Operational Reactor Safety
22.091/22.903

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Safety Goals
Risk Informed Decision Making
Lecture 12

Topics to be Covered

- Safety Goals

- Subsidiary Safety Goals

- Risk informed decision making

- Criteria for acceptance of design changes

- Risk informed framework

Quantitative Safety Goals

- Early and latent cancer mortality risks to an individual living near the plant should not exceed 0.1 % of the background accident or cancer mortality risk:

5×10^{-7} per year for early death and,

2×10^{-6} for death from cancer.

•**The prompt fatality goal applies to an average individual living in the region between the site boundary and 1 mile beyond this boundary.**

•**The latent cancer fatality goal applies to an average individual living in the region between the site boundary and 10 miles beyond this boundary.**

Societal Risks

- *Annual Individual Occupational Risks*
    - All industries 7×10^{-5}
    - Coal Mining: 24×10^{-5}
    - Fire Fighting: 40×10^{-5}
    - Police: 32×10^{-5}
    - US President $1,900 \times 10^{-5}$ (!)
- *Annual Public Risks*
    - Total 870×10^{-5}
    - Heart Disease 271×10^{-5}
    - All cancers 200×10^{-5}
    - Motor vehicles: 15×10^{-5}

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Page 4

From: Wilson & Crouch, *Risk/Benefit Analysis,* Harvard University Press, 2001.

Subsidiary Goals

- The average core damage frequency (CDF) should be less than 10^{-4}/reactor year (once every 10,000 reactor years)

- The large early release frequency (LERF) should be less than 10^{-5}/reactor year (once every 100,000 reactor years)

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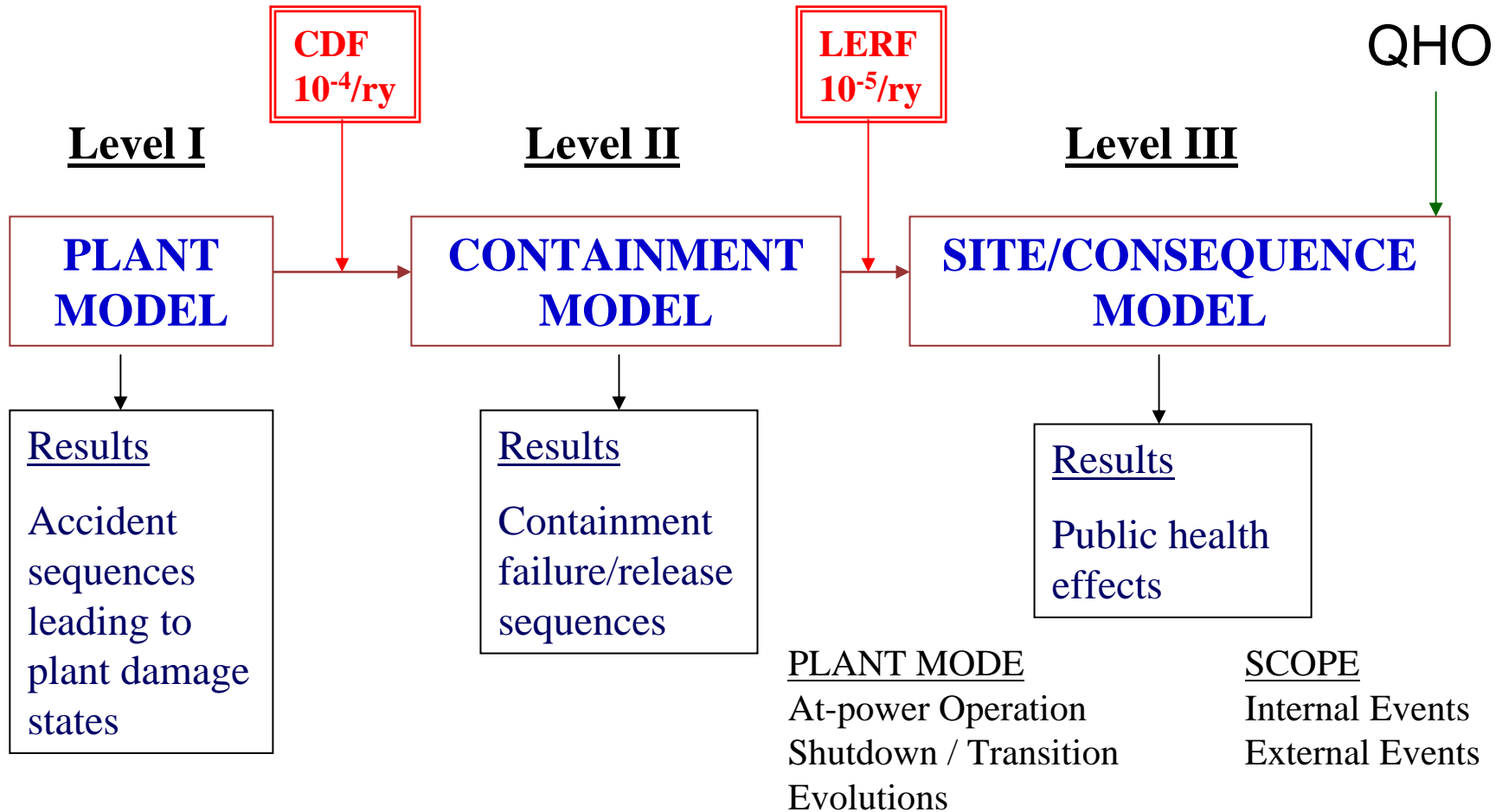**Department of Nuclear Science & Engineering**

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Large Early Release Frequency

- LERF is being used as a surrogate for the early fatalities.

- It is defined as the frequency of those accidents leading to significant, unmitigated releases from containment in a time frame prior to effective evacuation of the close-in population such that there is a potential for early health effects.

- Such accidents generally include unscrubbed releases associated with early containment failure at or shortly after vessel breach, containment bypass events, and loss of containment isolation.
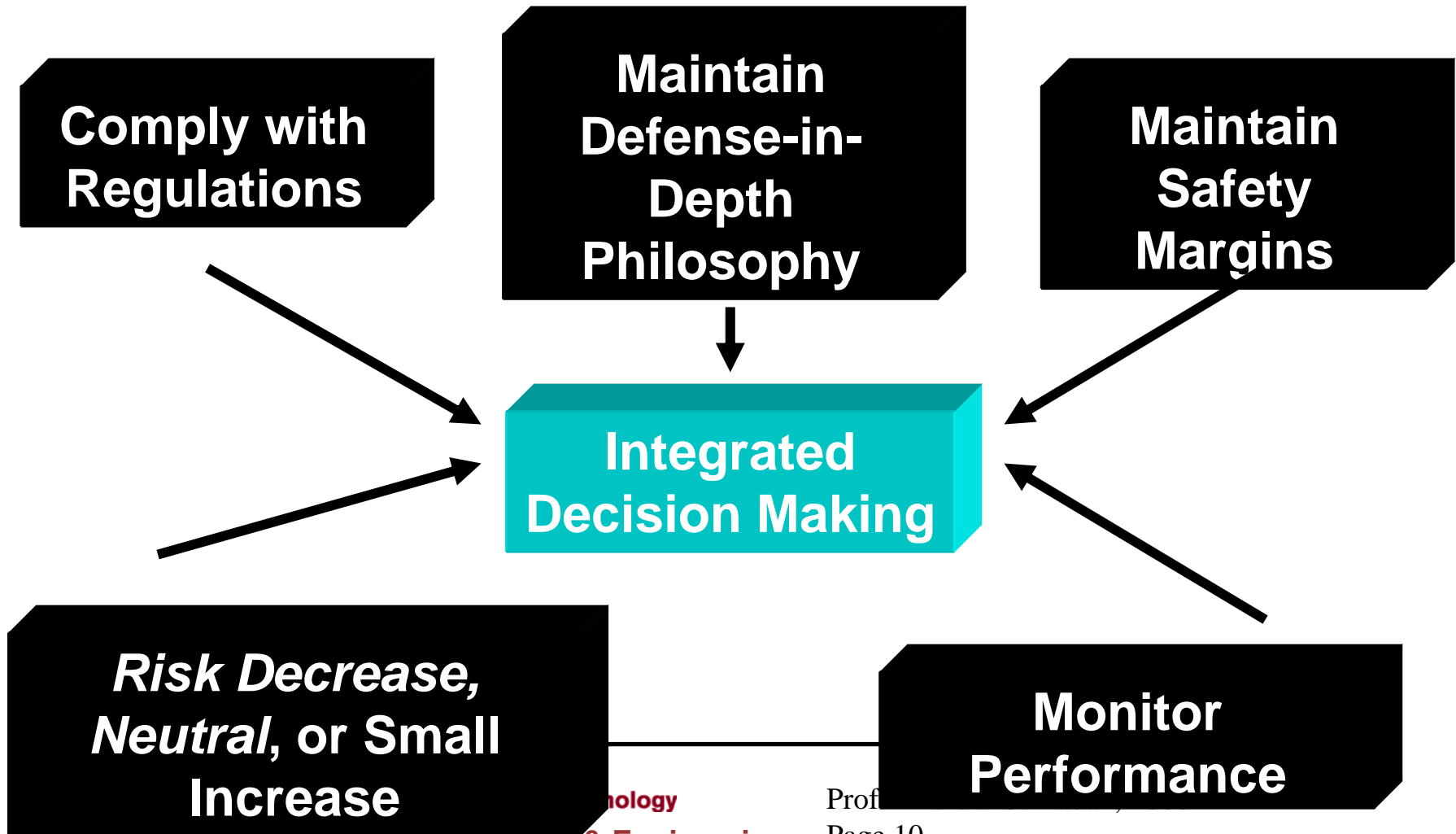
PRA Model Overview and Subsidiary Objectives

CDF
10^{-4}/ry

LERF
10^{-5}/ry

QHO

Level I

PLANT MODEL

Level II

CONTAINMENT MODEL

Level III

SITE/CONSEQUENCE MODEL

Results

Accident sequences leading to plant damage states

Results

Containment failure/release sequences

Results

Public health effects

PLANT MODE
At-power Operation
Shutdown / Transition
Evolutions

SCOPE
Internal Events
External Events

Uncertainties

Risk-Informed Decision Making
for Licensing Basis Changes (RG 1.174, 1998)

Comply with Regulations

Maintain Defense-in-Depth Philosophy

Maintain Safety Margins

Integrated Decision Making

***Risk Decrease, Neutral*, or Small Increase**

Monitor Performance

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Page 10

ΔCDF

10⁻⁵

10⁻⁶

Region I

Region II

Region III

Region I
 - No changes
Region II
- Small Changes
- Track Cumulative Impacts
 Region III
 - Very Small Changes
 - More flexibility with respect to Baseline
 - Track Cumulative Impacts

10⁻⁵   **10⁻⁴**   **CDF**

Acceptance Guidelines for Core Damage Frequency

Important Note

"The analysis will be subject to increased technical review and management attention as indicated by the darkness of the shading of the figure. In the context of the integrated decision-making, the boundaries between regions should not be interpreted as being definitive; the numerical values associated with defining the regions in the figure are to be interpreted as indicative values only."

Regulatory Guide 1.174

Increased NRC Management Attention

Consider:

- The cumulative impact of previous changes and the trend in CDF (the licensee's risk management approach);

- The cumulative impact of previous changes and the trend in LERF (the licensee's risk management approach);

- The impact of the proposed change on operational complexity, burden on the operating staff, and overall safety practices;

- Plant-specific performance and other factors, including, for example, siting factors, inspection findings, performance indicators, and operational events; and Level 3 PRA information, if available;

- The benefit of the change in relation to its CDF/LERF increase;

- The practicality of accomplishing the change with a smaller CDF/LERF impact; and

- The practicality of reducing CDF/LERF, in circumstances where there is reason to believe that the baseline CDF/LERF are above the guideline values (i.e., 10-4 and 10-5 per reactor year).

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Defense In Depth (RG 1.174)

- A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.

- Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided.

- System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers).

- Defenses against common-cause failures are preserved, and the potential for the introduction of new common-cause failure mechanisms is assessed.

- Independence of barriers is not degraded.

- Defenses against human errors are preserved.

- The intent of the GDC in Appendix A to 10 CFR Part 50 is maintained.

Uncertainties

- **Aleatory uncertainty is built into the structure of the PRA model itself. (random uncertainty – when pump fails)**

- **Epistemic uncertainties:**

  - ➢ **<u>Parameter uncertainties</u> are those associated with the values of the fundamental parameters of the PRA model, such as equipment failure rates, initiating event frequencies, and human error probabilities that are used in the quantification of the accident sequence frequencies.**

  - ➢ **In many cases, understanding of certain processes or phenomena is incomplete, and there may be different opinions on how the models should be formulated. Examples: modeling human performance, common cause failures, and reactor coolant pump seal behavior upon loss of seal cooling. This gives rise to <u>model uncertainty</u>.**

  - ➢ **Completeness is not in itself an uncertainty, but a reflection of scope limitations. The problem with <u>completeness uncertainty</u> is that, because it reflects an unanalyzed contribution, it is difficult (if not impossible) to estimate its magnitude. Examples: the analysis of some external events and the low power and shutdown modes of operation, and influences of organizational performance.**

Comparison with Acceptance Guidelines

- **The acceptance guidelines were established with the Commission's Safety Goals and subsidiary objectives in mind, and these goals were intended to be compared with mean values. Therefore, the mean values of the distributions should be used.**

- **For the distributions generated in typical PRAs, the mean values typically corresponded to the region of the 70th to 80th percentiles, and coupled with a sensitivity analysis focused on the most important contributors to uncertainty, can be used for effective decision-making.**

- **Approach: Address parametric uncertainty and any explicit model uncertainties in the assessment of mean values; perform sensitivity studies to evaluate the impact of changes in key assumptions or the use of alternate models for the principal implicit model uncertainties; and use quantitative analyses or qualitative analyses as necessary to address incompleteness as appropriate to the decision and the acceptance guidelines.**

# The Significance Determination Process

- Characterizes the significance of inspection findings using risk insights

- Provides framework for communicating potential safety-significant findings

- Provides basis for assessment and/or enforcement actions

Levels of Significance Associated with Performance Indicators and Inspection Findings

- **Green - very low risk significance (for PIs: Within peer performance)**

- **White - low to moderate risk significance**

- **Yellow - substantive risk significance**

- **Red - high risk significance**

$\Delta CDF < 1E\text{-}6$
$1E\text{-}6 < \Delta CDF < 1E\text{-}5$
$1E\text{-}5 < \Delta CDF < 1E\text{-}4$
$\Delta CDF > 1E\text{-}4$
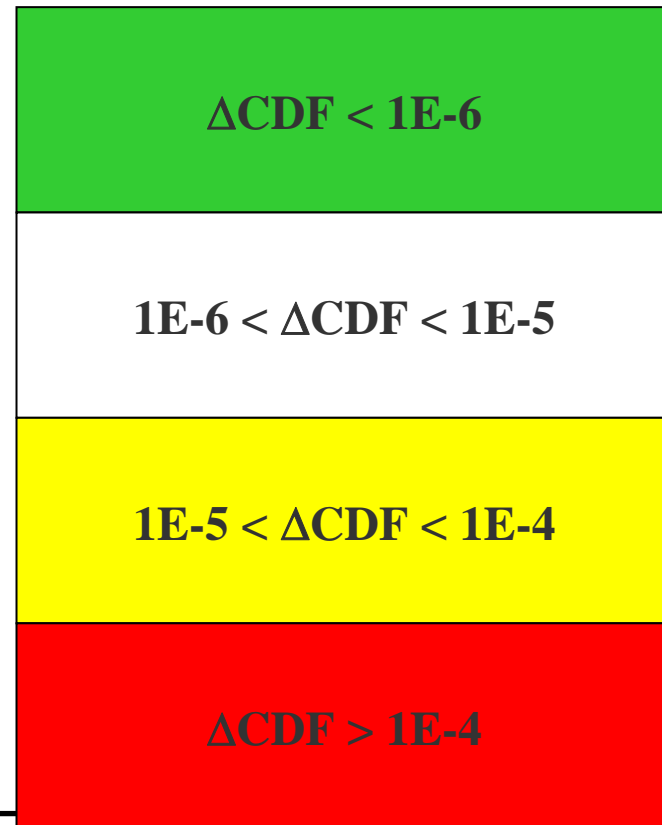
Phased Approach to PRA Quality

- In the 12/18/03 Staff Requirements Memorandum, the Commission approved the implementation of a phased approach to PRA quality.

- The phases are differentiated by the availability of standards.

- Phase 3 should be achieved by December 31, 2008. Guidance documents will be available to support all anticipated applications.

- *Standard for PRA for Nuclear Power Plant Applications*, ASME RA-S-2002.

- *"An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities,"* RG 1.200, February 2004

Risk-Informed Framework

Traditional "Deterministic" Approaches

- Unquantified Probabilities
- Design-Basis Accidents
- Structuralist Defense in Depth
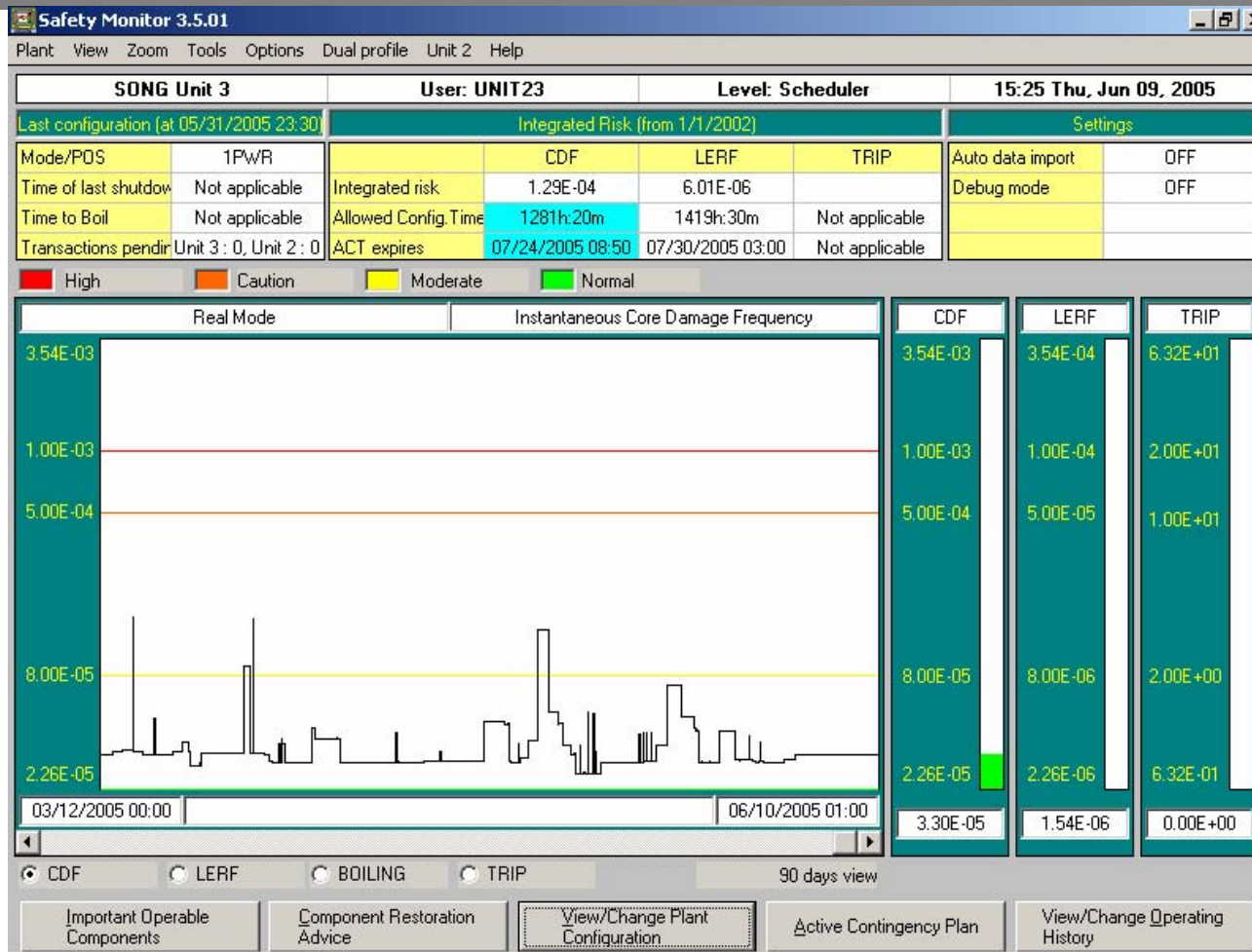- Can impose heavy regulatory burden
- Incomplete

Risk-Informed Approach

- Combination of traditional and risk-based approaches

Risk-Based Approach

- Quantified Probabilities
- Scenario Based
- Realistic
- Rationalist Defense in Depth
- Incomplete
- Quality is an issue

Safety Monitor

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