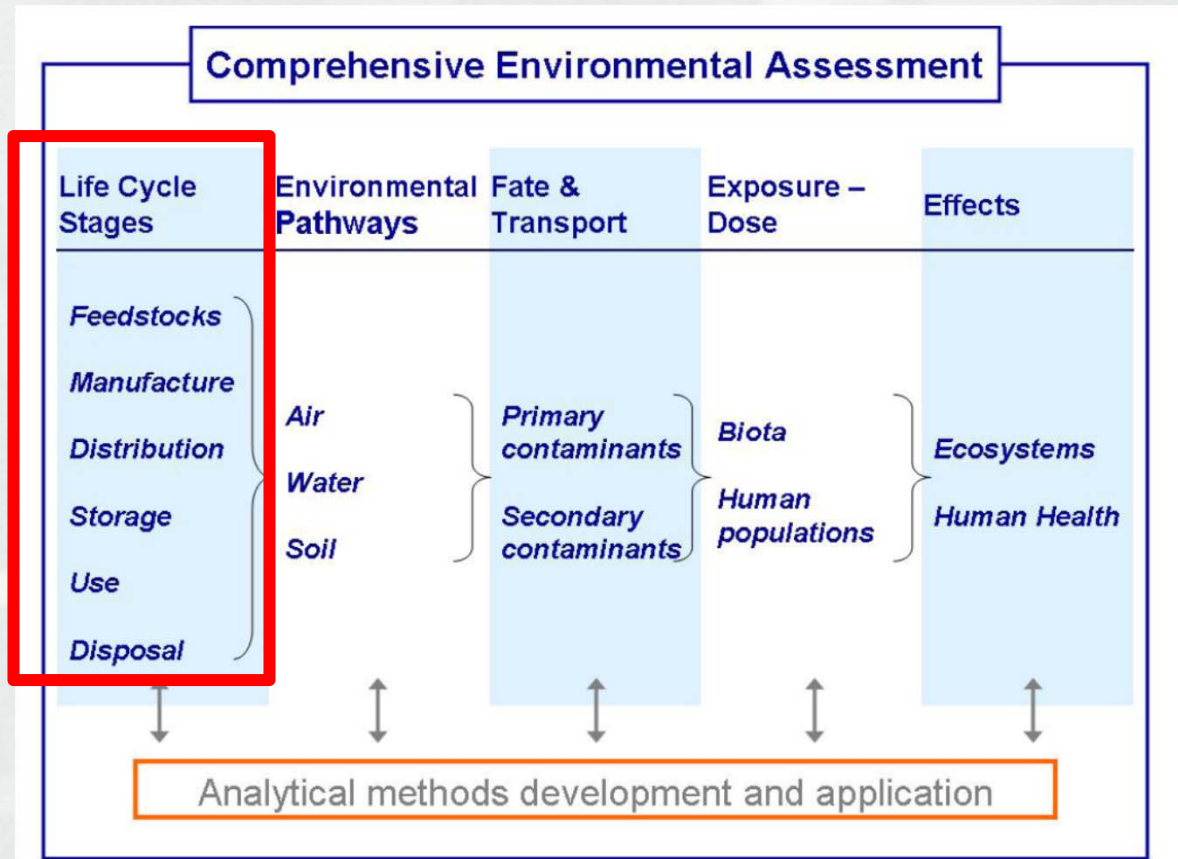


Applying CEA approach to nanotechnology in the R&D Phase

- Lack of mature industries
- Data lacking or evolving
- Characterization of materials
- Uncertainty is high
- Identify and prioritize knowledge gaps



CEA: Life Cycle Stages of nano-AI

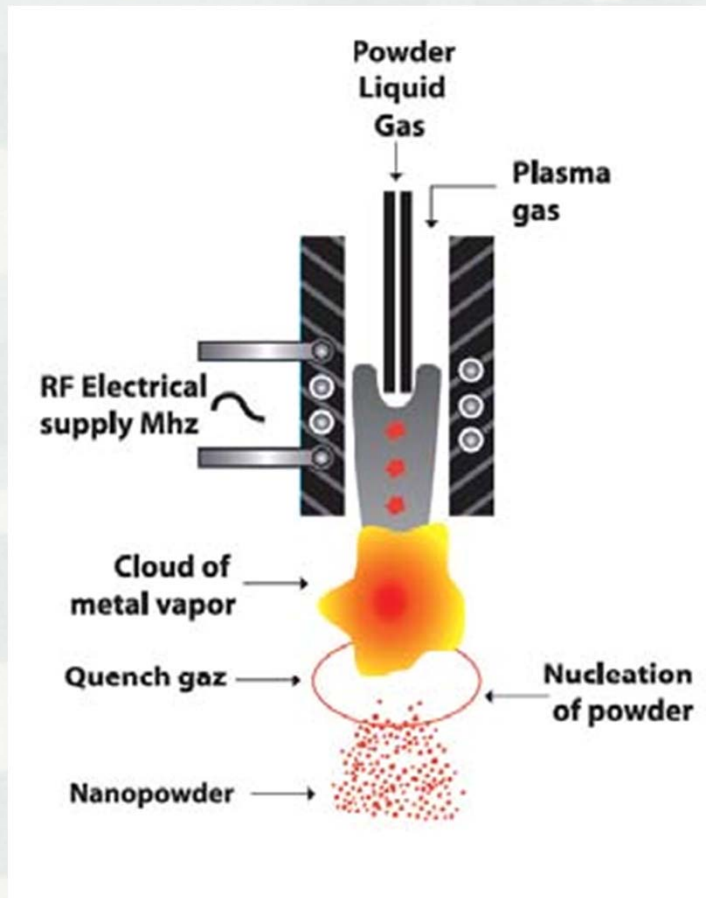


Site Visit: ARDEC Picatinny Arsenal Nanotechnology Research Center

- Operates North America's largest Radiofrequency (RF) Induction Plasma reactor (Tekna Plasma Systems) pilot plant for nano-Al and high performance nonmaterial:
 - ▶ Plasma Synthesis
 - ▶ 10 micron aluminum powder feedstock
 - ▶ Use of nano-aluminum still in the R&D phase
 - ▶ Characterization FE-SEM ,XRD, XRF, XRD, BET, Thermal analysis



CEA: Life Cycle Stages – Feedstocks



- Powder feeder system introduces 10 micron aluminum powder
- Plasma system combines “top down” and “bottom up” process, solid precursor vaporized and quenched enabling synthesis of nano-Al
- Feedstock is aluminum oxide passivated in situ with an approximately 5 nm oxide coating
- Nano-scale powder collected in stainless steel canister inside glove box



CEA: Life Cycle Stages – manufacture



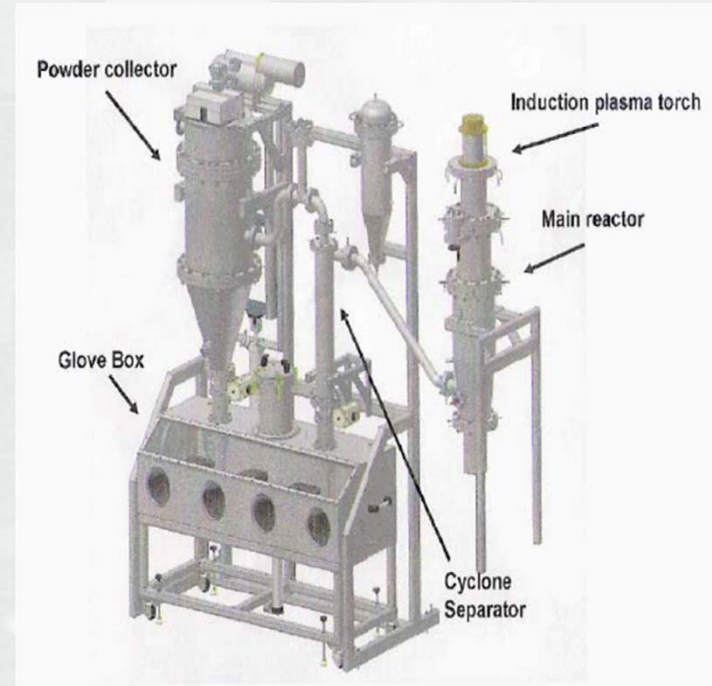
Picatinny Arsenal
Nanotechnology Research Center
maintains two 300kiloWatt RF
Tekna Plasma Systems:

- Metals and metal oxides
- Ceramics

- Cyclone classifier separates product by size, nano-scale powder is collected in a collection chamber under argon
- Synthesis efficiency is 10:1 nanopowder to aggregates, aggregates are stored for research purposes



CEA: Life Cycle Stages – manufacture

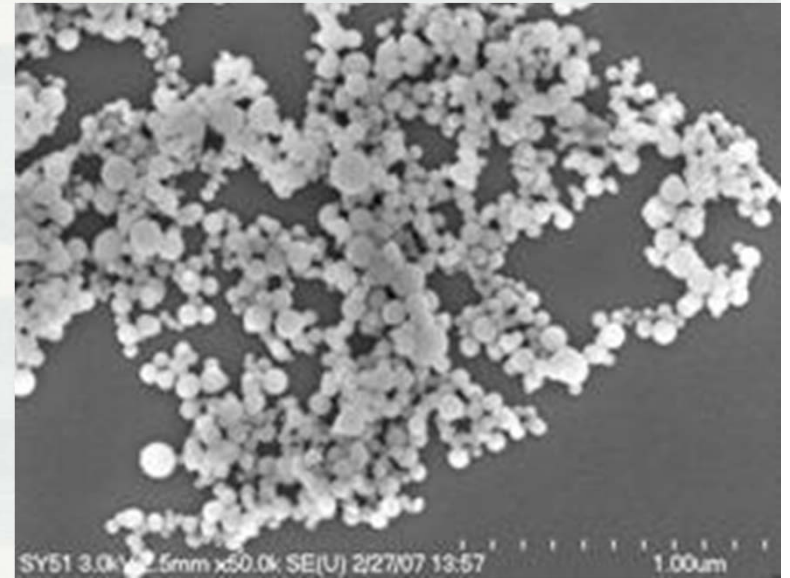


- HEPA filtered fan with 100 cfm exhaust hood, hydrogen sensors in enclosure to detect leaks
- Reactor process capacity of 4hrs per day with 4 hours remaining to rapidly characterize product FE-SEM ,XRD, XRF, XRD, BET, Thermal Analysis, etc.

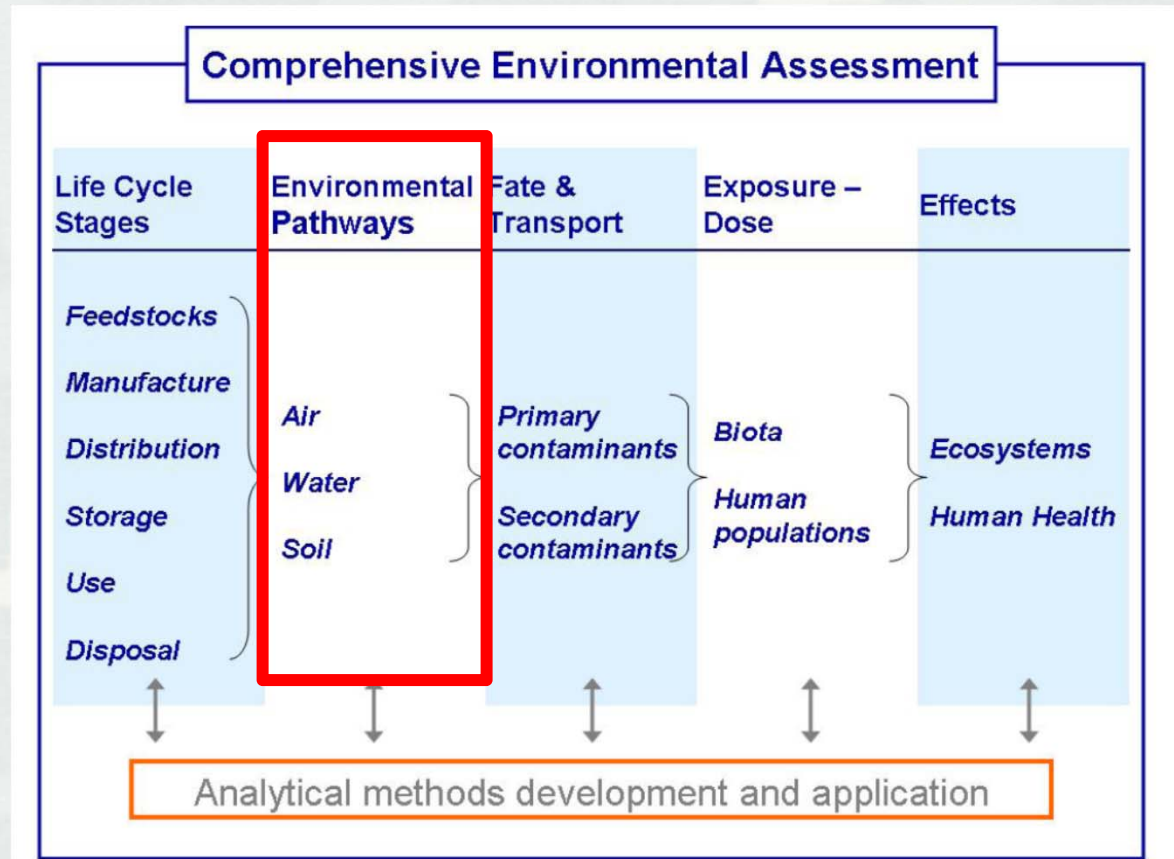


CEA: Life Cycle Stages – distribution and storage

- Use of nano-aluminum still in the R&D phase
- Stored under inert atmosphere
- Aggregates are stored at the facility (still have research value),
- Current synthesis of 200g batches for rapid characterization
- Stability studies indicate no loss in surface area, however a 20% loss in reactivity due to oxygen diffusion

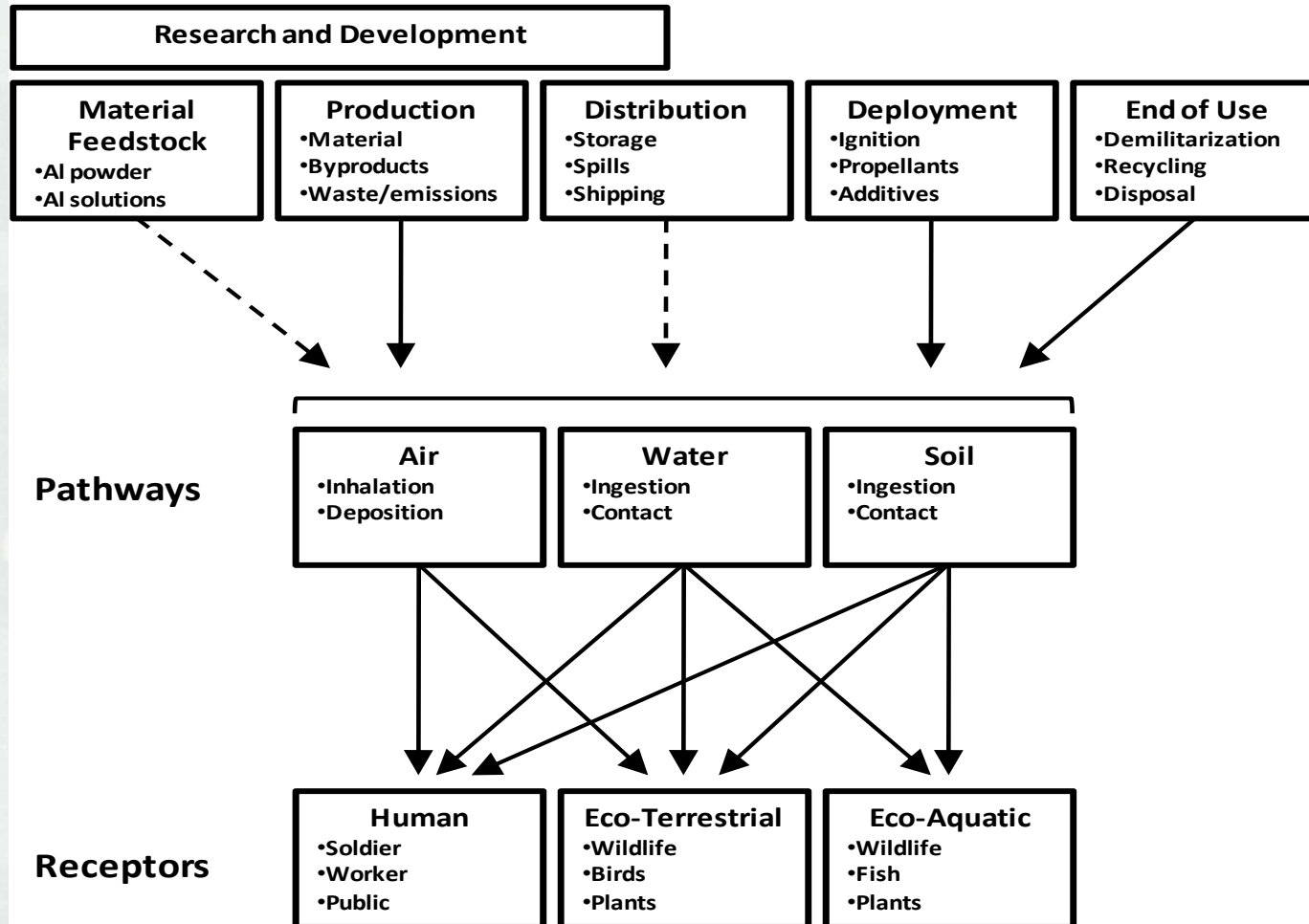


CEA: Environmental Pathways of nano-Al

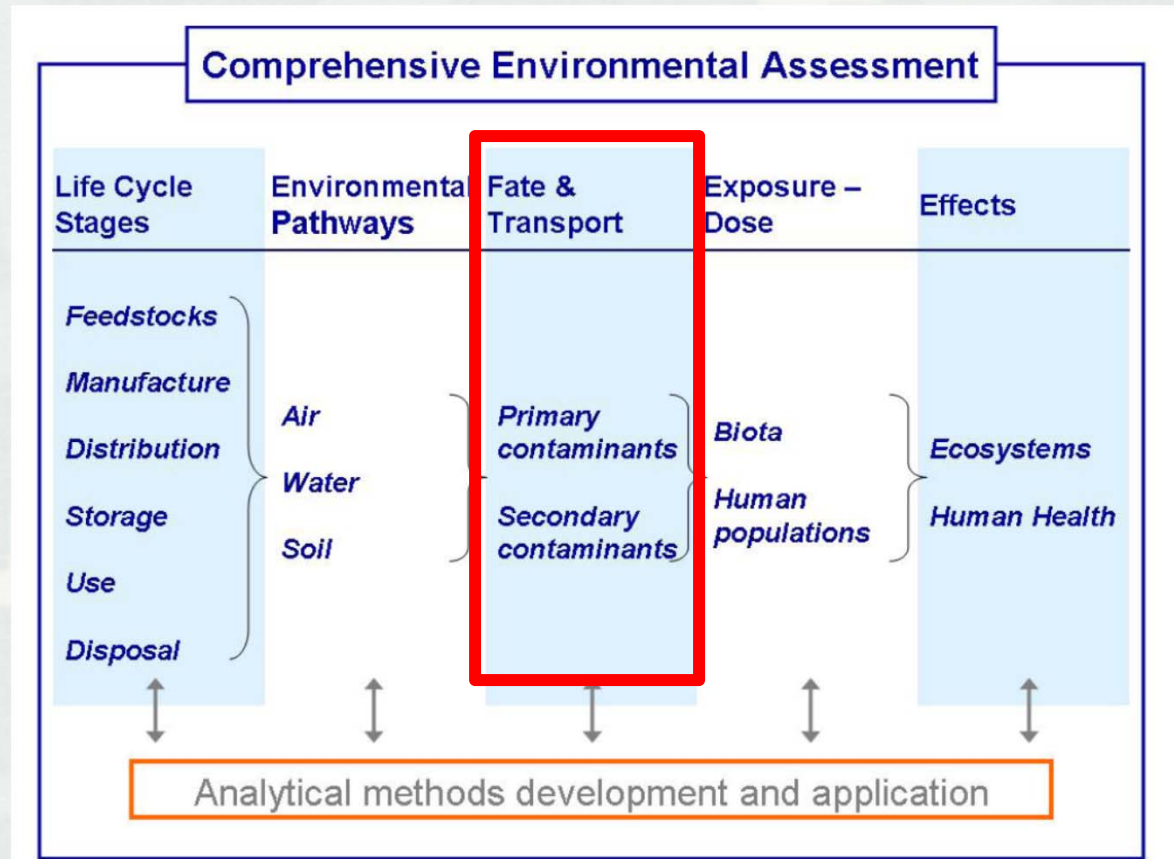


CEA: Environmental Pathways of nano-Al

Technology development and use for nanoaluminum



CEA: Fate and Transport of nano-Al

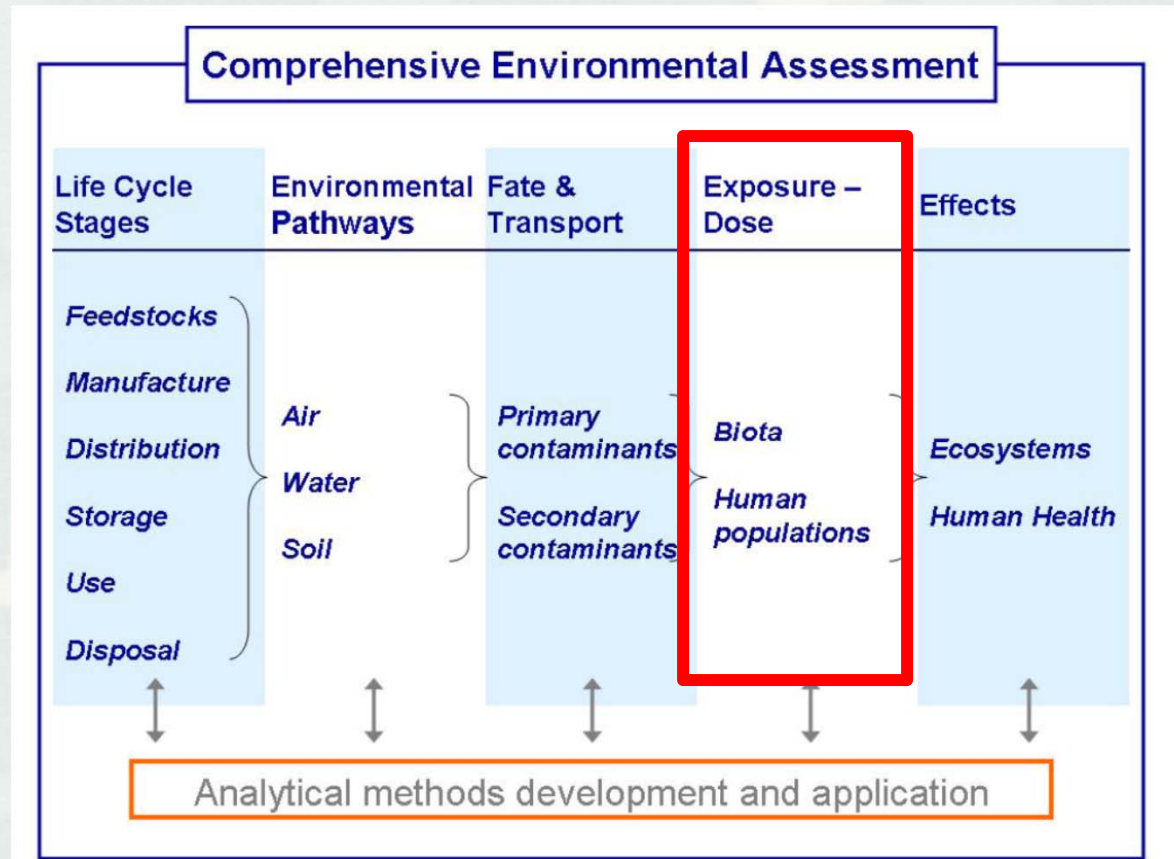


CEA: Fate and Transport of nano-Al

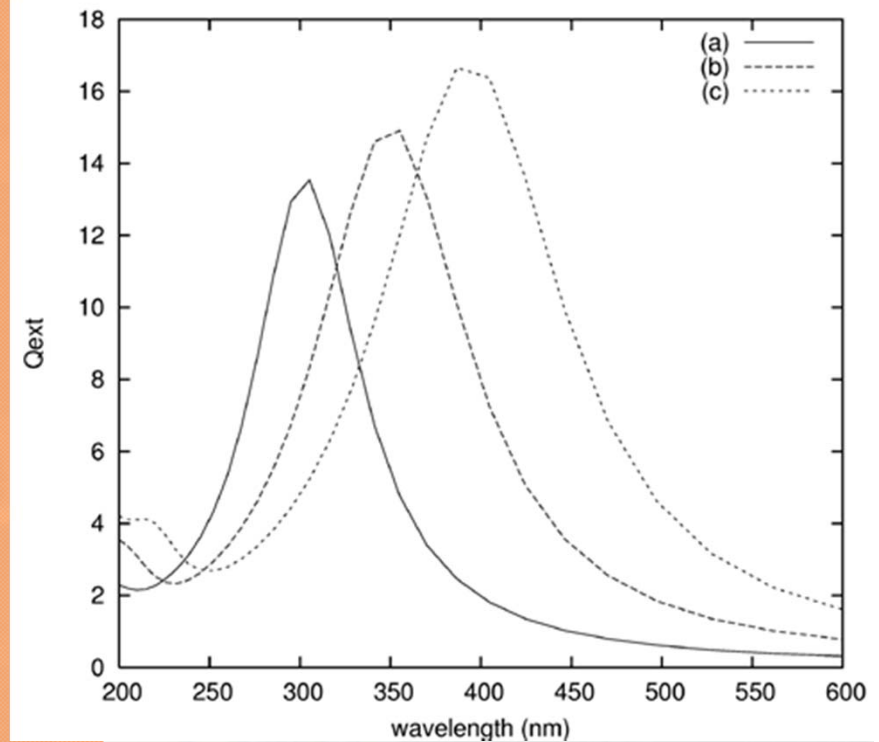
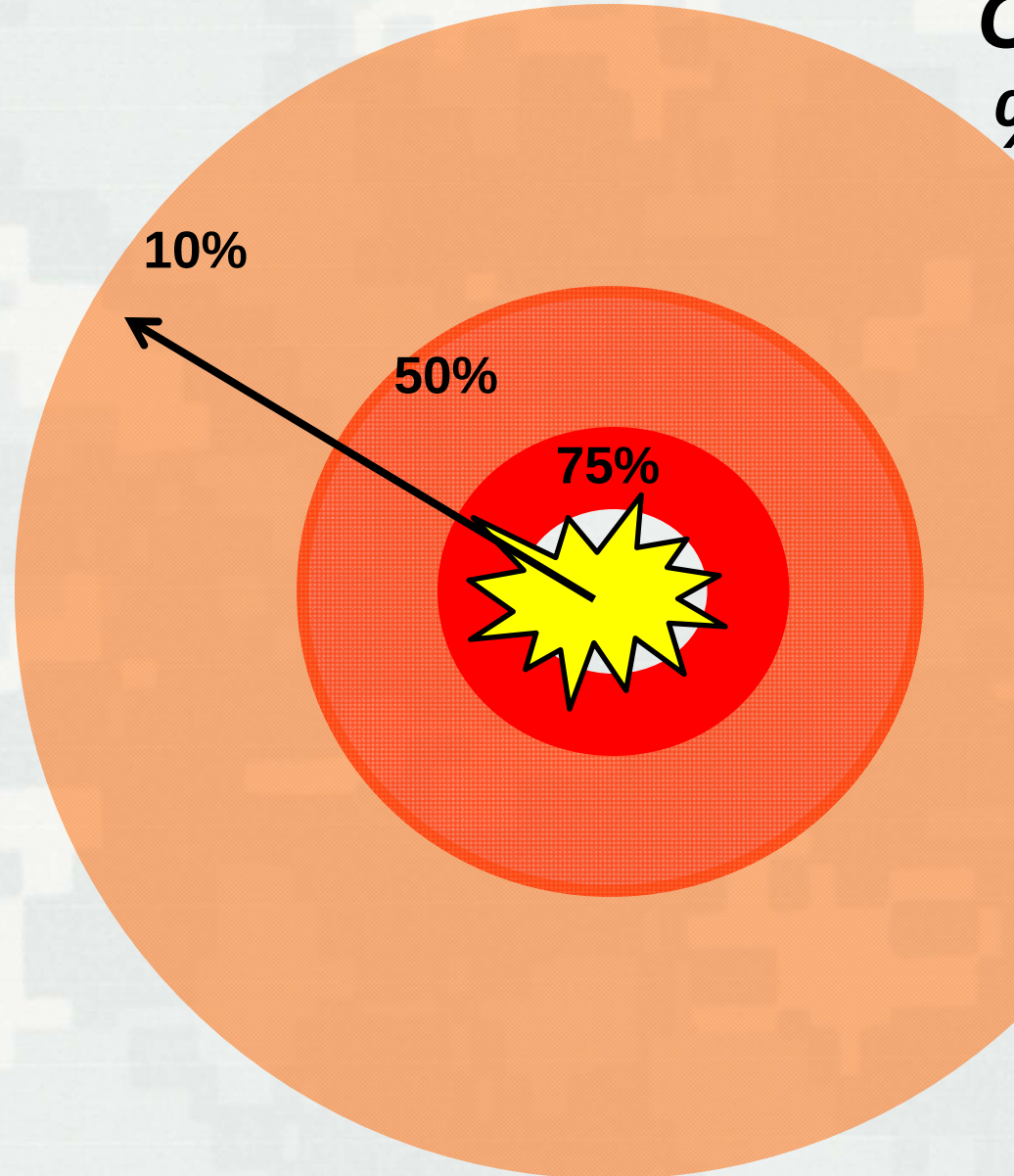
- Particle size dictates oxidation potential
- Nano-Al/ Al_2O_3 interacts with soil, water, and strongly with humic acids
- Highly agglomerates ➡ affects mobility in soil
- Surface charge changes with leachate ➡ alters mobility
- Micron-sized Al_2O_3 has greater sorption than nano- Al_2O_3



CEA: Exposure-Dose of nano-Al



CEA: Exposure-Dose % content of nano-Al



Plot of extinction values for Al triangular prisms (Faber et al. 2008)



CEA: Exposure-Dose of nano-Al

Most likely routes of
nano-Al/ Al_2O_3

exposure: Inhalation > Dermal > Internal (oral, ip, iv)



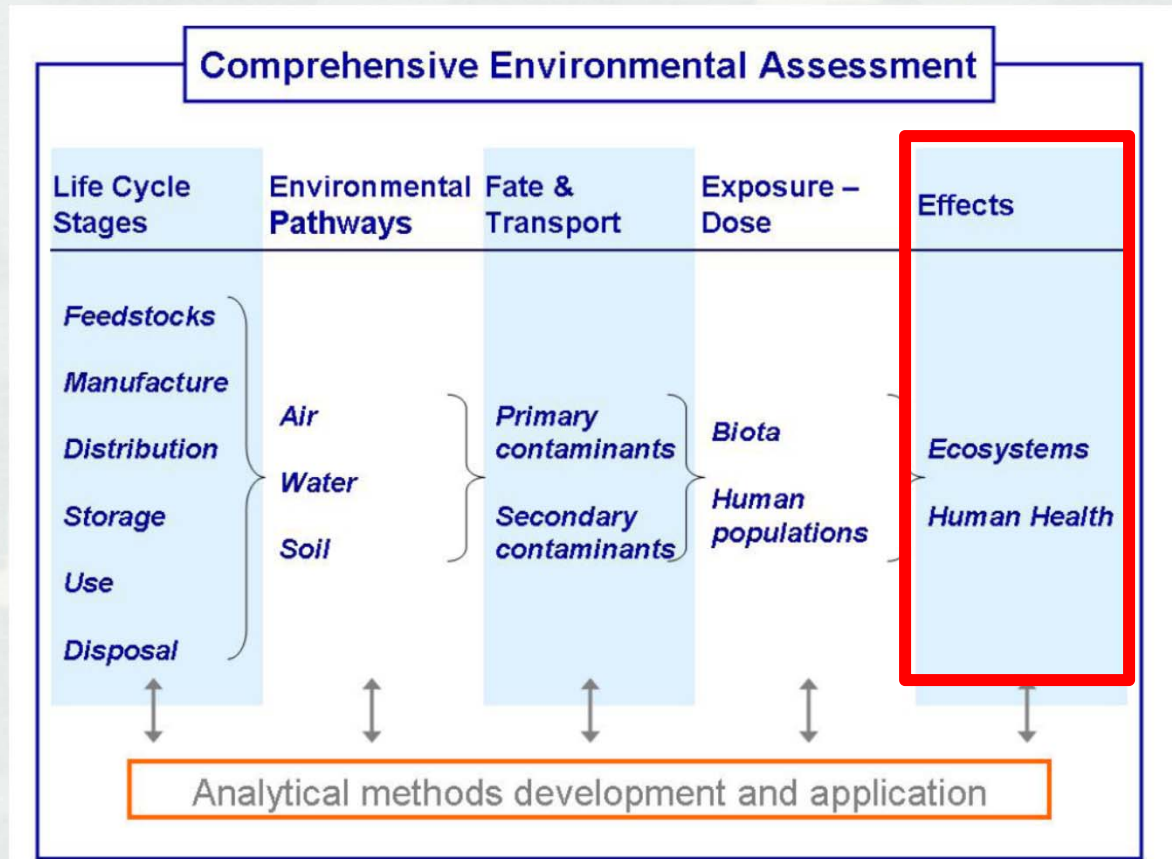
•**ARDEC-NIOSH collaborative framework** “*Nano-powder Synthesis & Associated Safety Precautions at ARDEC*”

TWA and other occupational exposure values?

R&D laboratory evaluations of occupational exposures?

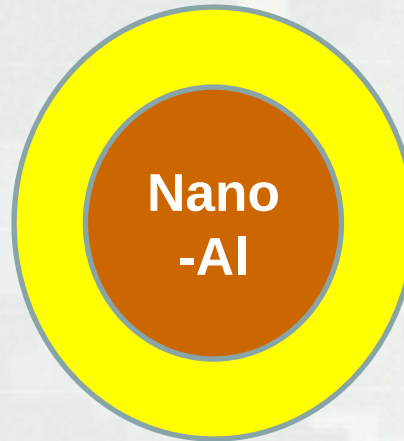


CEA: Effects of nano-Al

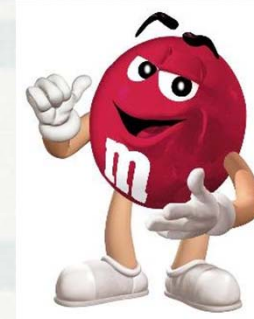


CEA: Problems with Effects of nano-Al

- Nano-Al/ Al_2O_3 is highly agglomerated
- Is aged nano-Al the same as nano- Al_2O_3 ?



Increased Oxidation



CEA: Effects of nano-Al

Ecosystems:

- Less toxic to daphnids and algae than other NPs
- More toxic to juvenile zebrafish than adults
- Causes atherothrombotic events in zebrafish
- Produces differential effects on benthic organisms
- Mildly toxic to bacteria
- Mildly phytotoxic (root growth inhibition) due to ROS
- Soil nematodes and earthworm reproduction negatively affected



CEA: Effects of nano-Al

Human Health:

1. Inhalation –

Negatively affects alveolar macrophages function

2. Dermal –

Dermal contact may increase proinflammation, dermatitis

3. Internal –

Neurotoxicity (blood brain barrier disruption) and

Increased genotoxicity



Preliminary Conclusions

- Potential sources and releases of nano-Al to the environment that will likely occur through air, water, or soil exposures through the production, use, and disposal of nano-Al propellants, igniters, and additives.
- However, these preliminary findings are the result of an assessment from the R&D community.
- Data collection is still required to gain a better understanding of the future deployment and handling of nano-Al as a military technology.

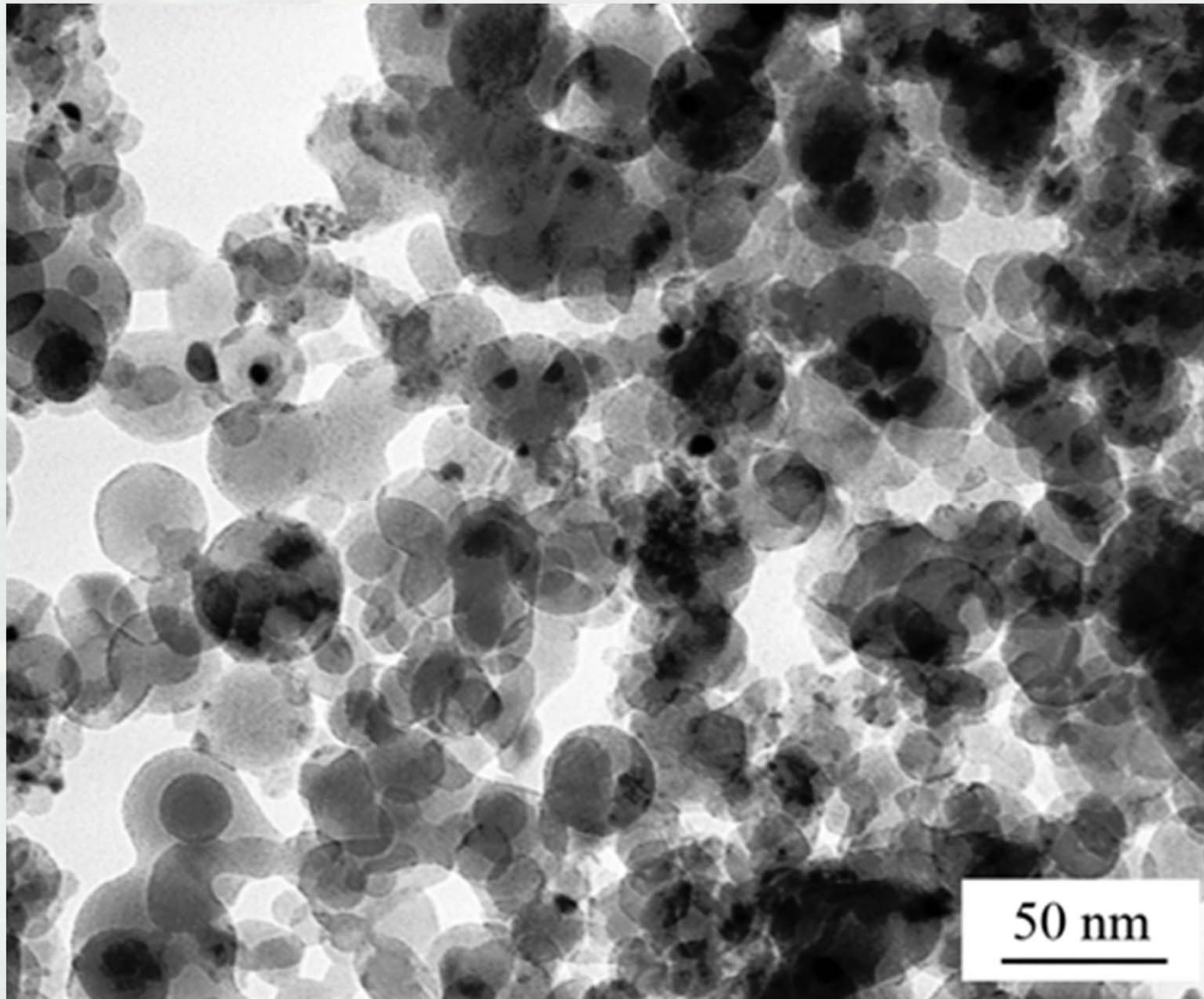


Data Gaps / Moving Forward

- **Life Cycle:** Further collaboration required within the R&D community such as ARDEC, NSWC-IHD, and AFRL to discuss life cycle phases.
- **Environmental Pathways:** This is a potential laboratory and field research project (modeling and hyperspectral imaging analysis for nano-Al/energetic combustion analyses)
- **Exposure:** Exposure to biota and humans is perhaps the biggest area of uncertainty in this entire nano-Al CEA.
- **Environmental Fate:** Once nano-Al has moved beyond the R&D phase, field testing will be imperative to study nano-Al/Al₂O₃ propellants and energetics in the field.
- **Effects:** Data needs to reflect of actual particle sizes, i.e., nanoparticle agglomerates vs. monodispersed nanoparticles.



Questions?



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Critical review and advising from Dr. Mike Davis, Senior Science Advisor, U.S. EPA and Dr. Thomas Seager, Professor, University of Arizona

