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Title: A Smart Device for Mine Dust Characterization and Coal Workers' Health Improvement: Combining Non-Destructive, Element-Specific X-ray CT with Big Data Analytics & Machine Learning

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Topic: Non-Destructive Inspection and Testing (NDT) Technologies

Concept Summary: In this proof-of-concept project, we aim to develop a smart device to solve the respirable mine dust problem by combining non-destructive, element-specific X-ray computed tomography (CT) technologies with big data analytics & machine learning capabilities. The proposed technology is a hardware/software-integrated solution to improving coal workers' health with respect to respirable mine dust problems. The device can identify chemical heterogeneity in a single particle, which is critical for accurately predicting larger-scale biological responses to harmful dust constituents. Meanwhile, the device uses data mining & machine learning to identify potentially predictive correlations between particle size, shape, and chemical composition, which has direct applications to whole-lung dust deposition models, regional aerodynamic modeling of dust transport and deposition, biological experiments, and diagnostic procedures.

Specifically, the non-destructive, element-specific CT scanner will be able to identify element heterogeneity in a single particle. Studies have shown that human lung's macrophage processes, which are the lung's primary defense against respired particles, behave differently when presented with pure silica particles and silica particles coated with clay or other minerals. Therefore, the surface chemical constituent of a dust particle is critical in determining the pathological development of lung diseases. Previous studies suggested that surface coating of quartz particles may modify the biologically available surface area of quartz particles [30]. Three-dimensional (3D), element-specific CT will provide a way to look at whether silica particles are pure or coated, which can provide very helpful information in identifying the most harmful dust constituents.

The autonomous image pattern recognition capability in the software component can extract information for all individual dust particles, such as size, shape, density, and element, on the basis of the raw CT images using computer vision and autonomous image processing technologies. The artificial neural network (ANN) model in the intelligent system will be able to use data mining & machine learning capabilities to identify potentially predictive correlations between particle size, shape, and chemical composition. Using such predictive correlations, we will be able to tell whether a specific element of interest is more likely to be associated with a particular range of particle size & shape, which will be extremely useful for predicting harmful element transport and deposition in the human lung using high-resolution, regional aerodynamic modeling. This knowledge will benefit the design of respiratory personal protective equipment (PPE) to catch dust hazards within a certain range of size & shape that is associated with the most harmful constituents.

The developed hardware/software-integrated device will also benefit dust transport and deposition modeling at the whole-lung scale. In the widely used whole-lung models, total dust deposition in the lung is usually measured as a function of dust size. Using the predictive correlation between dust size and chemical composition, we can tell which element is more likely to be associated with a certain range of particle size. Consequently, we will obtain a better prediction for the total deposition of a specific element of interest using the whole lung model data. By achieving these capabilities, we can bridge the knowledge gap between fundamental, local scale mine dust characterization and real-world improvement of coal workers' health.

Most of the laboratory, numerical, and data tools have been developed, validated, and in readiness. In the proposed proof-of-concept project, we will integrate the hardware and software components and then test the device's functionality in a laboratory environment. Should follow-up funding be provided, we will aim to extend the proof-of-concept device to a fully functional working prototype and test it in a real operational environment. The ultimate development levels will be targeted at Technology Readiness Levels (TRLs) 8 and 9.