# Managing Potential Environmental and Human Health Risks of Lead Halide Perovskite Photovoltaic Modules

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## Introduction and Objective

Design → End of Life

**Risk Types: Inhalation, Skin Contact, Water, and Soil Contamination**


Torrence et al. iScience. 2023

**Exposure Pathways**

**Design and Manufacturing**
- Materials Selection
- Mfg. and Machining
- Solvent Selection

**Transport, Staging, and Installation**
- Module Damage

**Operation**
- Weather Events
- Fire
- Aging Modules

**End of Life (EoL)**
- Landfill
- Recycling Processes
- Decommissioning

- Potential environmental and human health risks of perovskite solar modules (PSMs) are present across the value chain
- **Pb in the most efficient PSMs has a higher water solubility than other photovoltaic (PV) module technologies posing uncertain potential environmental and human health risks**

**Overview:**
- Identify experimental approaches and other possible solutions for managing potential Pb-related environmental and human health risks of PSMs in the operational lifetime by:
  - Identify Pb concentration regulatory risk thresholds
  - Design experiments that yield results comparable to Pb concentration regulatory thresholds
- Highlight potential solutions that address and mitigate risk

## Pb-related Regulation Thresholds

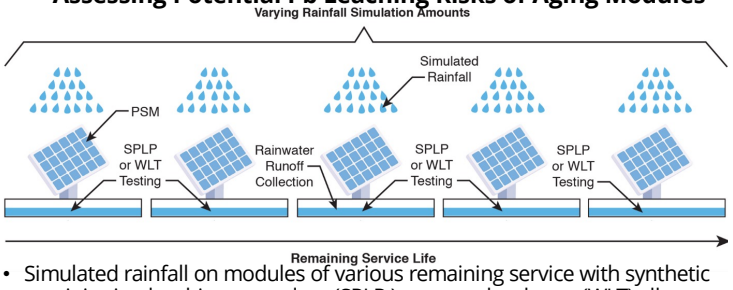
**Identifying Pb concentration regulatory thresholds allows for experiments to be designed that result in comparable data outputs for risk assessment**

| Environmental Aspect | Standard/Regulation/Guidance | Regulatory/Guidance Threshold Value |
|---|---|---|
| Water | Clean Water and Safe Drinking Water Act | 0.15 mg/L of lead (maximum contaminant level) |
| | NPDES | Subject to site |
| Air | NAAQS | 0.15 µg/m$^3$ over a 3 month average for lead |
| | Temporary Emergency Exposure Limit (TEEL) | 0.15 mg/m$^3$ of lead over 1 hr (Category 1) |
| | | 120 mg/m$^3$ of lead over 1 hr (Category 2) |
| | | 700 mg/m$^3$ of lead over 1 hr (Category 3) |
| Human | OSHA 1910.1025 | <50 µg/m$^3$ of lead over 8 hrs |
| | OSHA 1926.62 | |
| | IEC 61730 Series | Meet all standard criteria |
| | IEC 62941 | |
| | ISO 9001 | |
| Waste | RCRA subpart B 261.24 | 5 mg/L of lead |
| Land and Wildlife | TSCA | 400 ppm of lead in bare soil in play areas |
| | Incidental Take Permit | Subject to site |
| | State and Local Ordinances/Permits | |

National Pollutant Discharge Elimination System (NPDES); National Ambient Air Quality Standards (NAAQS); Occupational Health and Safety Administration (OSHA); International Electrotechnical Commission; International Organization for Standardization (ISO); Resource Conservation and Recovery Act (RCRA); Toxic Substances Control Act (TSCA)

## In-field Damage & EoL Experimental Approaches

### Assessing Potential Pb Leaching Risks of Aging Modules

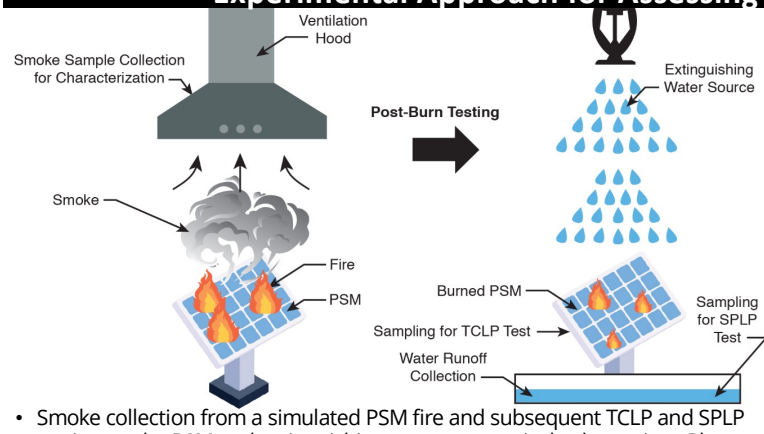



- Simulated rainfall on modules of various remaining service with synthetic precipitation leaching procedure (SPLP ) or water leach test (WLT) allows for simulation of testing Pb concentration in rainwater runoff
- Other experimental approaches can be designed to assess in-field leaching potential after weather-related damage, such as hail damage

### Approaches for Assessing Potential Pb Leaching Risks at EoL

- New methods for module sampling for TCLP testing as current ASTM standard calls for waterjet cutting
- Can other acceptable EPA approaches be utilized, such as total analysis?
- Can generator knowledge be utilized to make a hazardous waste determination?

## Experimental Approach for Assessing Pb Exposure Risk and Leaching from Fire




- Smoke collection from a simulated PSM fire and subsequent TCLP and SPLP testing on the PSM and extinguishing water, respectively, determines Pb concentration in the smoke, PSM laminate, and extinguishing water

| Potential Characterization Technique Option | Purpose | Potential Species of Interest for PSMs |
|---|---|---|
| Fourier Transform Infrared Spectroscopy | Identify Organic Gaseous Compounds from Smoke | Carbon Monoxide, Nitrogen Dioxides, Ammonia, Formaldehyde |
| Gas Chromatography-Flame Ionization Detection | Quantify Concentrations of Organic Gaseous Compounds | |
| Inductively Coupled Plasma Atomic Emission Spectroscopy | Determine Concentrations of inorganic elements | Lead |
| Engine Exhaust Particle Sizer | Characterize Number and Size Distribution of Particulate Matter | Any Species Below 10 µm |
| Cascade Impactor | | |
| Toxicity Characteristic Leaching Procedure | Determine Concentrations of Toxic Volatile, Semi-Volatile, and Metal Species for Hazardous or Non-hazardous Waste Classification | Lead |
| SPLP | Determine Concentrations of Toxic Species Leaching into Groundwater or Soil | Lead |

## Conclusions and Future

- Some Pb-containing PSMs may pose potential environmental and human health risks due to higher Pb solubility in water than other current Pb-containing PV module technologies
- Experimental approaches can be designed with existing equipment and technology to assess potential Pb leaching and exposure risks from PSMs using regulatory Pb concentrations as a comparable metric to experimental data outputs
- Future work would consist of performing the proposed experiments to begin to assess potential Pb leaching risks from PSMs during operational lifetimes
- Other possible solutions and mitigation strategies are 1) leveraging strategies from other commercialized PV module technologies (e.g., cadmium telluride modules), such as module takeback services and 2) Design PSMs to mitigate the risk, such as including external encapsulants, barrier films, sequestration layers, and metal organic frameworks

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