United States Nuclear Regulatory Commission

Protecting People and the Environment

Development of a Trend Curve for Charpy Upper Shelf Energy (USE) Drop Using USA Surveillance Data

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* **The opinions expressed here are those of these authors. They do not represent an official position of the NRC.**

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Presentation Overview

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- **NRC requirements & guidance regarding USE**
  - Upper shelf energy drop (ΔUSE) prediction
  - Upper shelf energy requirements
  - Periodic evaluation of regulatory guides

- **Assessment of RG 1.99(R2) ΔUSE prediction**
  - Motivation
  - Previous work on ΔUSE prediction
  - Current investigation
  - Initial data evaluation and some trends
  - Next steps and plans

NRC Requirements

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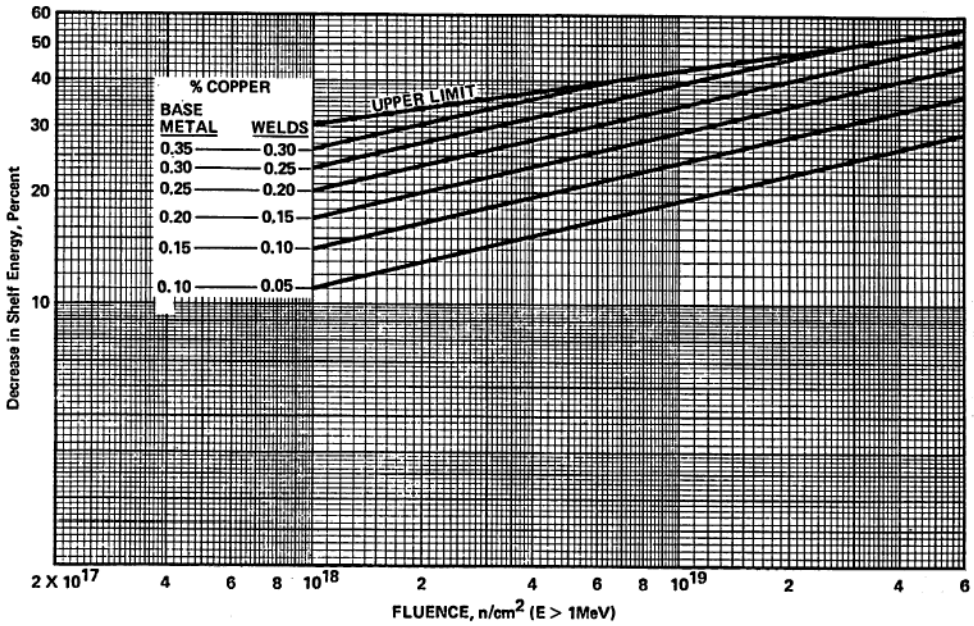
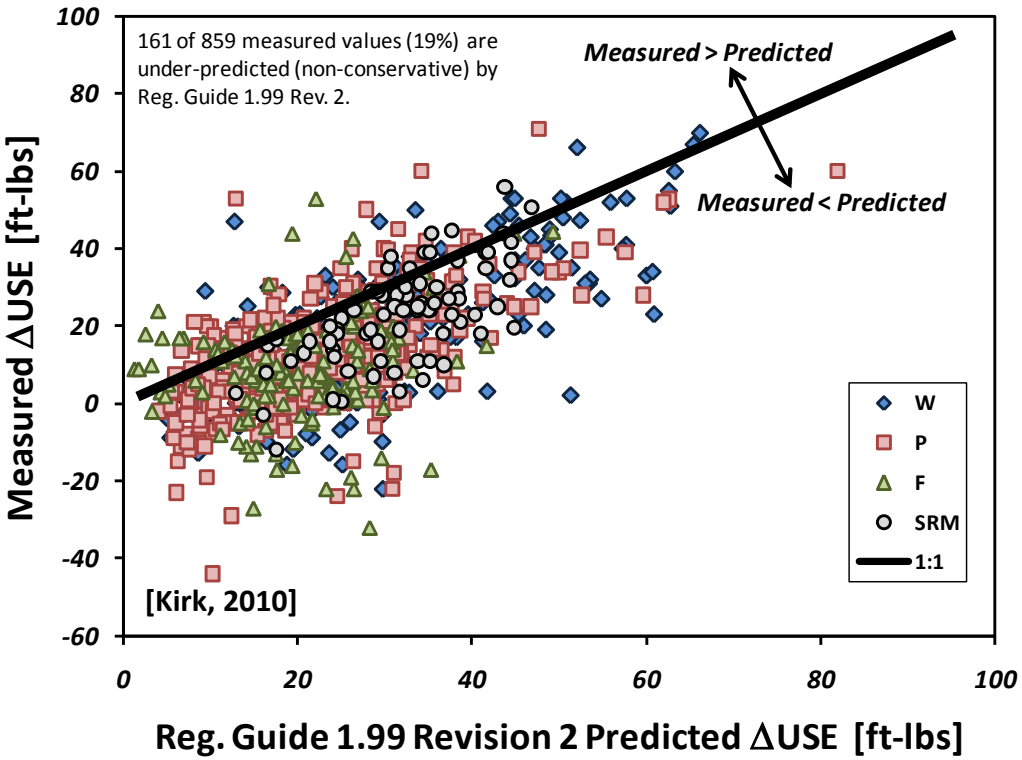
- **Current USE requirements**
  - Found in Appendix G to 10 CFR Part 50
  - USE > 75 ft-lbs (102 J) before service
  - USE > 50 ft-lbs (68 J) after irradiation exposure
- **Current guidance on ΔUSE estimation**
  - Found in Revision 2 of Regulatory Guide 1.99
- **Periodic evaluation of Regulatory Guides**
  - Approximately once every 5 years
  - In 2014 NRC committed to issue report evaluating the adequacy of Revision 2 of Regulatory Guide 1.99 for continued use in 2016 (see ADAMS ML13346A003)



Motivation

- The RG 1.99(R2) equation for ΔUSE over estimates 81% of ΔUSE data
  - a +1.3σ bound
- This differs from the RG 1.99(R2) equation for ΔT_{41J}, which over-estimates 95% of ΔT_{41J} data
  - a +2σ bound



Previous Work on ΔUSE Predictions

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Author	Y value fit	Data Source	Fitting Form*
Eason ['98]	USE_{IRRAD}, ΔUSE	USA surveillance	One feature
Sakamoto ['03]	ΔUSE	MTR irradiations	One feature
Kirk ['10]	ΔUSE	USA surveillance	One feature
Various	ΔT_{41J}	various	Mostly multi-feature

*** Possible Fitting Forms (very general)**

- **One Feature:** $y = f\{\text{various } x_s\}$
- **Multi Feature:** $y = f_1\{\text{Cu \& other } x_s\} + f_2\{\text{NOT(Cu) \& other } x_s\}$

Current Investigation

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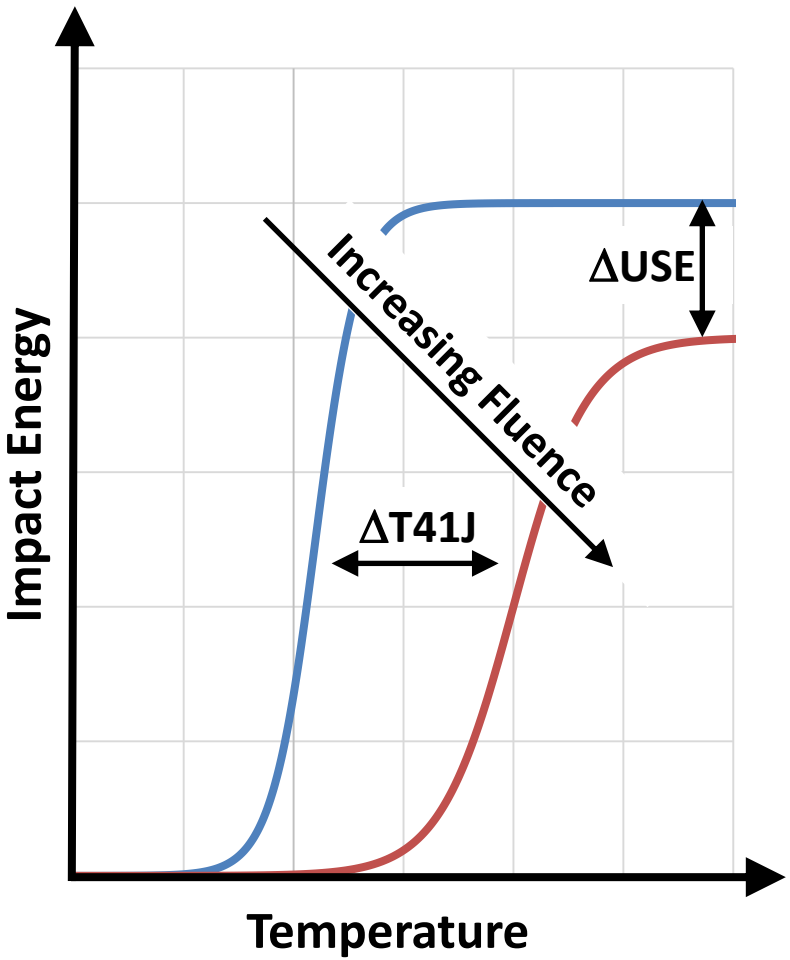
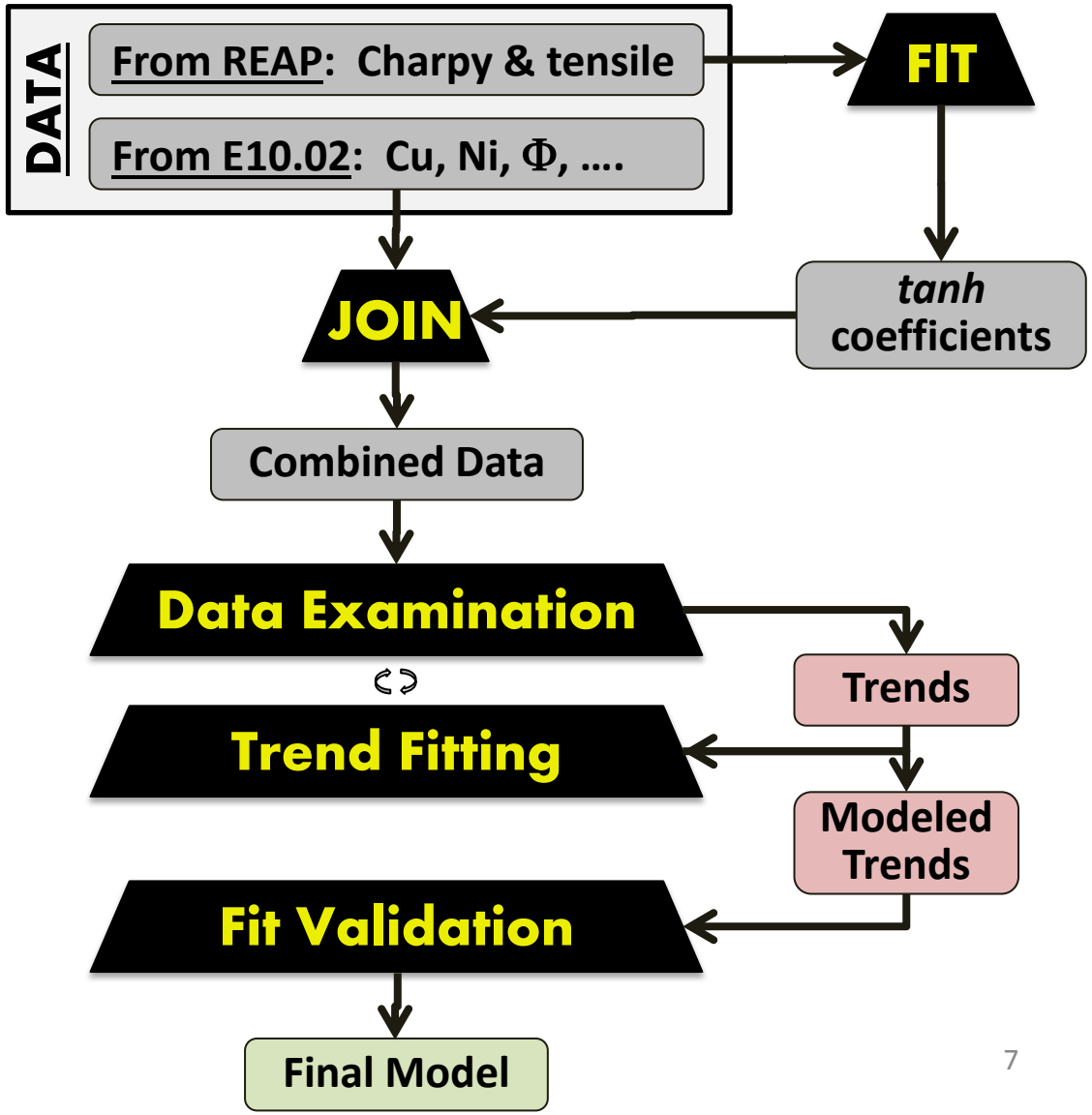
- **Overall objective**: Evaluate adequacy of ΔUSE, as estimated by RG 1.99(R2), for continued use
- **Key features of approach**
  - Charpy data from reactor embrittlement archive project (REAP) database (see https://reap.ornl.gov/register/)
    - All curve fits traceable to source data
    - Permits outlier evaluation
  - Composition, fluence, & temperature data recently compiled by ASTM E10.02
  - Bases fit on USA data



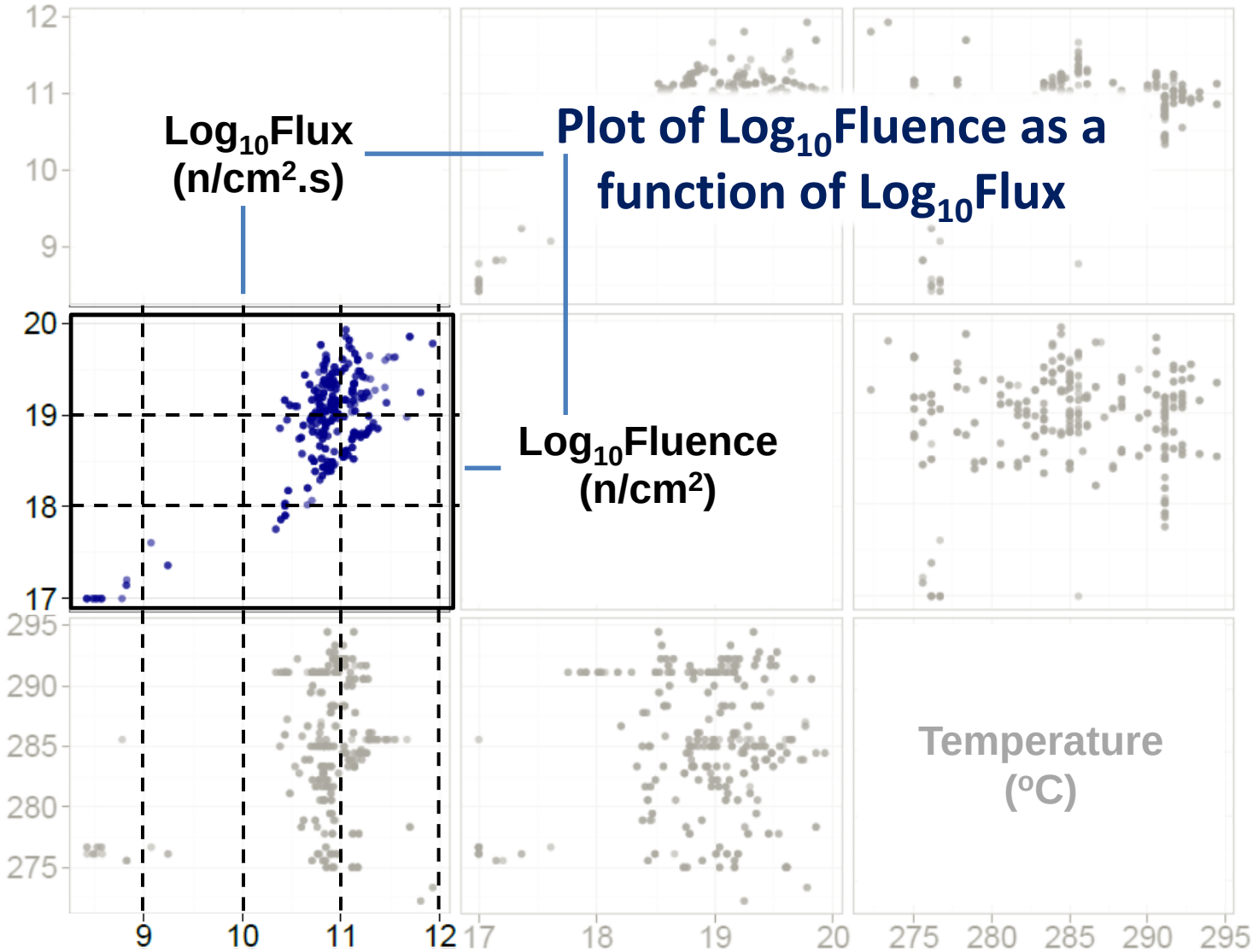
Approach

- Still early in the process
- Effort permits us to QA / reconcile discrepancies in source data
- Work will mature in the next 6 – 12 months



Data

Exposure Variables



Data

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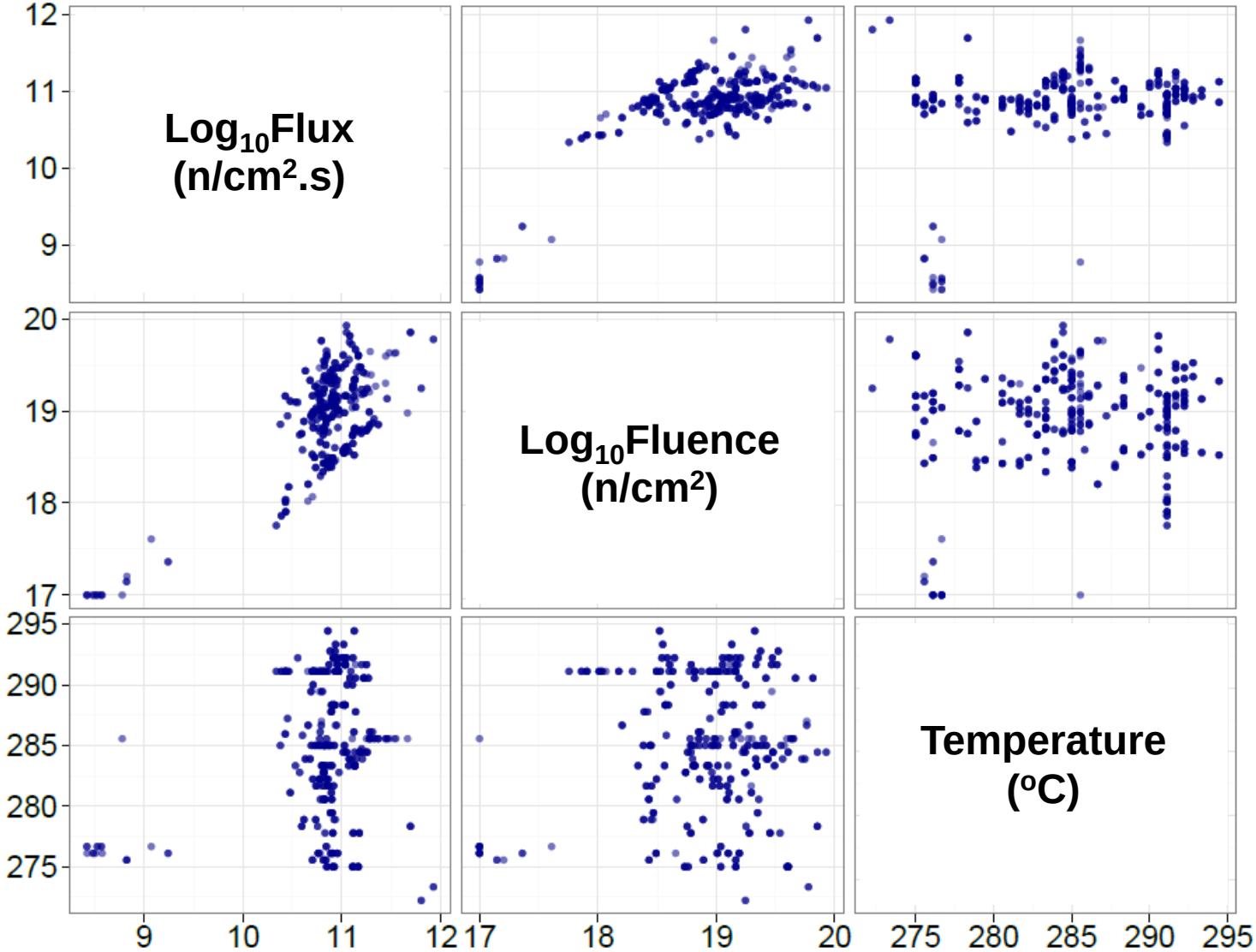
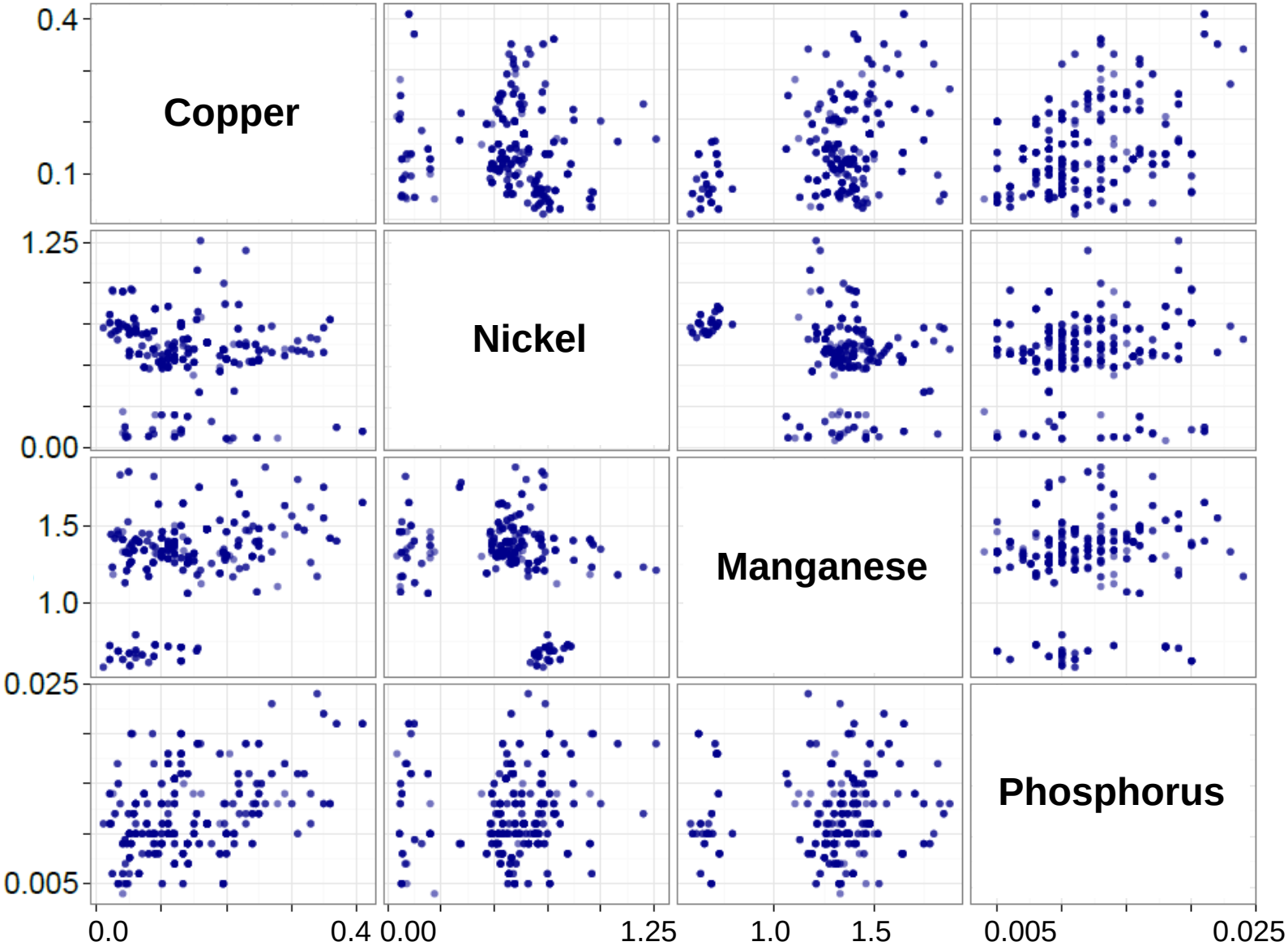


Data

Composition Variables



Data Trends

Upper Shelf Energy and Chemistry / Fluence

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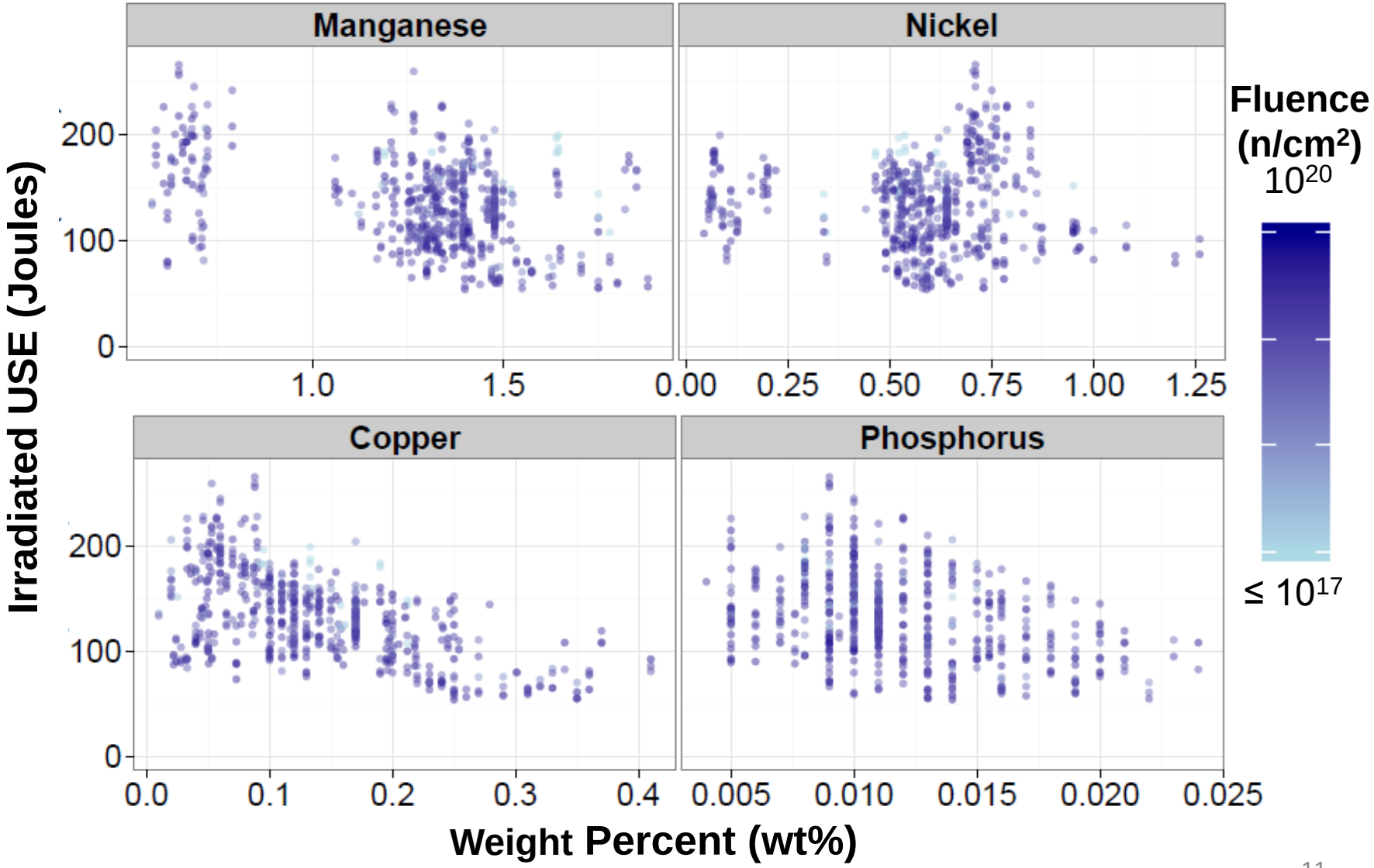
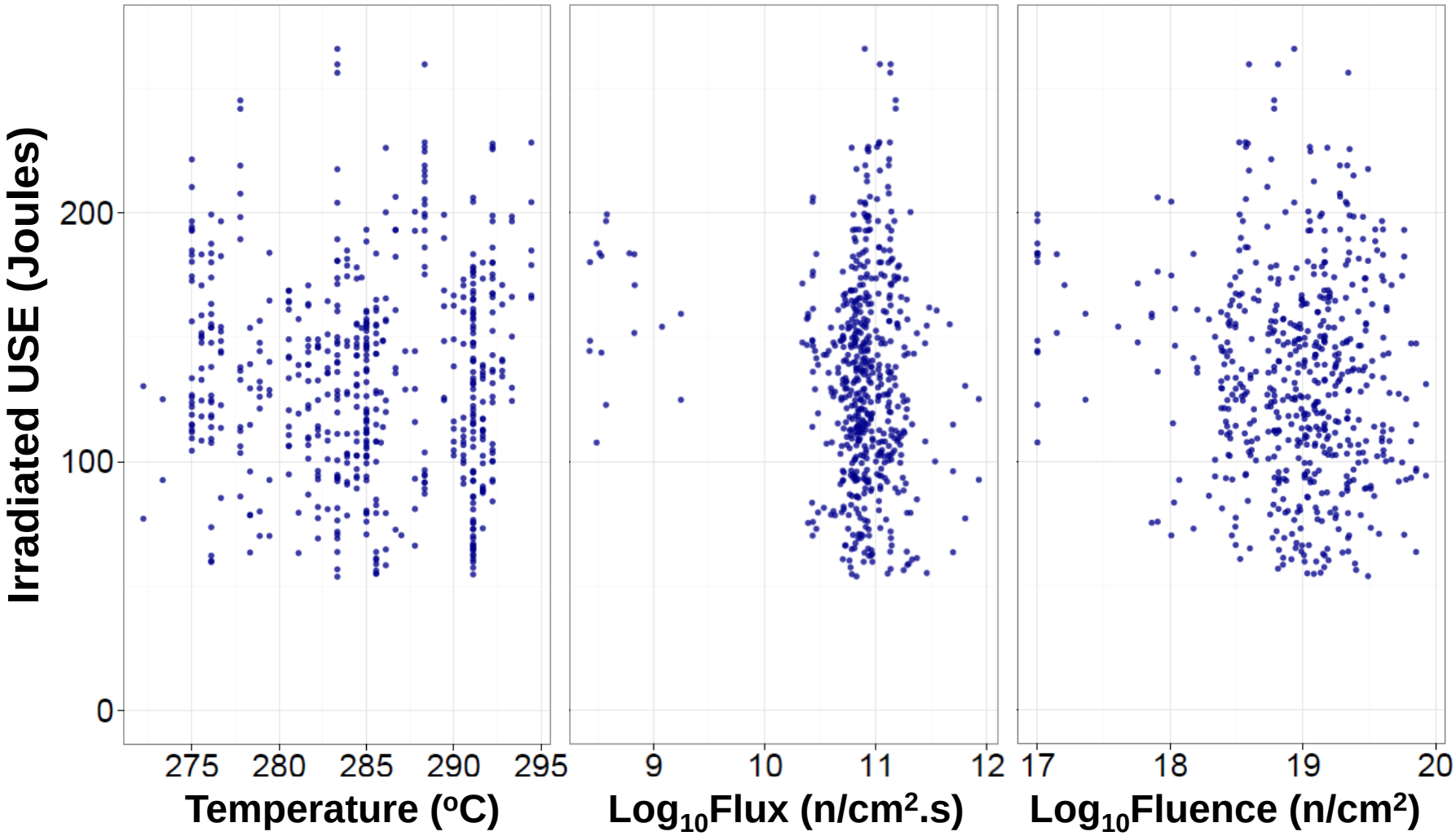


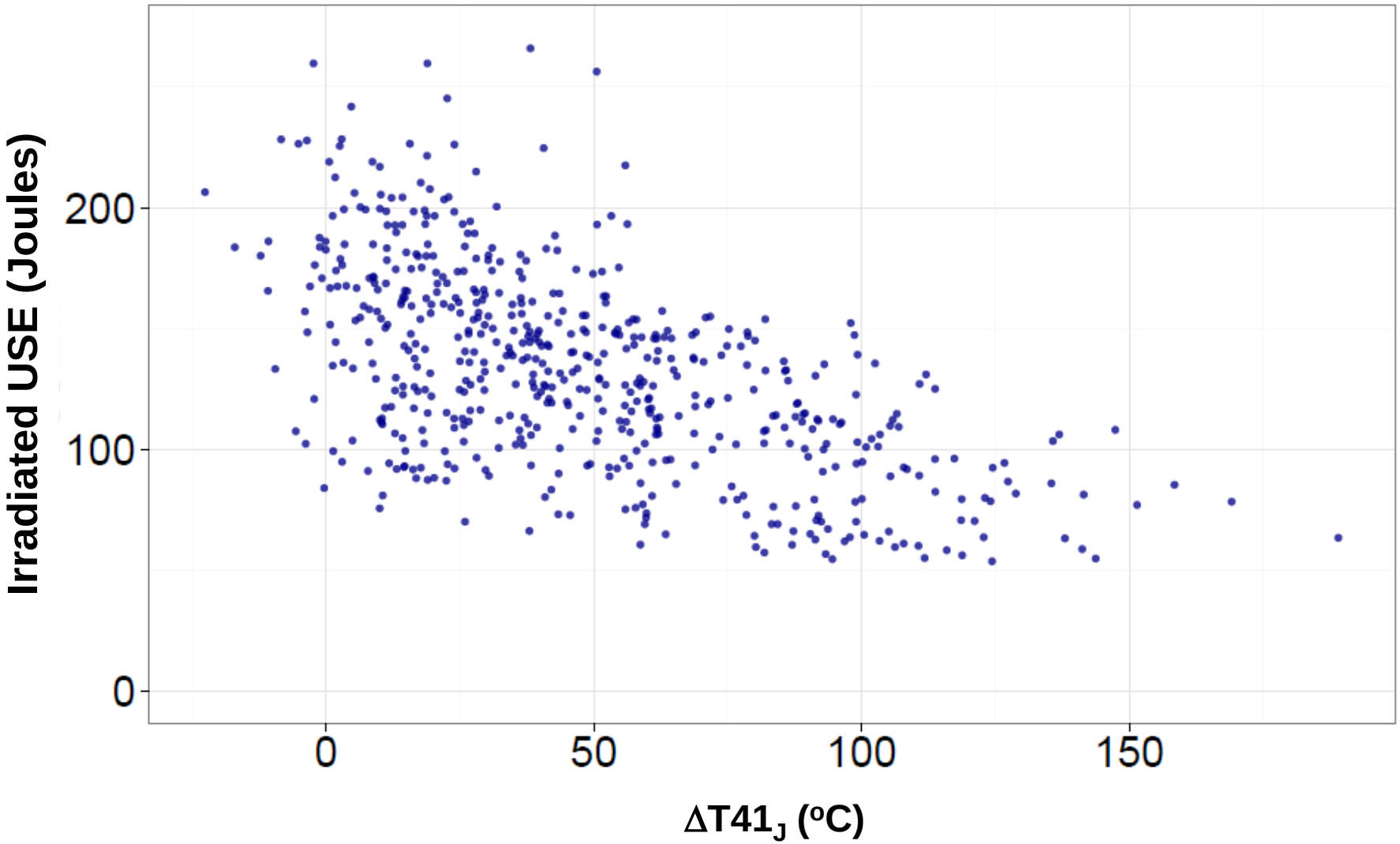
Data Trends

Upper Shelf Energy and Exposure Variables



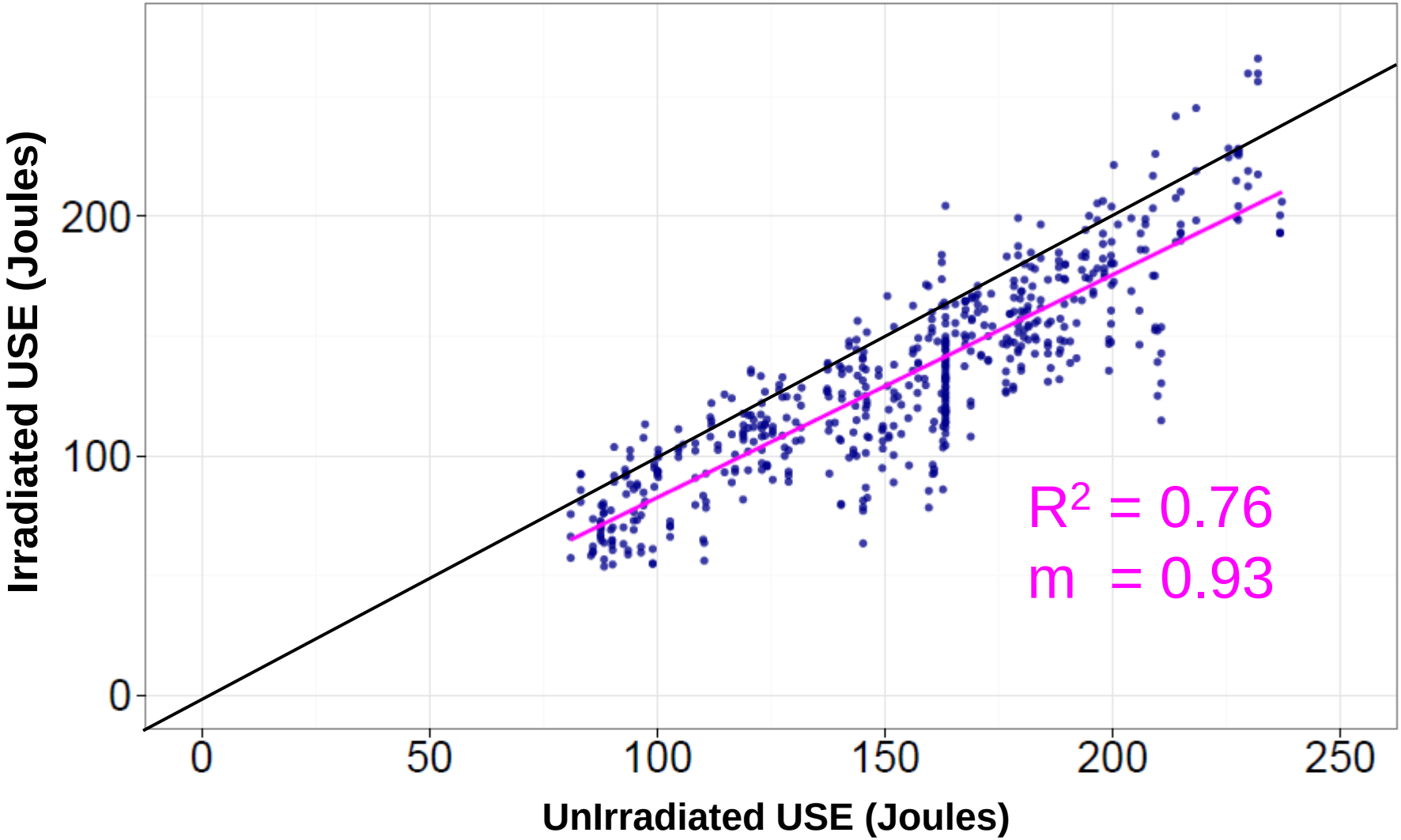
Data Trends

Upper Shelf Energy and $\Delta T41_J$



Data Trends

Upper Shelf Energies



New Model Investigated

$USE_{UN\text{-}IRRADIATED}$, Fluence, Cu Model

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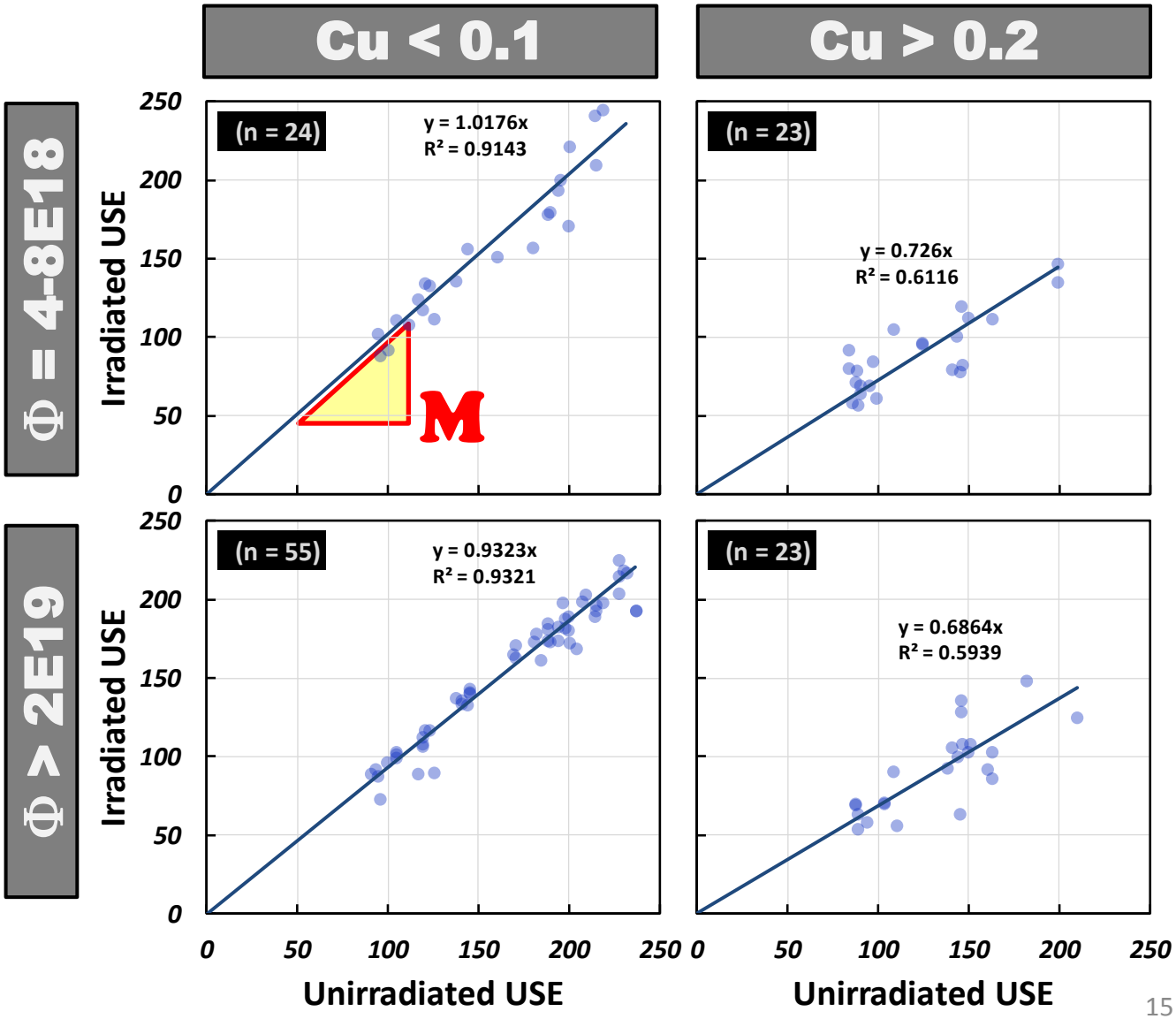
Decrease of USE (i.e., ↓ M) from its un-irradiated value most affected by

- **Fluence**
- **Copper**



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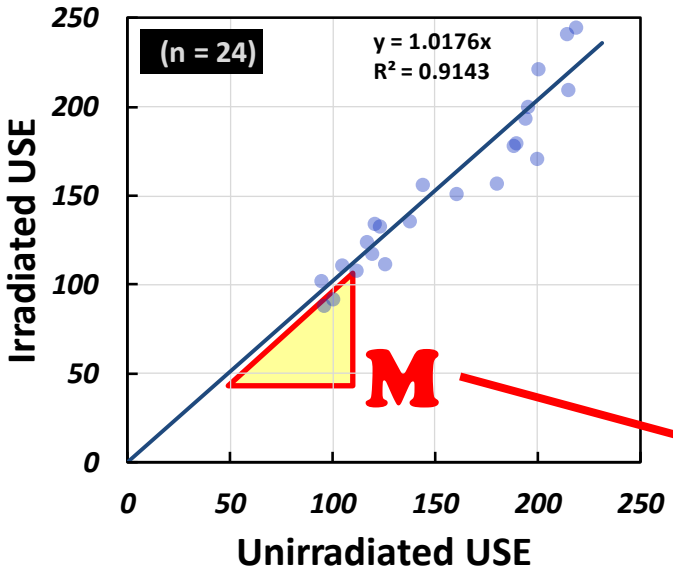
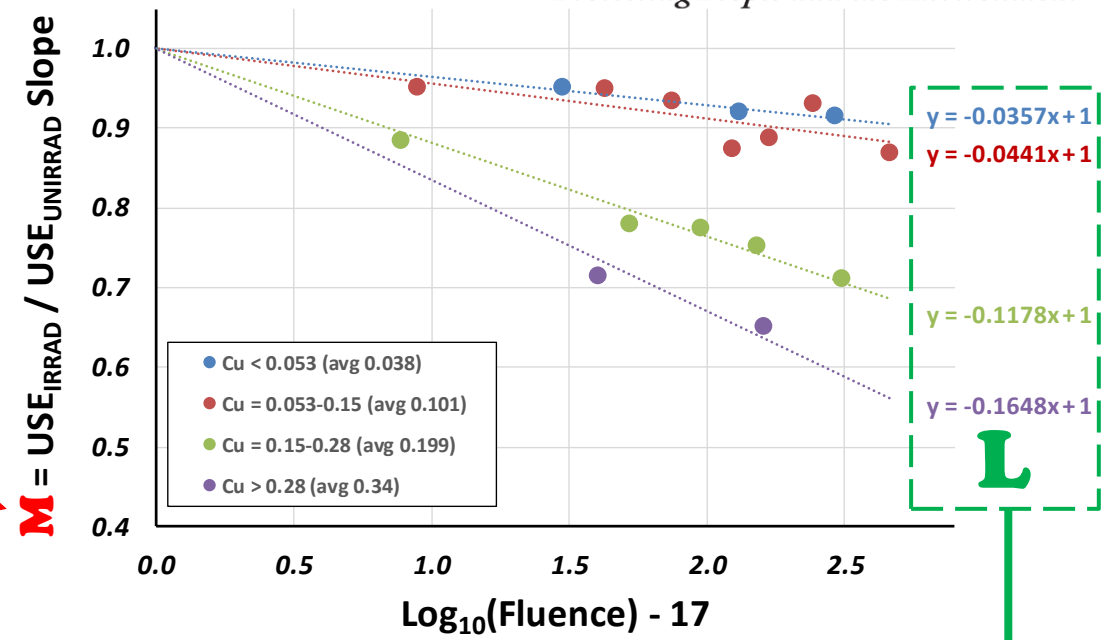
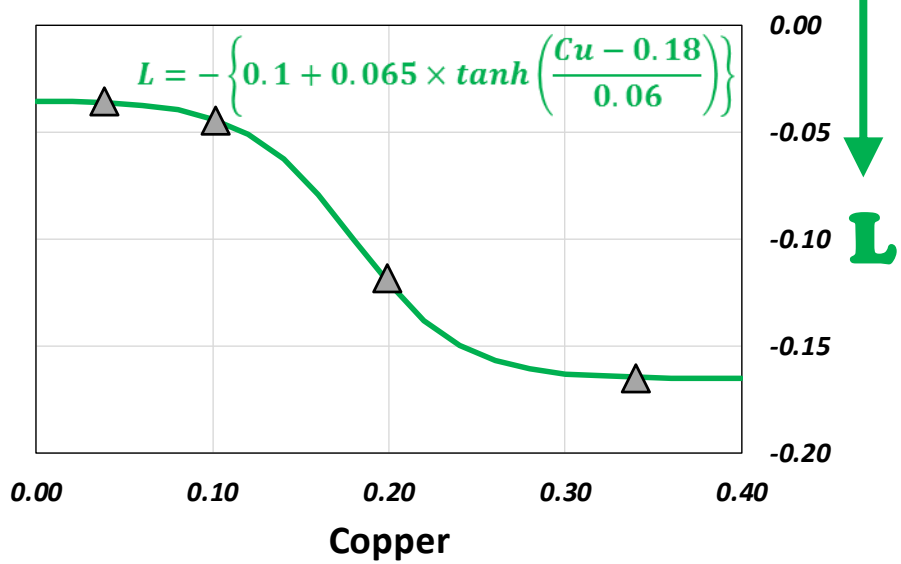




$$USE_{IRRAD} = USE_{UNIRRAD} \times \{1 + L \times [log_{10}(\Phi) - 17]_{+}\}$$

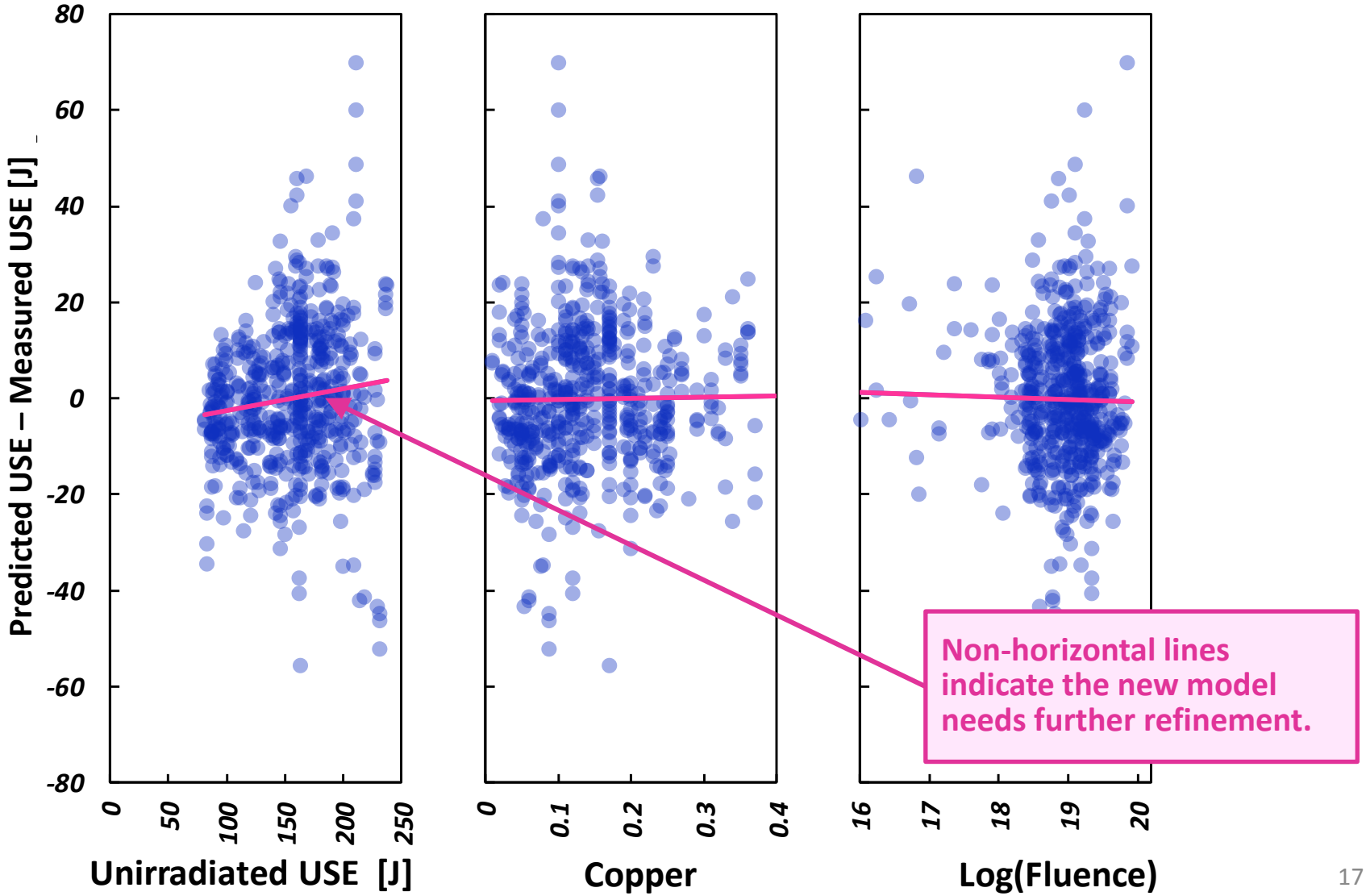


Assessment

… of variables in the new model

$$USE_{IRRAD} = USE_{UNIRRAD} \times \{1 + L \times [log_{10}(\Phi) - 17]_+\}$$

σ = 15.1J

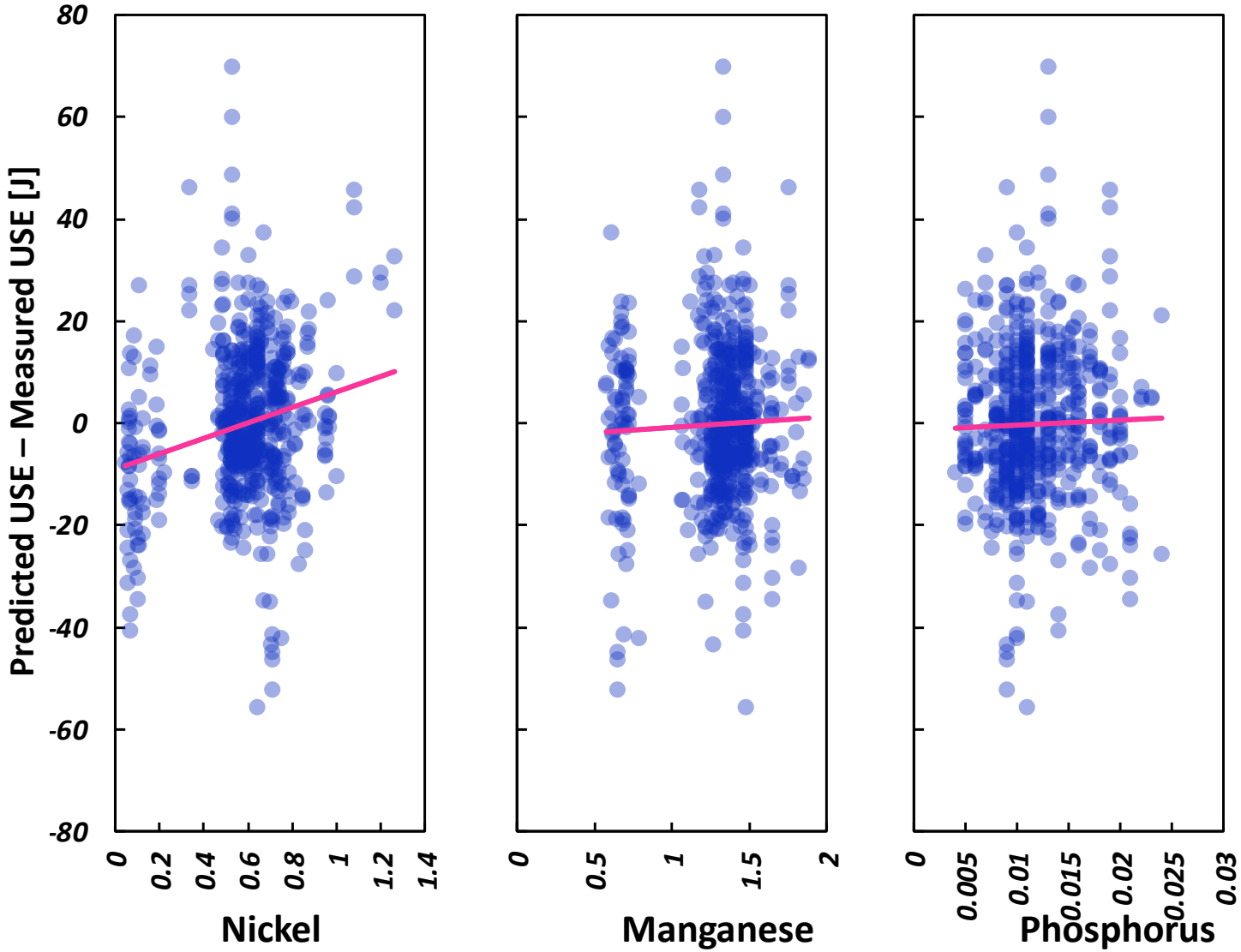


Non-horizontal lines indicate the new model needs further refinement.

Assessment

… of composition variables not in the new model

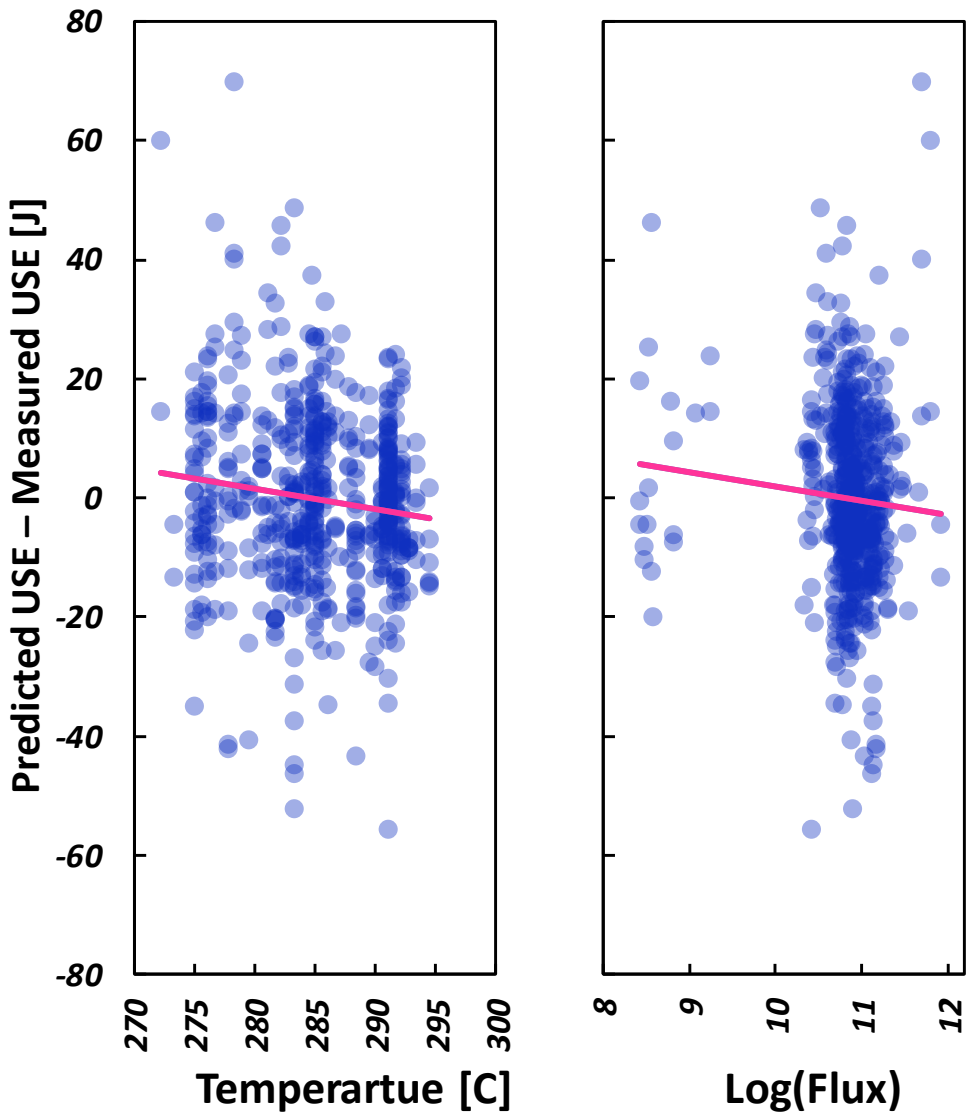
$$USE_{IRRAD} = USE_{UNIRRAD} \times \{1 + L \times [log_{10}(\Phi) - 17]_+\}$$



Assessment

… of exposure variables not in the new model

$$USE_{IRRAD} = USE_{UNIRRAD} \times \{1 + L \times [log_{10}(\Phi) - 17]_{+}\}$$



Next steps

- Finalize fitting database
- Refine this model
- Explore other models
- Model validation

Presentation Summary

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- Data indicates highest dependencies of USE_{IRRAD} on copper content and fluence.
- Initial equation for predicting USE_{IRRAD} based upon the joined REAP and E10.02 data.
- Additional work on fitting data continues from the REAP and E10.02 datasets.