Using Weibull Distribution Analysis to Evaluate ALARA Performance

E.L. Frome, J.P. Watkins, and
D.A. Hagemeyer

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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

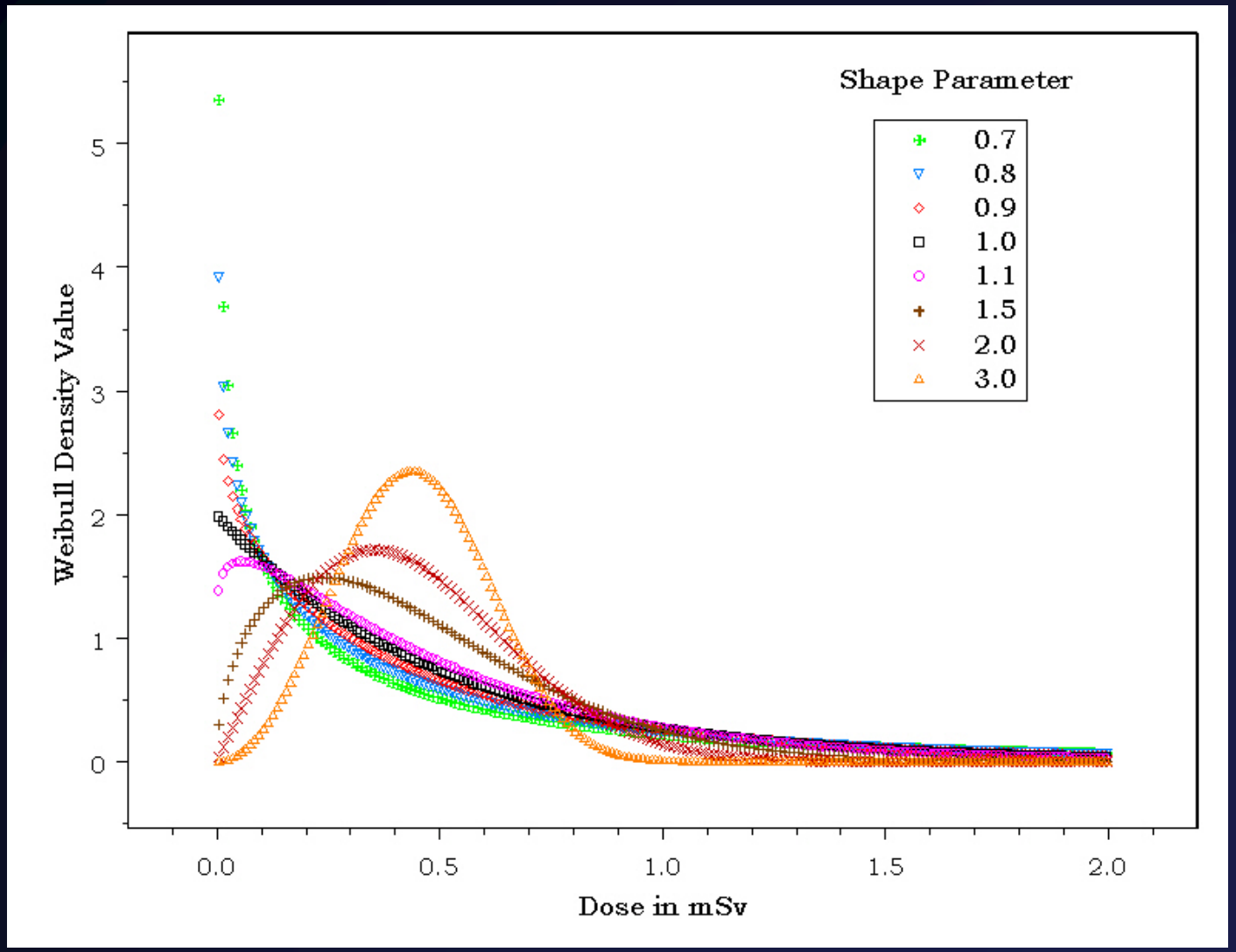
Research Objectives

- **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

Weibull Distribution Analysis

- **Weibull**
  Flexible statistical distribution for describing positive data, especially when frequent lower values and rare high values
- **Proportion of doses > x**
  $S(X) = 1 - F(X) = \exp(-[x/\beta]^{\alpha})$, $\alpha>0$ (shape), $\beta>0$ (scale)
- **Definition of x**
  Each worker's annual TEDE – MIT, where MIT fixed at 0.1 mSv
- **Maximum likelihood**
  Statistical method to select the shape and scale parameters for the particular Weibull that best matches a site's doses

Weibull Density Function
for Scale Parameter of 0.5



Weibull Analysis Approach

- **Weibull model fits to dose distributions**
  Generally good since density function is asymptotic to y-axis when shape parameter < 1
- **Performance indicators**
  Generated from Weibull parameters estimates for the site
- **R software functions**
  Written to calculate ML parameter estimates and performance indicators and to create Weibull plots

ALARA Performance Indicators

- **Multiple ALARA indicators recommended**
  - Shape parameter α
    - Slope of Weibull probability plot regression line (negative)
  - Fitted 99th percentile with confidence interval -- or
  - Percent exceedance with confidence interval
- **Weibull probability plots**
  - Provide visual evidence of ALARA effectiveness

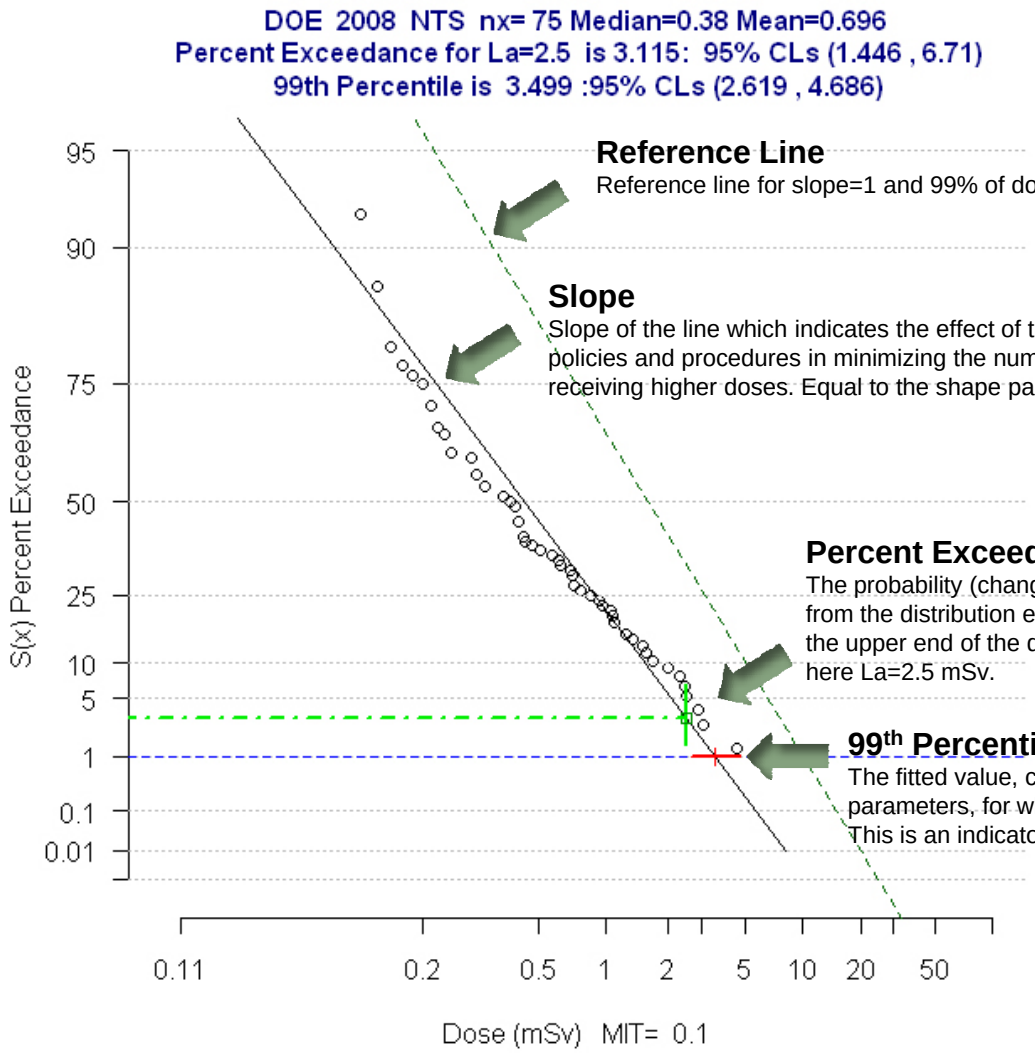
Details of Weibull Probability Plot

- 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 99th %tile:
  - Intersection of blue horizontal dashed line with regression line
  - 95% CL indicated by horizontal red segment

Details of Weibull Probability Plot (cont.)

- Percent exceedance: Shown for 2.5 mSv
  - Intersection of green horizontal dot-dashed line with regression line
  - 95% CI indicated by vertical green segment
- Reference line for comparisons
  - Slanted green dashed line with slope = 1
  - Indicates boundary for 99% of doses being < 10 mSv

Annotated Probability Plot



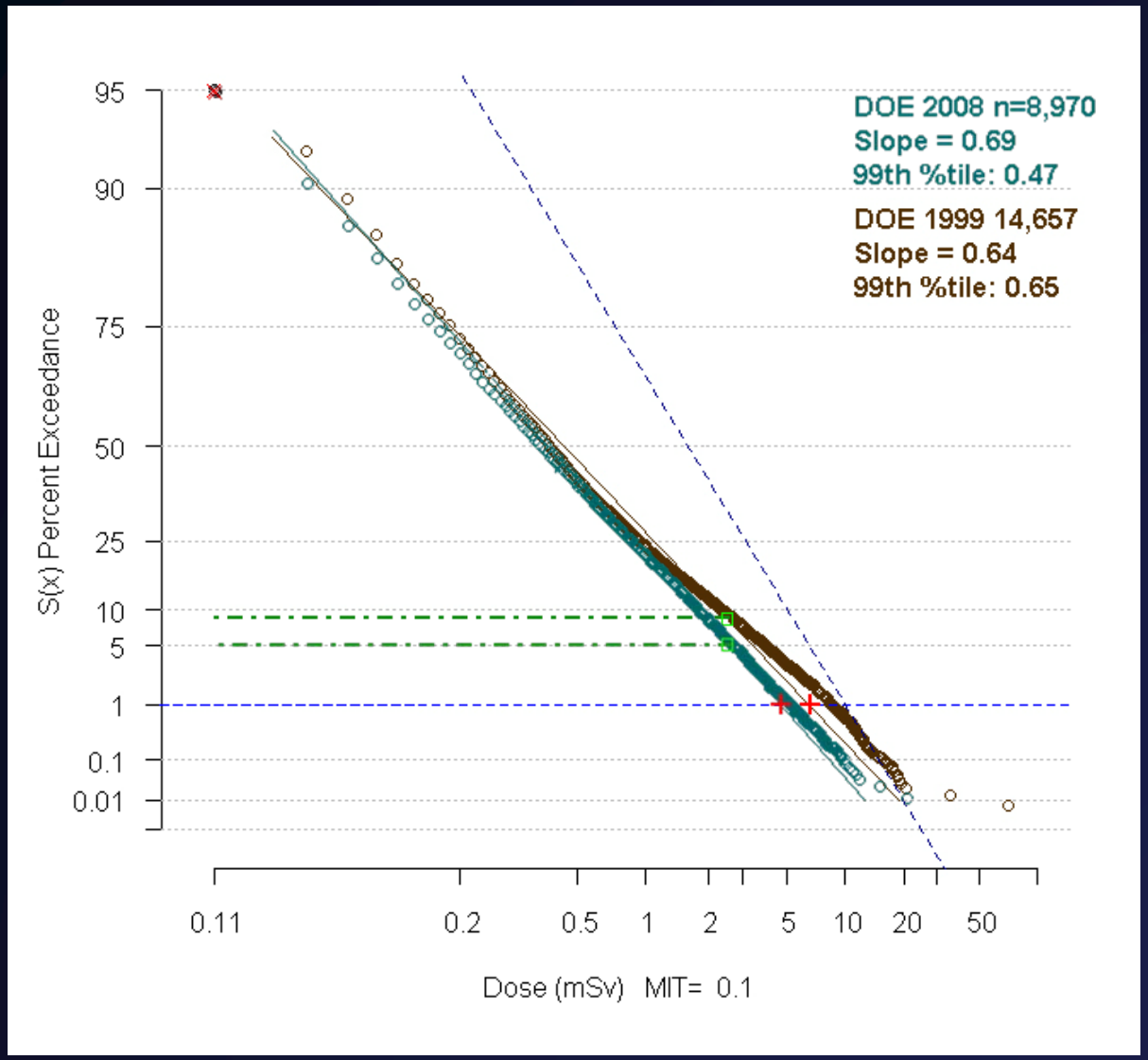
Reference Line
Reference line for slope=1 and 99% of doses < 10 mSv

Slope
Slope of the line which indicates the effect of the licensee's ALARA policies and procedures in minimizing the number of individuals receiving higher doses. Equal to the shape parameter alpha.

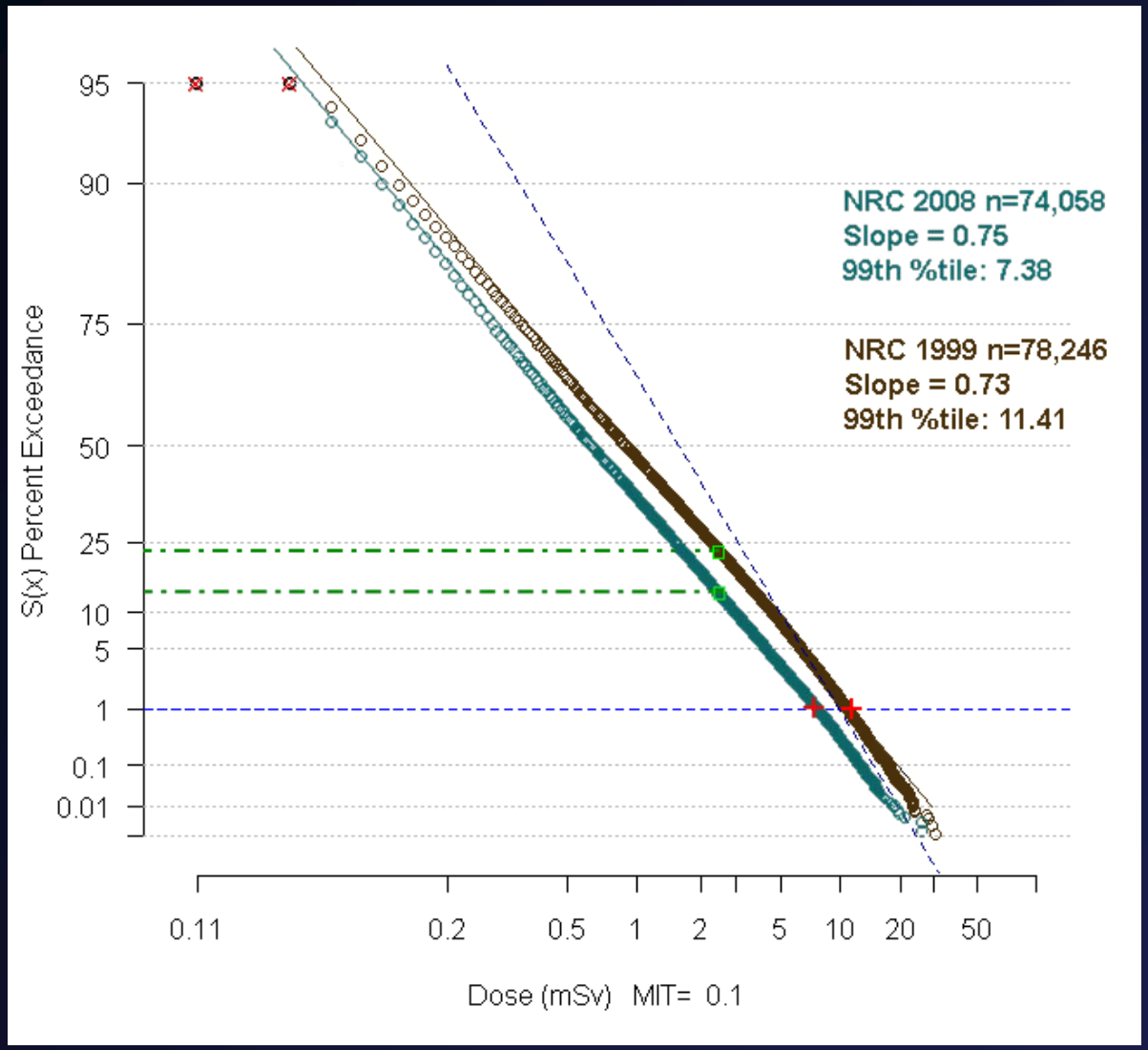
Percent Exceedance
The probability (changed to percent) that an individual dose from the distribution exceeds a limit La. This is an indicator of the upper end of the distribution above a given value of interest; here La=2.5 mSv.

99th Percentile
The fitted value, calculated from the Weibull shape and scale parameters, for which 99% of the individual doses are smaller. This is an indicator of the upper end of the distribution.

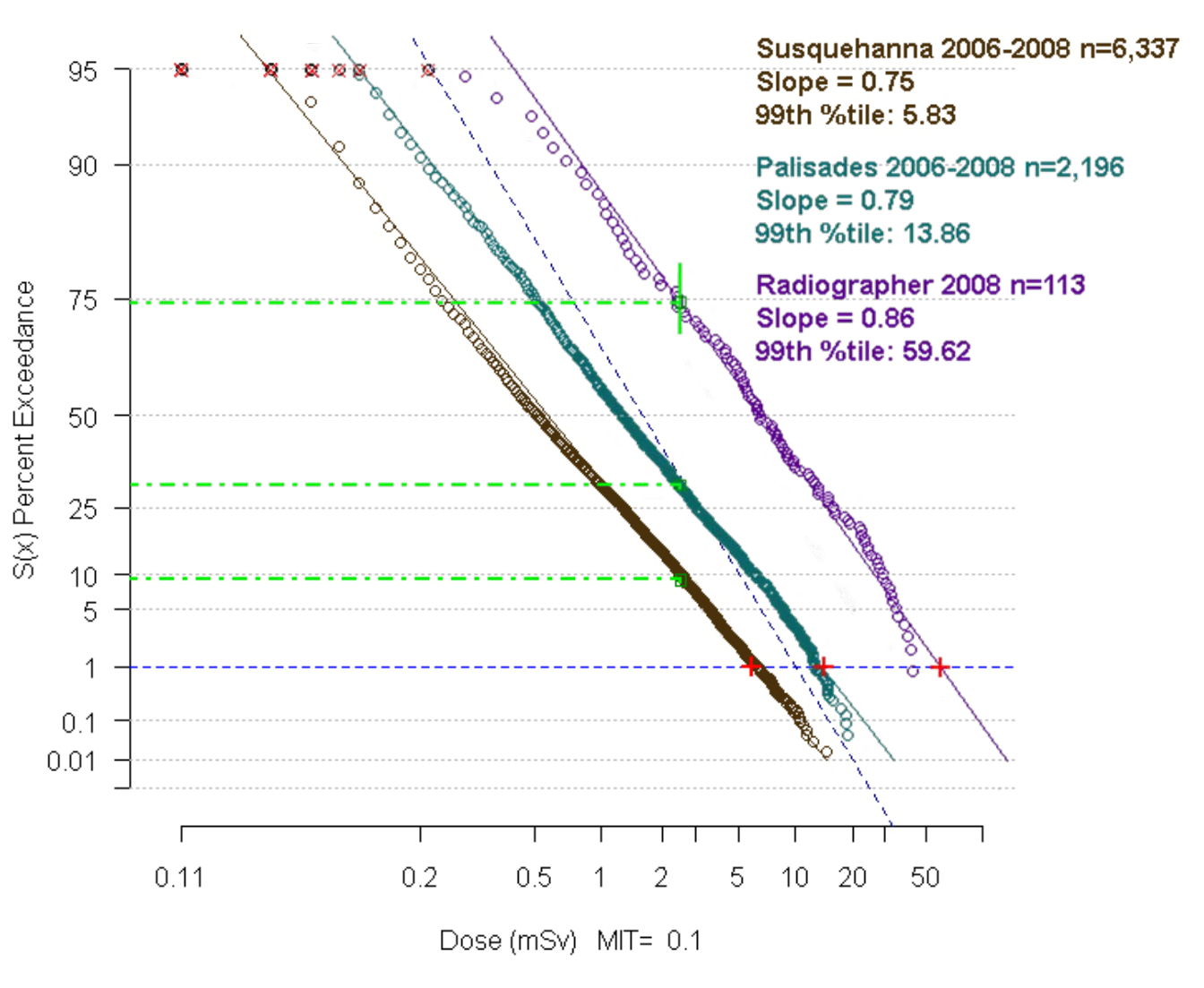
All DOE Sites - 1999 and 2008



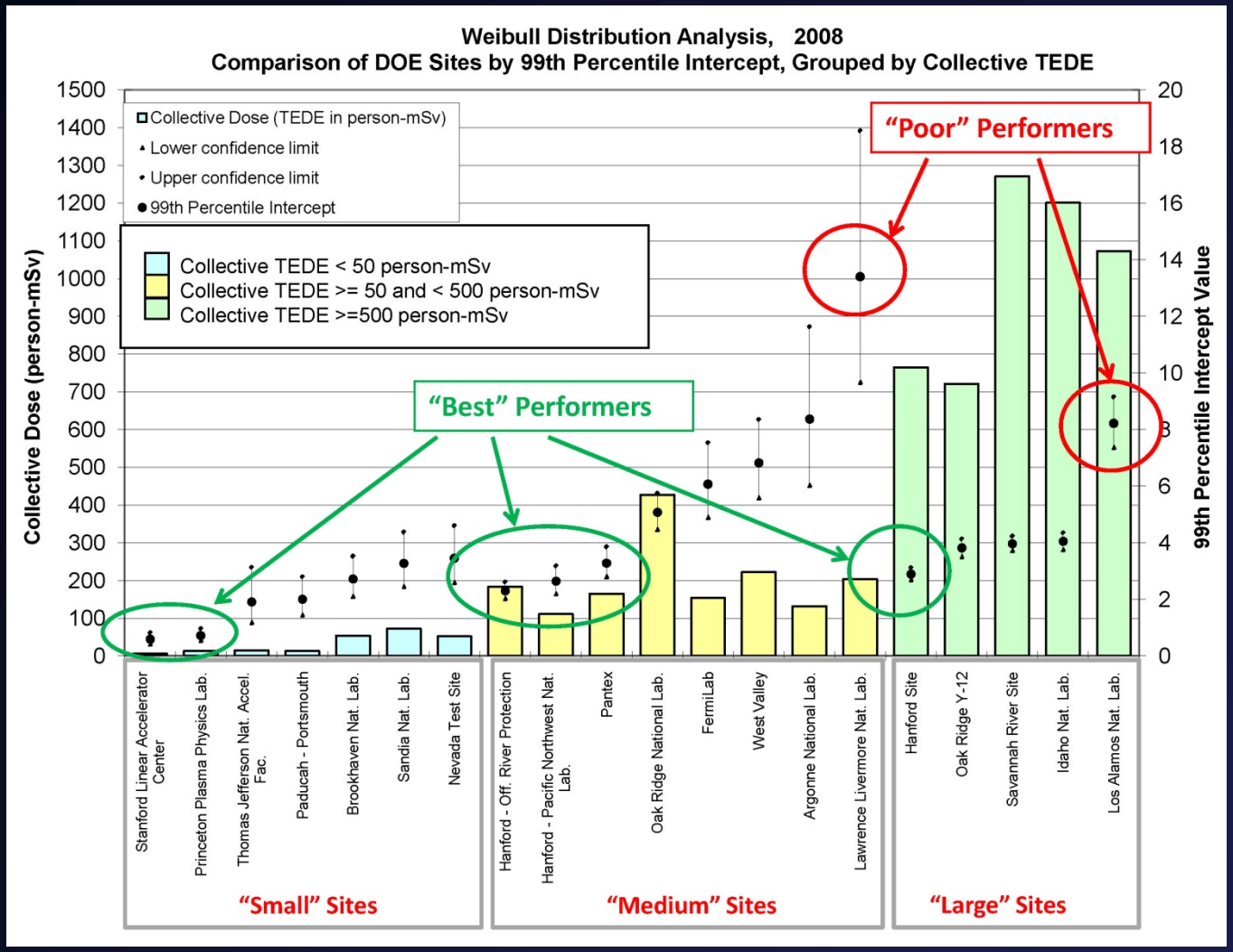
All NRC Reactors - 1999 and 2008



Comparison of NRC Licensees



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



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

Contact

Derek A. Hagemeyer, ORAU

865-241-3615

Derek.Hagemeyer@ orise.orau.gov