

# Using Weibull Distribution Analysis to Evaluate ALARA Performance

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## Introduction – Who We Are

- **Janice Watkins and Derek Hagemeyer of Oak Ridge Associated Universities (ORAU)**
- **Ed Frome, Consulting Scientist for Oak Ridge Institute for Science and Education (ORISE)**
- **Project work through ORISE**
- **Under contract to the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission**
- **ORAU maintains the occupational radiation exposure databases for DOE and NRC.**

# Measuring ALARA

- ALARA is a fundamental philosophy of radiation protection codified in NRC and DOE regulations
- ALARA requires a *balance* between collective and individual dose optimization
- Current performance indicators give valuable but incomplete information
  - Collective dose,
  - Number of workers with measurable dose,
  - Average measurable dose,
  - Three-year average dose per reactor
- These are based on collective data and do not consider the distribution of dose to individuals

## Our Goal

- **To develop objective, data-driven statistically justifiable ALARA performance indicators**
- **Applicable to a variety of facility types**
- **In combination with existing parameters, provides a more balanced measure of radiation protection performance based on the way the dose is distributed among the exposed workforce**

# Research Objectives

- **Objective 1**  
Evaluate utility of Weibull distribution for assessing ALARA application to radiation exposed workers
- **Objective 2**  
Derive ALARA performance indicators based on Weibull distribution parameters
- **Objective 3**  
Design graphics that illustrate ALARA performance indicators and properties of site dose distributions

# ALARA Performance Indicators

- **Multiple ALARA indicators possible**
  - Shape parameter  $\alpha$ 
    - Slope of Weibull probability plot regression line (negative)
  - Fitted 99<sup>th</sup> percentile with confidence interval -- or
  - Percent exceedance with confidence interval
- **Weibull probability plots**
  - Provide visual evidence of ALARA effectiveness

## Details of Weibull Probability Plot

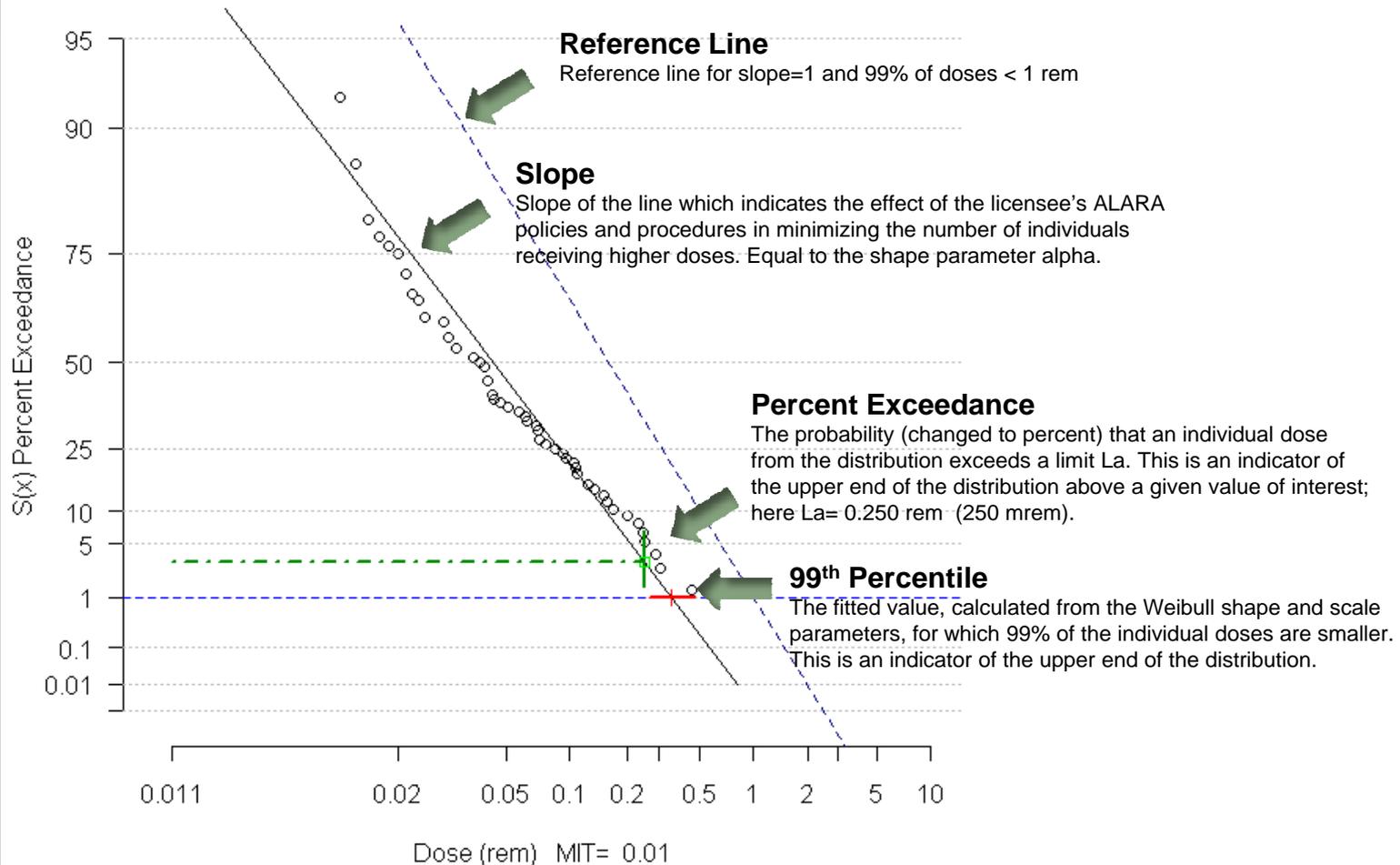
- Points (  $\ln x, -\ln(-\ln x)$  )
- Regression line: solid black line
- Labels on axes adjusted
  - Horizontal: TEDE before MIT subtracted
  - Vertical: % exceedance for values of interest
- Fitted 99<sup>th</sup> %tile:
  - Intersection of blue horizontal dashed line at 1% with regression line
  - 95% CL indicated by horizontal red segment

## Details of Weibull Probability Plot (cont.)

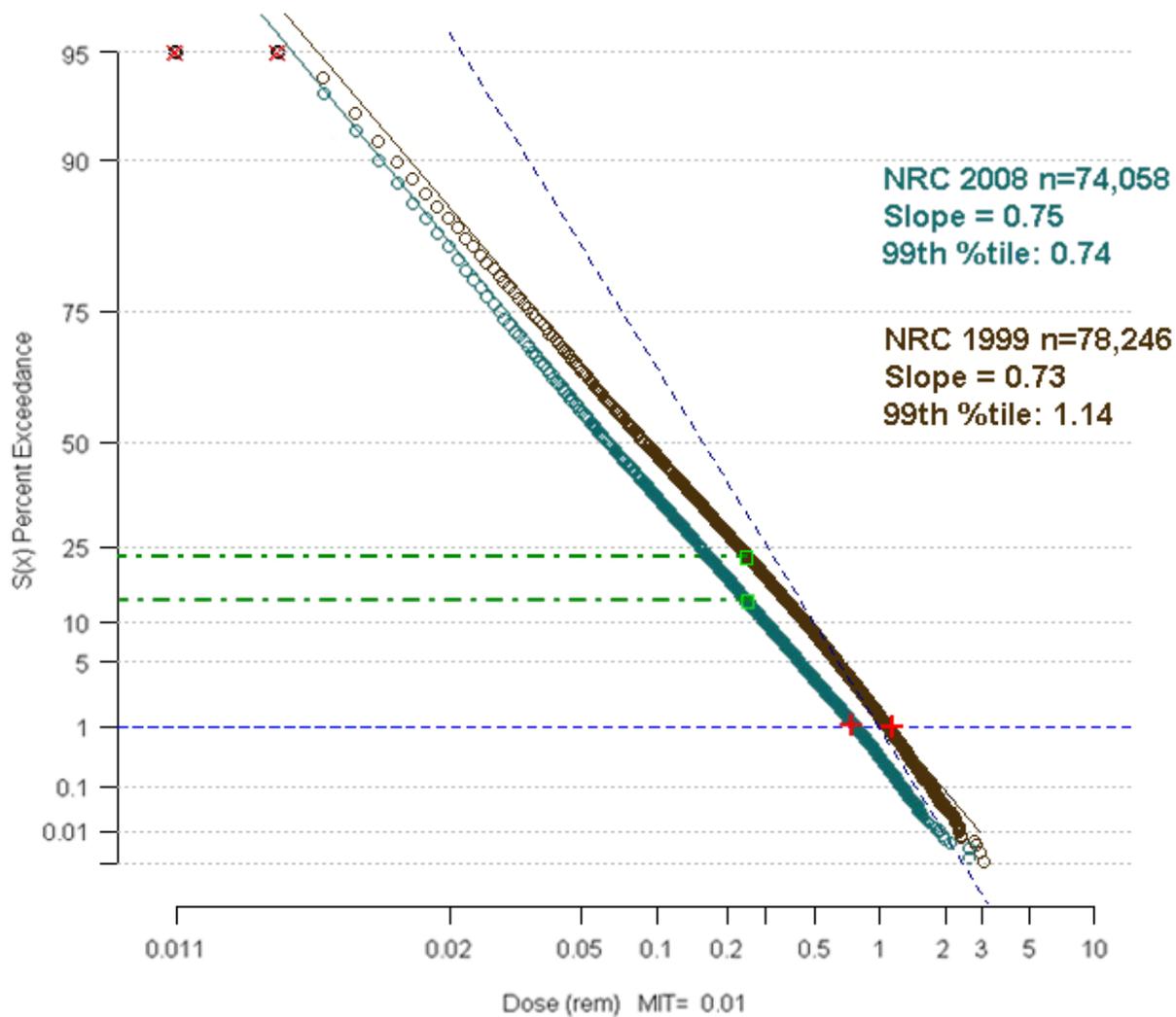
- **Percent exceedance: Shown for 0.25 rem**
  - Intersection of green horizontal dot-dashed line with regression line
  - 95% confidence interval indicated by vertical green segment
- **Reference line for comparisons**
  - Slanted green dashed line with slope = 1
  - Indicates boundary for 99% of doses being  $< 1$  rem

# Annotated Probability Plot

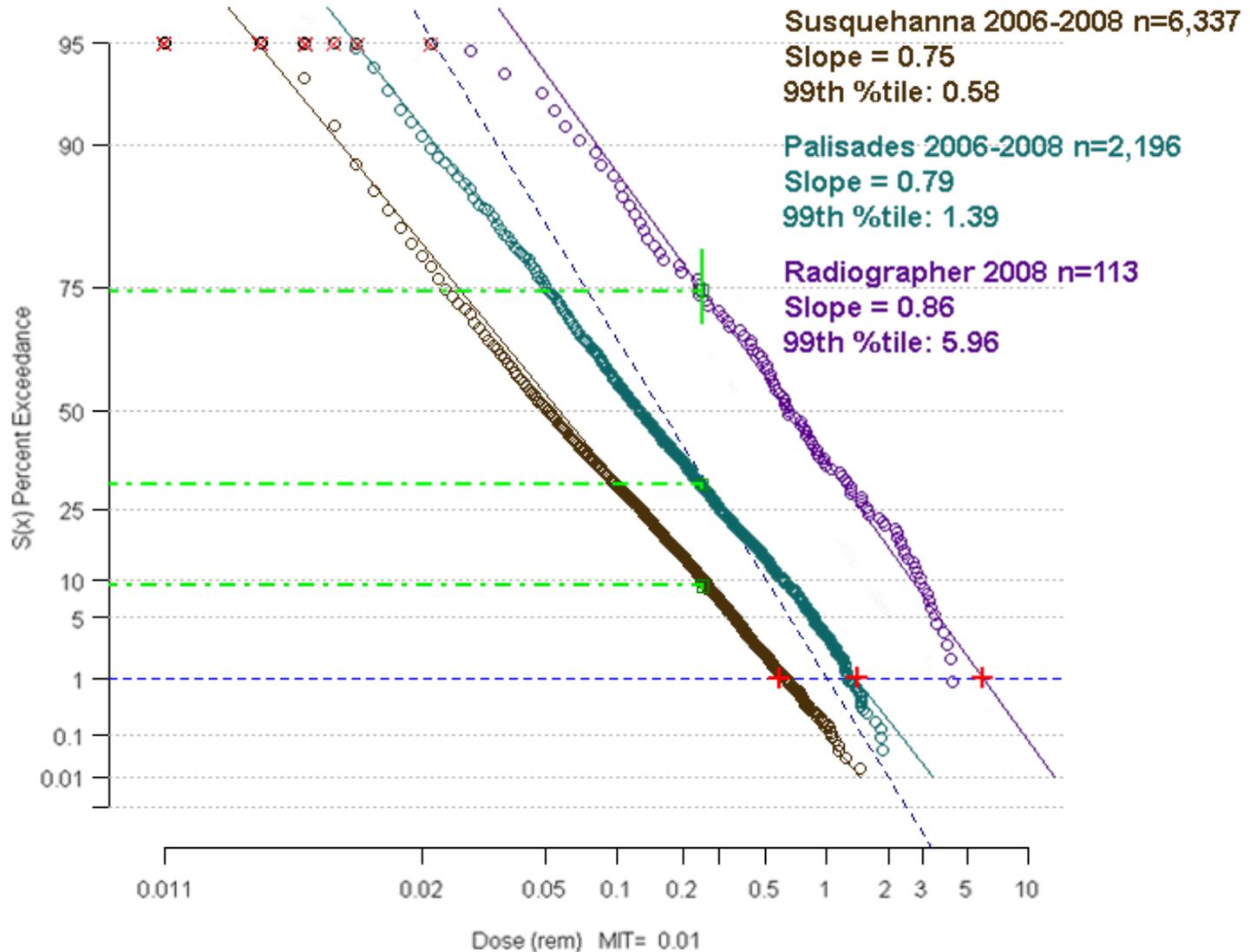
DOE 2008 NTS  $n_x = 75$  Median=0.038 Mean=0.07  
Percent Exceedance for  $L_a=0.25$  is 3.115: 95% CLs (1.446, 6.71)  
99th Percentile is 0.35 :95% CLs (0.262, 0.469)



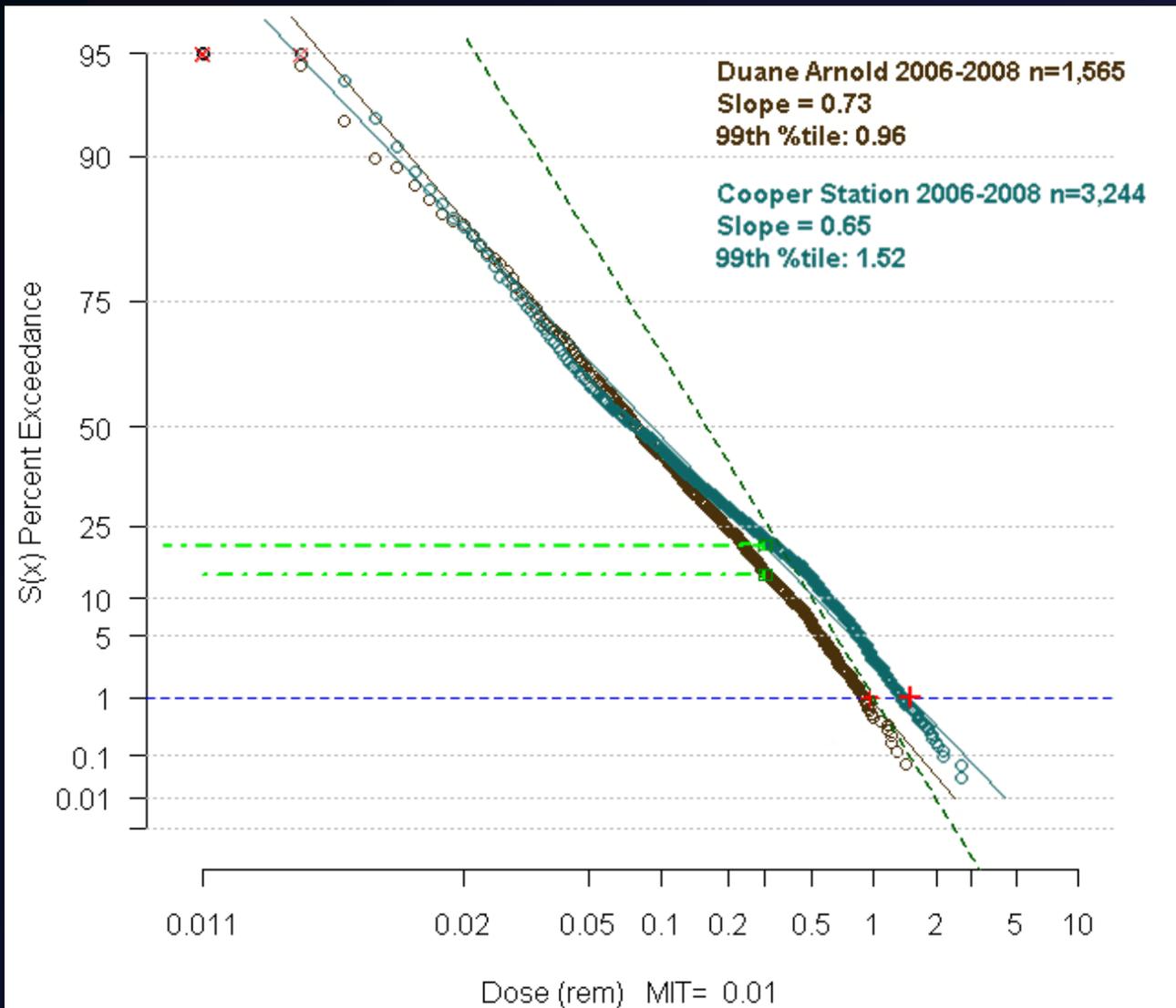
# All NRC Reactors Combined - 1999 and 2008



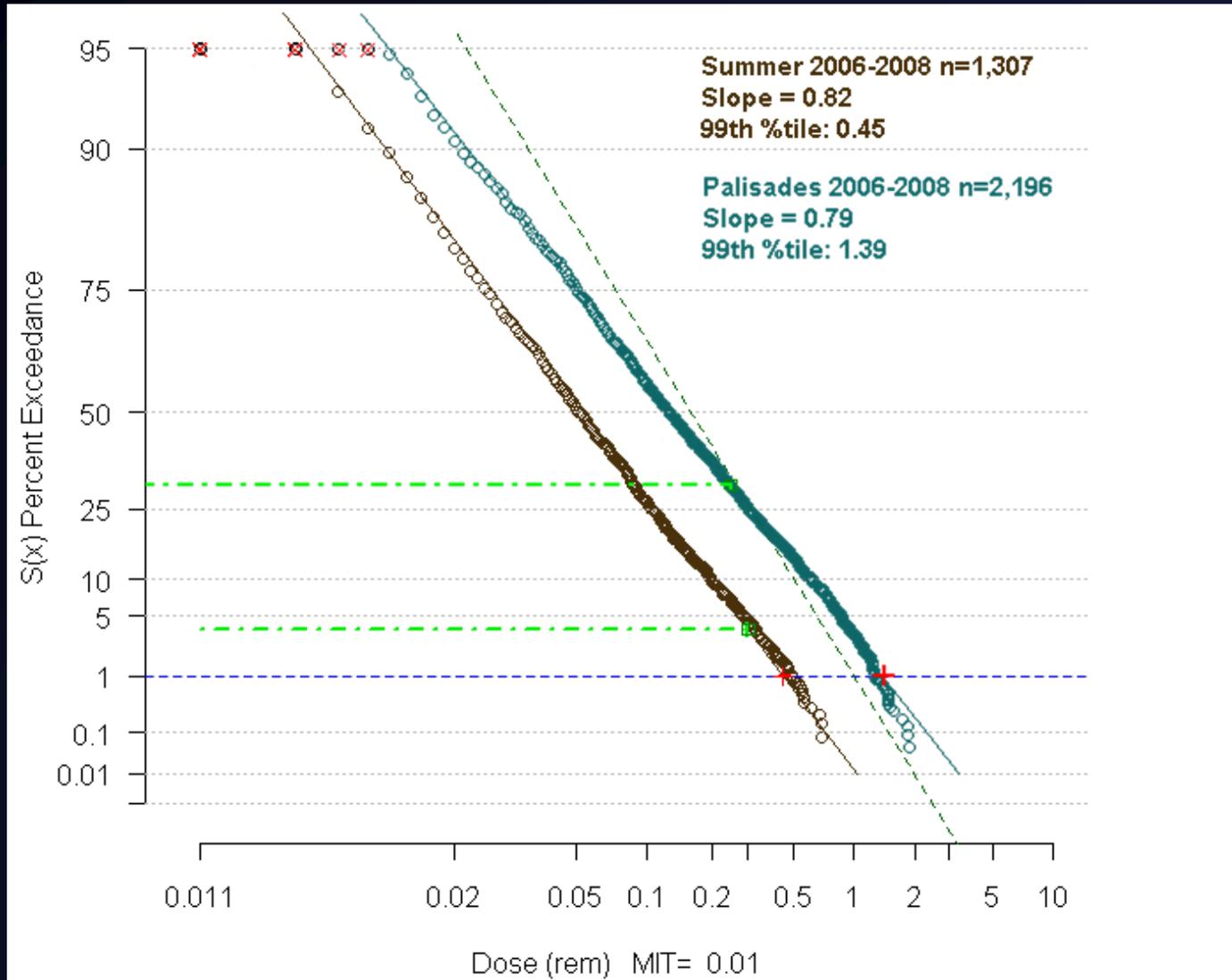
# Comparison of NRC Licensees



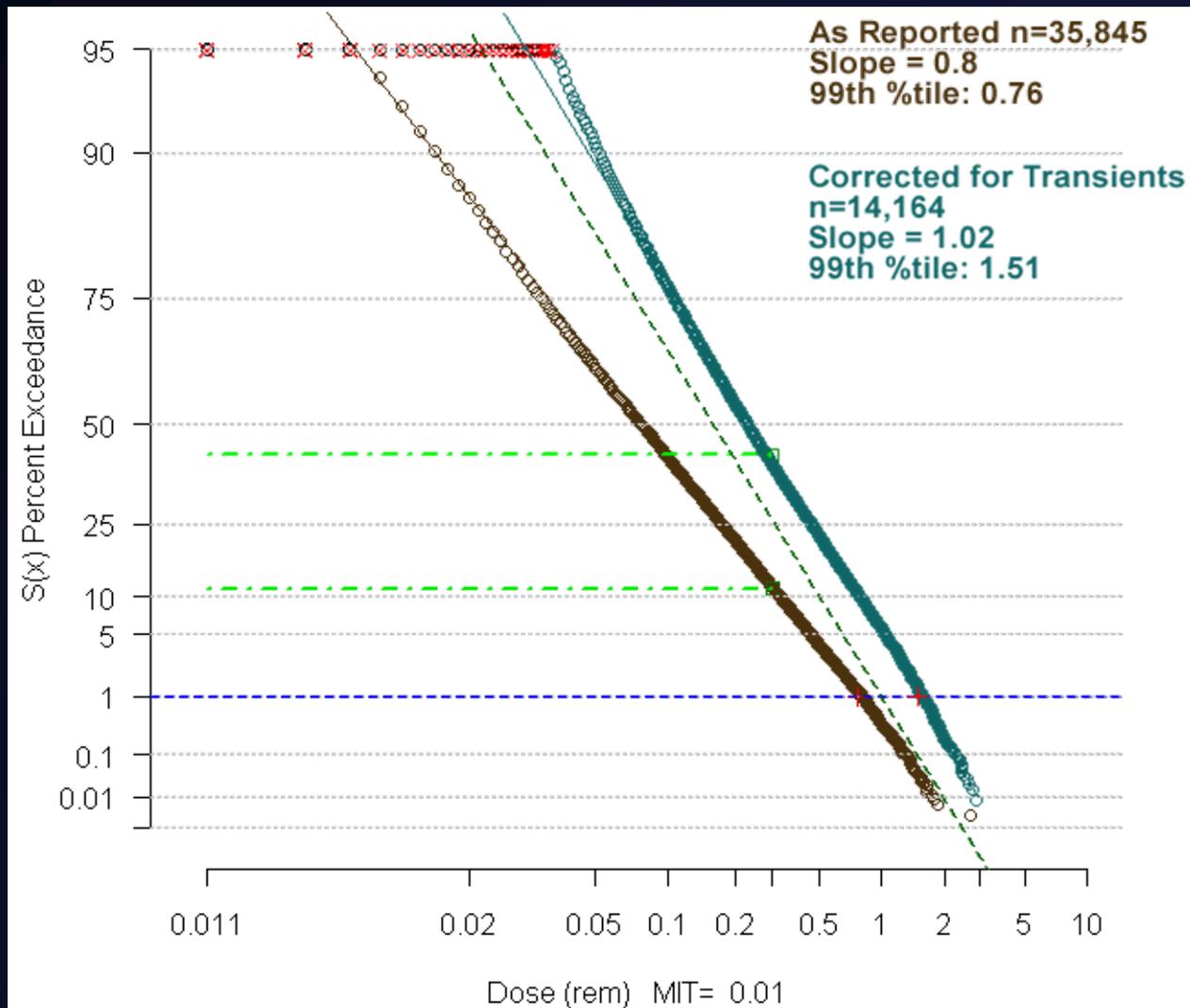
# BWRs - Duane Arnold, Cooper



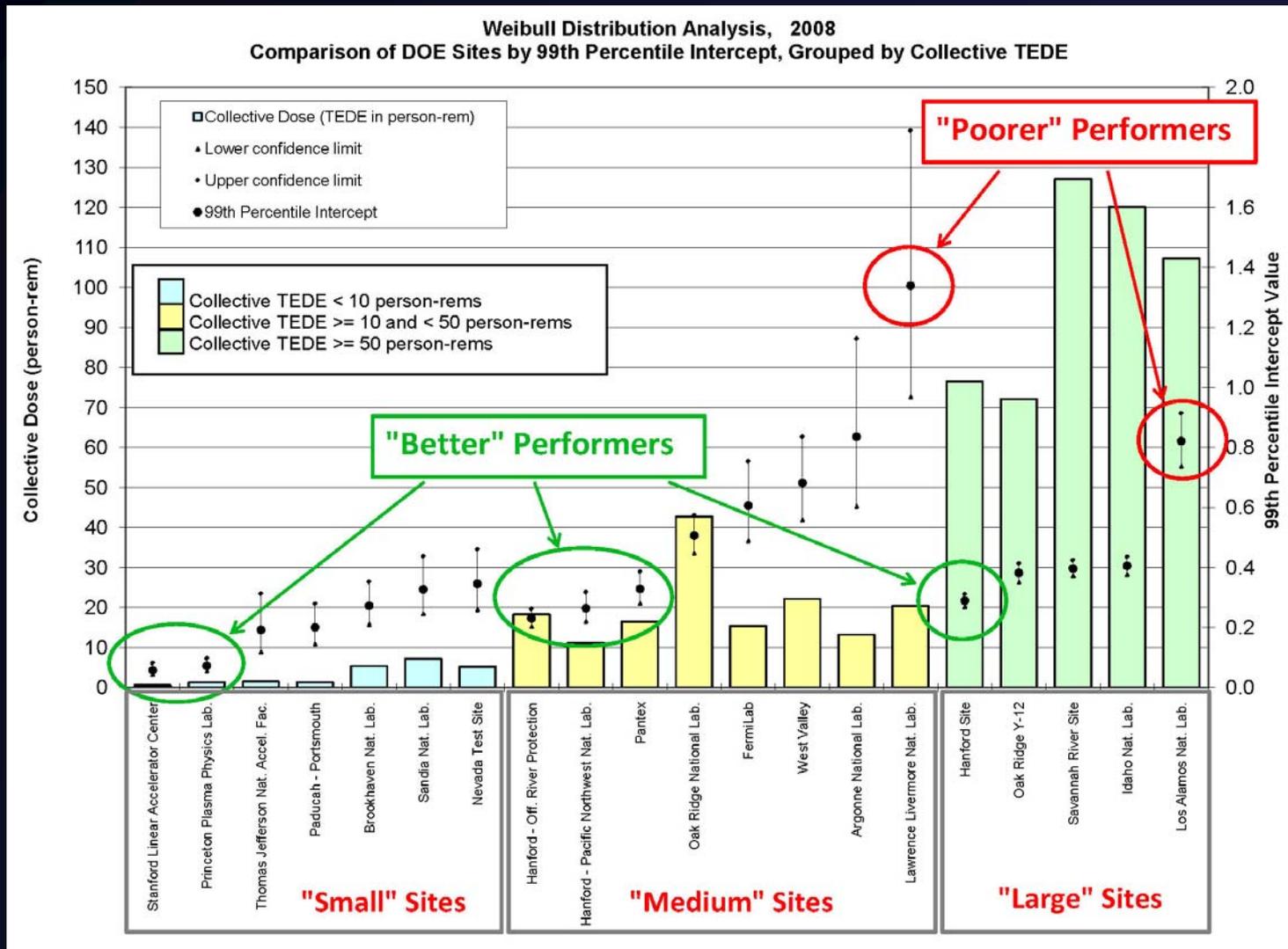
# PWRs - Summer, Palisades



# Transient Workers at Reactors, 2008

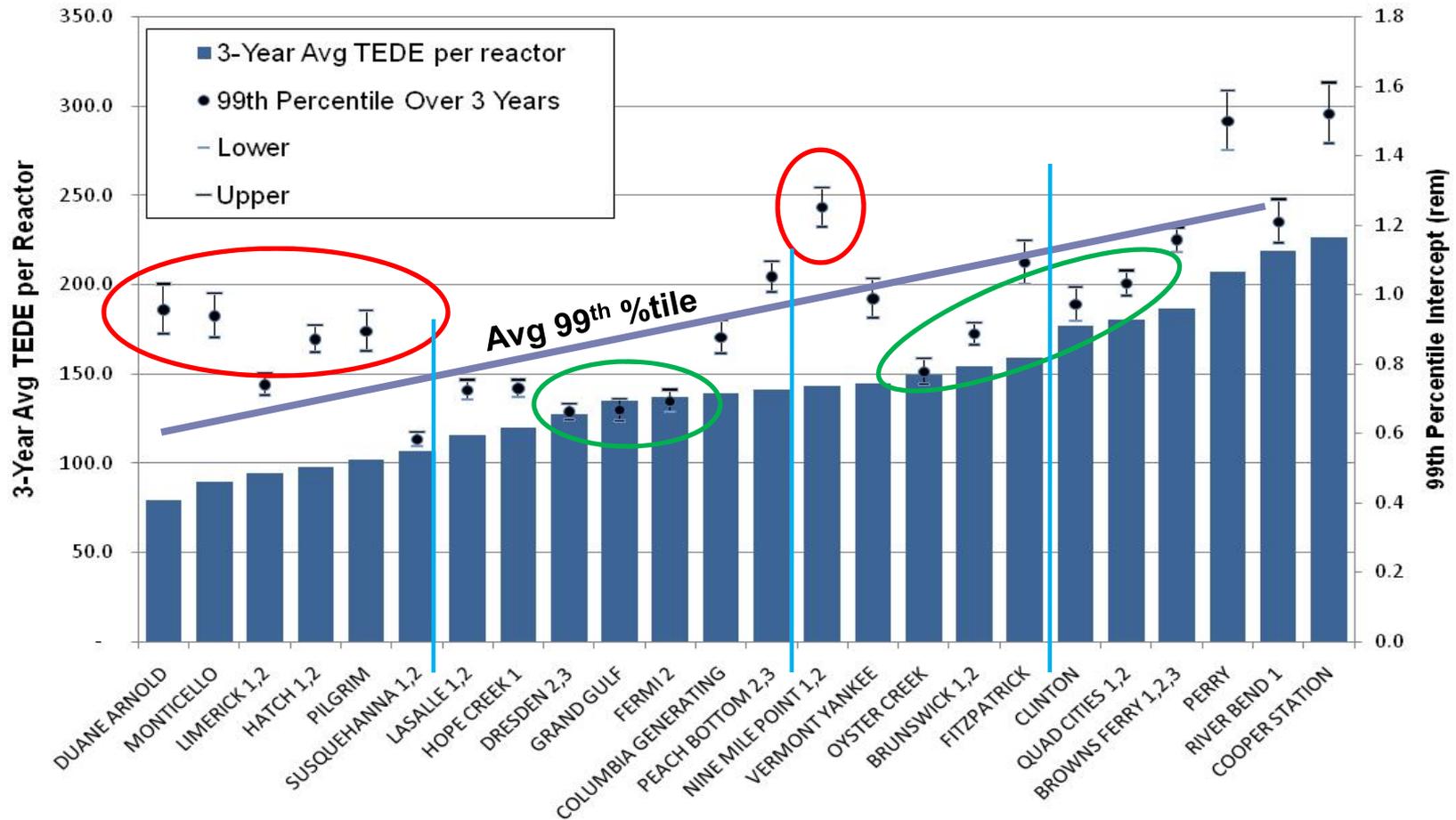


# Using Collective Dose and Weibull Performance Indicators to evaluate ALARA among Sites



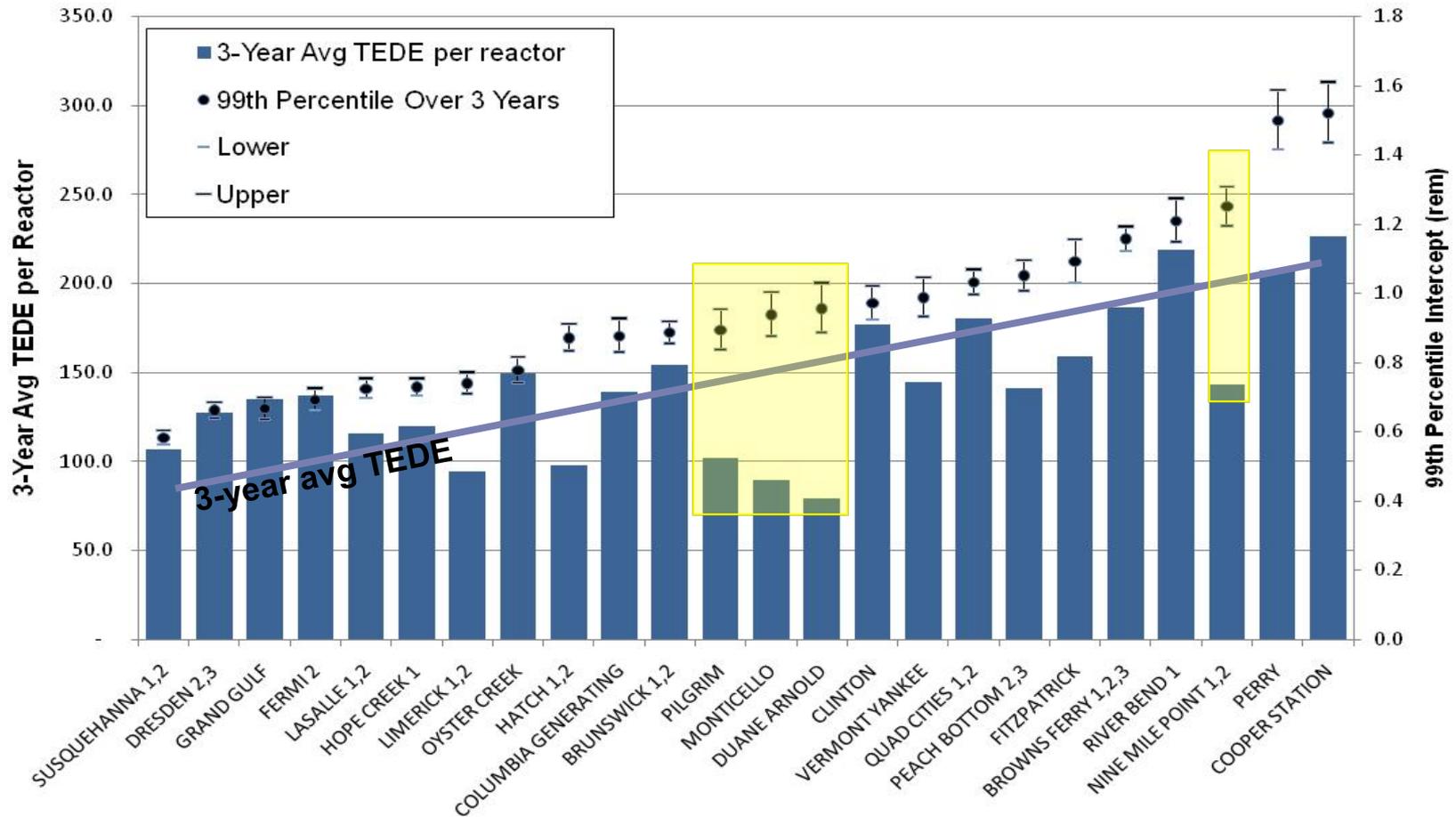
# BWRs Listed by 3-Year Avg TEDE

BWR 2006-2008 3-Year Avg TEDE and 99th Percentile

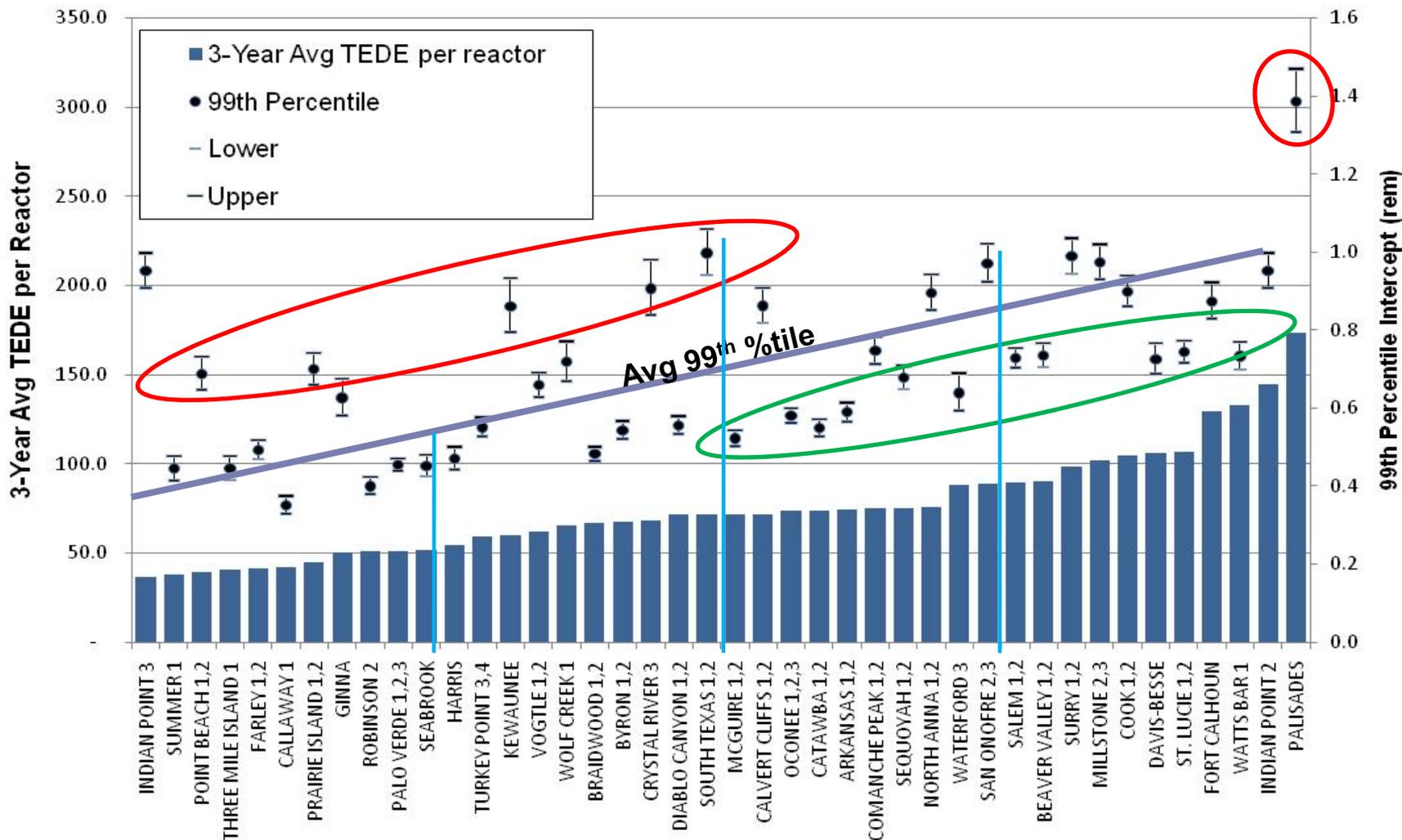


# BWRs Listed by 99th Percentile

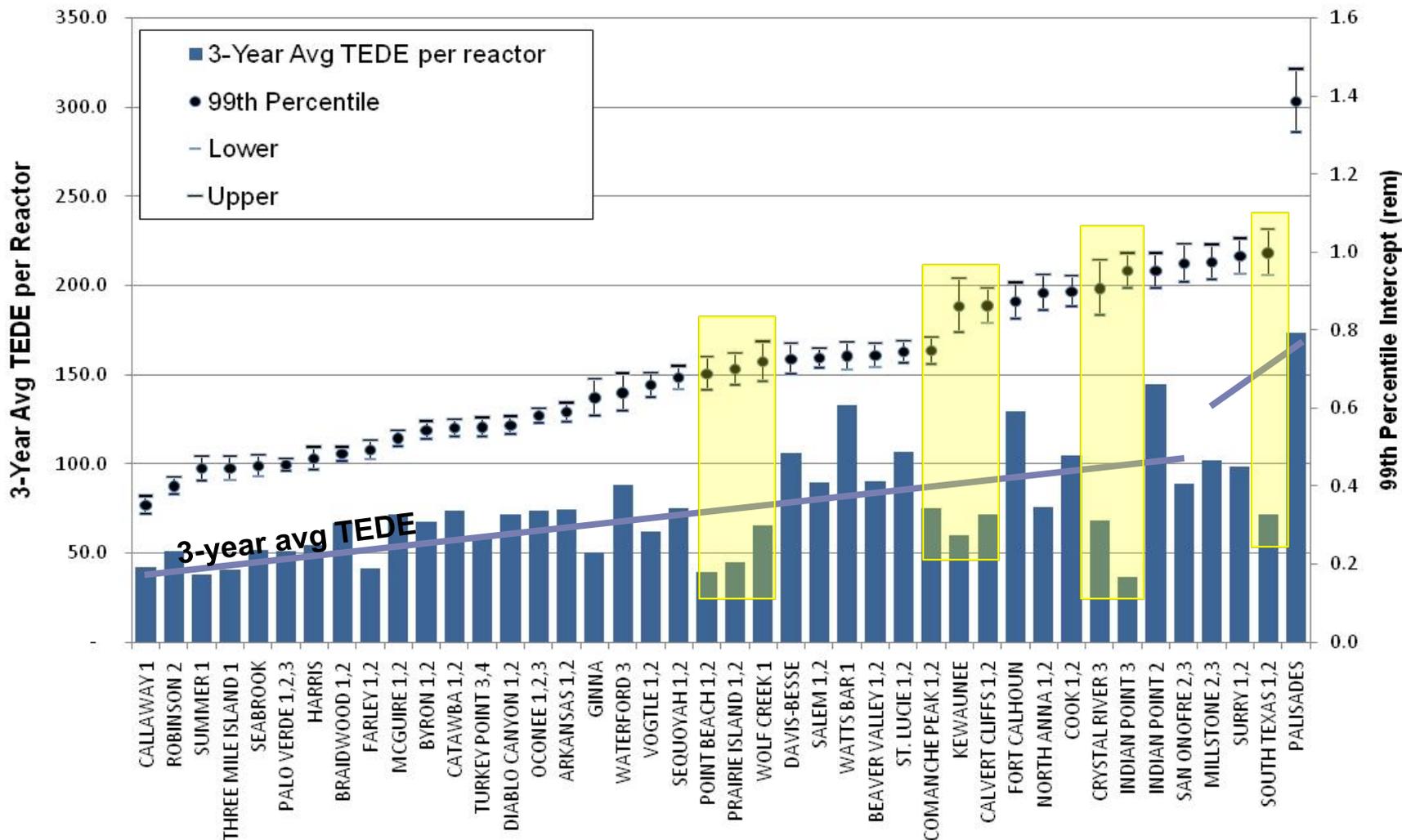
BWR 2006-2008 3-Year Avg TEDE and 99th Percentile



# PWR 2006-2008 3-Year Avg TEDE and 99th Percentile



# PWR 2006-2008 3-Year Avg TEDE and 99th Percentile



## Conclusions

- Objective performance indicators based on Weibull distribution analysis provide enhanced information for evaluating ALARA at a site
- Graphs demonstrate this approach is useful for comparing ALARA over time or among sites
- Analysis of dose distributions from a variety of sites establish the wide applicability of the Weibull approach
- Software is being developed to implement these methods
- Provides *additional* perspective on ALARA performance

# Contact

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