

**Plutonium Aerosol Informatics:
Understanding, Communicating, and Managing Radiation Safety in Plutonium Science**

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INTRODUCTION

Recent work to create a second edition of the classic Plutonium Handbook includes a new chapter on Plutonium Aerosol Characterization and Safety Issues. The chapter draws heavily on historical studies including those reported in the reference text *Radioactive Air Sampling Methods* (1) to provide information of practical value to researchers, technologists, radiation safety officers (RSOs), operational health physicists, dosimetrists, managers, and regulators working in the area of plutonium science. Using that information to build and sustain effective management of radiation safety in plutonium science requires a convergence of disciplines (Fig. 1).

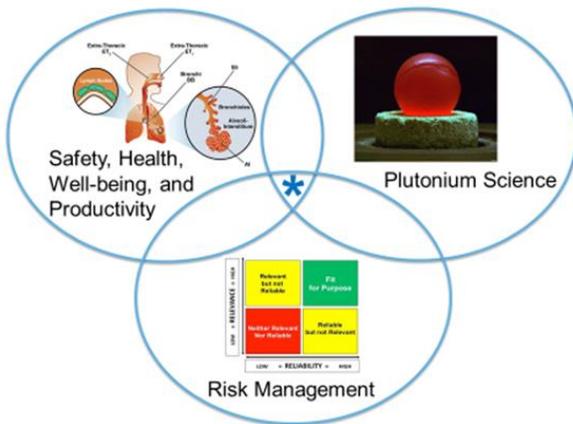


Fig. 1. Convergence to understand, communicate, and manage risks to safety, health, well-being, and productivity in plutonium science. Adapted from Ref. (2).

To achieve that convergence, the science and practice of informatics for radiation safety in plutonium science can be defined as:

- Setting mission objectives and determining which information is relevant to meeting the safety, health, well-being, and productivity objectives of the plutonium science and engineering community;
- Developing and implementing effective mechanisms for collecting, validating, storing, sharing, analyzing, modeling, and applying the information;
- Confirming that appropriate decisions were made and that desired mission outcomes were achieved as a result of that information; and finally

- Conveying experience to the broader community, contributing to generalized knowledge, and updating standards and training.

The goal of an informatics approach in any setting is to make it easier for everyone to get the right things done right for protection by helping to build and sustain connected, protected, and respected communities with leaders, cultures, and systems that have all the tools, training, and experience needed to anticipate and recognize hazards, evaluate exposures, and control and confirm protection from risks to safety, health, well-being, and productivity in all the places we live, learn, work, and play (Fig. 2).



Fig 2. Essential components to control and confirm protection from risks in any setting.

UNDERSTANDING PLUTONIUM AEROSOL PROPERTIES AND BEHAVIORS

Key aerosol concepts are described in the chapter. Airborne materials can exist in a range of forms including gases, particles, droplets, vapors, and fumes. Airborne particle motion and collection are influenced by a range of mechanisms (Fig. 3).

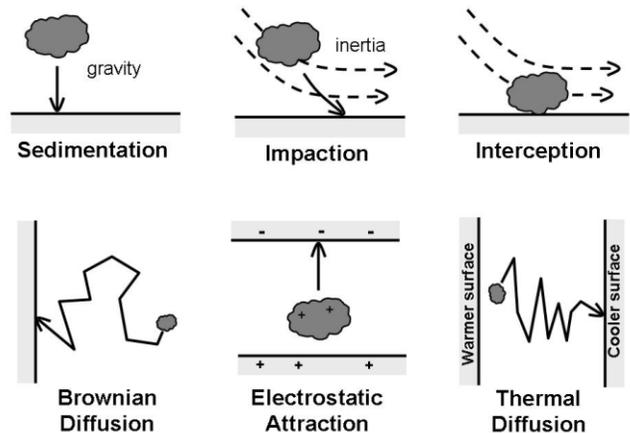


Fig. 3. Mechanisms of airborne particle collection in the environment, air filtration and air cleaning systems, and the human respiratory tract.

Resuspension of particles from surfaces is influenced by a range of mechanisms (Fig. 4).

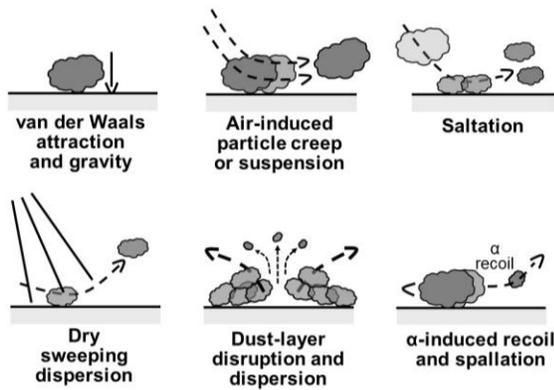


Fig. 4. Mechanisms that influence particle adherence to or resuspension from surfaces.

Dustiness of particles is influenced by a range of factors including the form of the material (e.g., solid, particles in a liquid suspension, “sticky” particles, or dry “dusty” particles) and the energetics of the process (e.g., scooping, pouring, mixing, sawing, grinding, vacuuming, spraying, or vaporization). Behavior of larger airborne particles is dominated by inertia, whereas behavior of ultrafine airborne particles is dominated by Brownian diffusion. Aerosol particle volume equivalent diameter, thermodynamic diameter, and aerodynamic diameter are useful and related. Thermodynamic and aerodynamic diameters can both characterize particle deposition in the respiratory tract. Regional deposition in the respiratory tract and particle collection efficiency by filtration are strongly dependent on particle size, with larger-sized particles depositing by inertial, smallest-sized particles depositing by diffusion, and particles of intermediate size (e.g., 0.01 to 0.3 μm) most able to penetrate a filter or deep into the lung (Fig. 5).

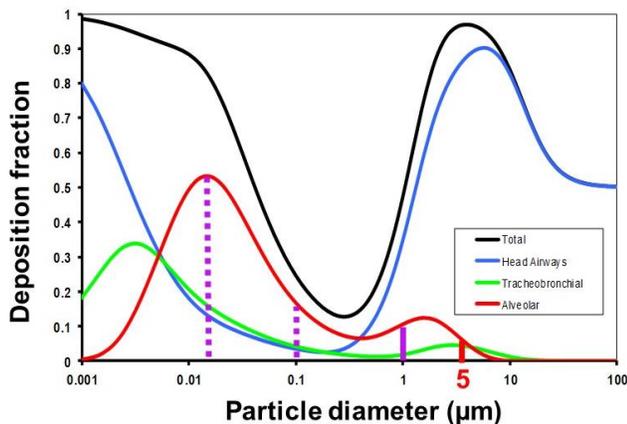


Fig. 5. Fractional deposition in the respiratory tract for spherical particles of unit density as calculated from the ICRP-66 Human Respiratory Tract Model (3) for an adult male engaged in light exercise and nose breathing.

Aerosol particle size distributions are frequently lognormal. Ultrafine particles exist to some extent in the majority of occupational aerosols; larger particles dominate the mass distribution, whereas ultrafine particles dominate the count distribution. Ultrafine particles have a greater fraction of their atoms at the particle surface compared to larger particles, which affects radiation dosimetry and material bioavailability. Airborne particle number concentrations of concern depend on the material of concern. Realistic airborne particle number concentrations can be limited by coagulation. The probability of particle inhalation for materials of high specific activity can be very low at airborne particle number concentrations of concern. Particle size and solubility influence biokinetic behavior and dosimetry for inhaled radioactive materials. A combination of factors influence the total probability of aerosol dispersion and health consequences. Aerosol dispersion parameters are best addressed as probability distributions.

SAMPLING AND CHARACTERIZATION METHODS FOR PLUTONIUM AEROSOLS

A variety of methods can be used to judiciously characterize a comprehensive array of physical, chemical, and biological properties of interest for plutonium aerosols. Nearly all standard aerosol sampling and characterization methods be applied to some extent. Alpha continuous air monitors (CAMs) are widely used for real-time detection and alarming for airborne plutonium. Alpha detection efficiency is influenced by detector and filter geometry. The spatial distribution of plutonium or other radioactivity on calibration sources should be uniform to avoid errors related to the influence of source geometry on detection efficiency.

Filter media characteristics influence plutonium detection by way of both collection efficiency and attenuation of plutonium α -energies for spectroscopy. Prior collection of dust on a filter does not interfere with detection of newly collected plutonium. Simultaneous collection of dust and plutonium reduces the detection and results in the underreporting of collected plutonium.

Other methods can also be used, such as radioactivity counting for β , γ , and neutron emission energies associated with plutonium decay, optical particle counting of the number of airborne particles per unit volume (regardless of particle composition), piezoelectric monitoring systems that measure airborne mass on cascade impaction substrates in real time, collection of particles for microscopic, autoradiographic, or biological dissolution examination, gas pycnometry methods that determine particle density by volume displacement, and particle surface area determination methods that employ gas adsorption techniques.

COMPREHENSIVE SELECTION AND USE OF SAMPLING AND CHARACTERIZATION METHODS

An effective health and safety program should use a life-cycle approach to selection and use of methods for sampling and characterizing plutonium (Fig. 6).

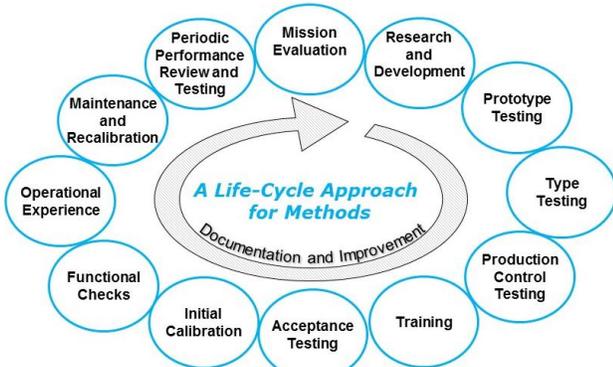


Fig. 6. Life-cycle approach for sampling and characterization methods. (4)

The cycle begins with understanding details of the range of objectives that drive sampling activities, including characterization of materials being encountered, protection of worker health, protection of the environment, process quality assurance and control, emergency preparedness and response, confirmation of regulatory compliance, and research.

A graded approach should be used to prioritize sampling needs and to select and use methods for initial screening and detection, comprehensive characterization and detection, and routine monitoring and control (Fig. 7).

Level 0	Level 1	Level 2	Level 3
Prioritization of Sampling Needs	Initial Screening and Detection	Comprehensive Characterization and Assessment	Routine Monitoring and Control
<ul style="list-style-type: none"> • Process knowledge - Work flows - Anticipated or recognized hazards and potentials for exposure 	<ul style="list-style-type: none"> • Process knowledge • Gross mass or activity counting • Optical particle counting • Condensation particle counting • Microscopy 	<ul style="list-style-type: none"> • Composition - Elemental and chemical • Particle size - Physical, aerodynamic, thermodynamic, electrical mobility • Concentration - Peak, mean, variability • Biophysical factors - Shape, surface area, solubility • Other factors relevant to the assessment 	<ul style="list-style-type: none"> • A necessary and sufficient subset of Level 1 and Level 2 methods for the material and situation of interest

Fig. 7. Graded approach to sampling.

FRAMEWORK AND PROCESS FOR DECISION-MAKING

Programs to understand, communicate, and manage risks for applications such as plutonium science can also benefit from an organized framework and process for decision-making such as illustrated in Fig. 8.

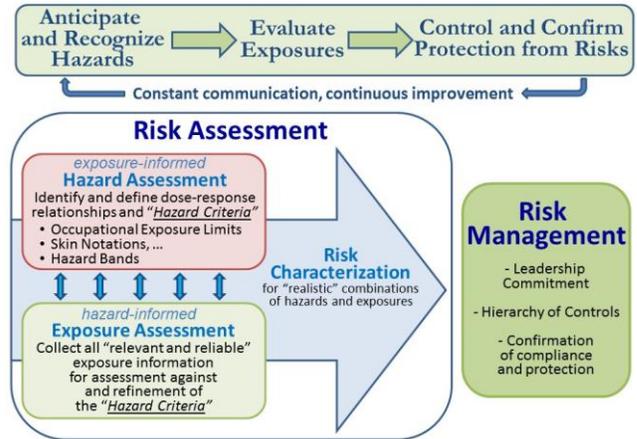


Fig. 8. The anticipate, recognize, evaluate, control, and confirm (ARECC) framework and process for hazard-informed, exposure-informed, and risk-informed decision-making to confirm protection of safety, health, well-being, and productivity.

Fig. 9 is a newly configured depiction of the hierarchy of controls as a pyramid of interrelated components.

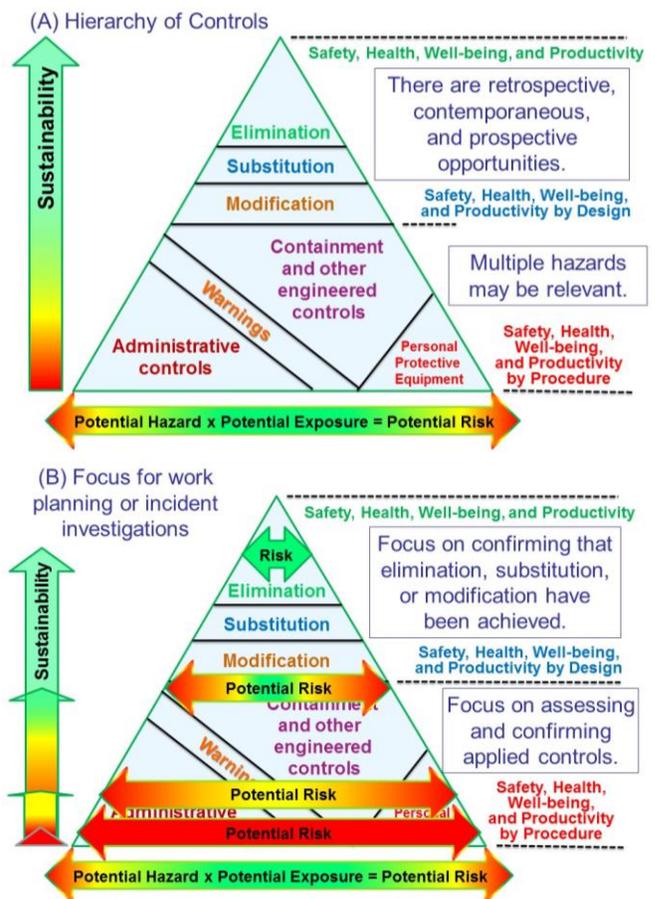


Fig. 9. Depiction of the hierarchy of controls as a pyramid of interrelated components to assess and manage risk.

The upper and lower panels of Fig. 9 convey (A) how various levels of control are associated with different levels of potential risk and sustainability and (B) how retrospective investigations of past incidents or job safety analyses and planning for contemporaneous or prospective work can be informed by knowledge about the types of controls being applied.

AWARENESS REMINDERS TO ACHIEVE SAFETY, HEALTH, WELL-BEING, AND PRODUCTIVITY

A well-thought-out safety awareness reminder is the TAKE2-4U message developed by the Los Alamos National Laboratory Worker Safety and Security Team shown in Fig. 10A. The message was presented on banners, posters, and easily worn, identity-badge-size plastic cards. Fig. 10B conveys a complementary message to promote safety, health, and total well-being at and away from work. (5)

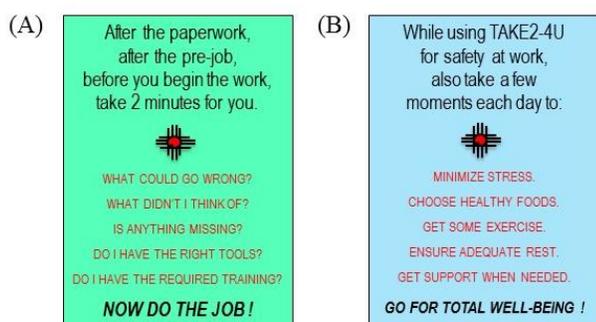


Fig. 10. The TAKE2-4U safety message (A) and a complementary message to achieve total well-being (B).

CONCLUSION

Handling and characterizing plutonium aerosols safely can be accomplished by ensuring that key concepts of plutonium aerosol characterization and behavior are understood; radiation control and characterization methods are appropriately selected, communicated, and carried out; and that radiation exposures are within statutory limits and As Low As Reasonably Achievable.

Each of these steps benefits from an informatics-based approach to radiation safety in plutonium science, along with a commitment to clear mission objectives and safety by all levels of management and workers. Proper attention is needed on a daily basis to all aspects of a well-developed and well-documented plutonium research and safety program.

Two key insights are:

- “The method is not the message; [the message] is in the managerial frame of mind determined to make robust decisions.” (6)

- “If money is being spent to reduce an already minuscule risk, while larger risks are going unaddressed, that is not only foolish; it is in effect an unsafe act.” (7)

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