Technical Evaluation of Relative Risk Measures, Including Reexamination of Pros and Cons

Technical Lead: Eric Powell, NRO/DSRA

Background

The Commission directed the U.S. Nuclear Regulatory Commission (NRC) staff in SRM-SECY-12-0081, "Risk-Informed Regulatory Framework for New Reactors" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12296A158), to give additional consideration to the use of relative risk metrics or other options that would provide a more risk-informed approach to the determination of the significance of inspection findings for new reactors. Specifically, the Commission directed the staff to perform a technical evaluation of the use of relative risk measures, including a reexamination of the pros and cons listed in the staff's 2009 white paper.

As shown in Figure 1, the current significance determination process (SDP) of the Reactor Oversight Process (ROP) has quantitative thresholds for an increase in core damage frequency (CDF) at 10^{-6}/yr, 10^{-5}/yr, and 10^{-4}/yr for the green-white, white-yellow, and yellow-red thresholds, respectively. Also, the current SDP has quantitative thresholds for an increase in large early release frequency (LERF) at 10^{-7}/yr, 10^{-6}/yr, and 10^{-5}/yr, for the green-white, white-yellow, and yellow-red thresholds, respectively. These thresholds are independent of the baseline CDF of the plants to which they are being applied, and each threshold denotes an increase in the safety significance of a finding.

Relative Risk Approach

At a public meeting on March 25, 2013, the staff presented the conceptual relative risk approach as proposed by the Advisory Committee on Reactor Safeguards (ACRS) (Figure 2). Also, the staff presented a slightly different relative risk approach with change in core damage frequency (ΔCDF) on the y-axis (Figure 3) instead of fractional change in CDF on the y-axis which the ACRS proposed. These two graphs have the same finding thresholds, but portray the information differently (i.e., ΔCDF vs. fractional change in CDF). The staff used ΔCDF instead of fractional change in CDF, because ΔCDF is used in the SDP and is consistent with RG 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis." The change from fractional change in CDF to ΔCDF is not a substantive change, but one that the staff believed would be useful in discussions moving forward with the technical evaluation of a relative risk approach.

The relative risk approach uses the total baseline CDF (x-axis) and the ΔCDF (y-axis) for a plant to determine the significance of an inspection finding using the sloped lines shown on the graph (Figure 3). The concept behind this approach is that the lower the baseline CDF of a plant, the lower the ΔCDF value, or larger fractional change, necessary for increased significance of a finding. Conversely, the higher the baseline CDF of a plant, the higher the ΔCDF value, or the smaller the fractional change, necessary for increased significance of a finding. Therefore, the significance of a finding would be relative to the baseline CDF value, instead of the current thresholds which do not change given a particular plant's baseline CDF.

Technical Evaluation of Applying Relative Risk Approach

The staff conducted a series of tabletop exercises in 2011 in response to SRM-SECY-10-0121, "Modifying the Risk-Informed Regulatory Guidance for New Reactors" (ADAMS Accession No. ML102230076). As part of those tabletops, the staff looked at the application of the ROP to new reactors. The ROP tabletops tested various scenarios that are or will be relevant to the licensing basis for new reactors to confirm the adequacy of the current ROP risk-informed processes for regulatory decisionmaking or to identify areas for improvement. For each scenario, the staff applied similar situations to the new reactor designs, and then compared the risk values and resulting regulatory responses from the new reactor scenarios to those derived from the current fleet. In order to exercise the SDP for the new reactor designs, the staff assumed long exposure times and common-cause failure (CCF) of multiple trains of equipment. Also, the Standardized Plant Analysis Risk (SPAR) models used to evaluate some of the scenarios were only internal events at-power and did not include external events.

The staff presented the results of its technical evaluation at the public meeting on March 25, 2013. The staff took the same scenarios from the 2011 tabletop and applied the conceptual ACRS relative risk approach to determine the significance of potential findings. The cases in 2011 were evaluated using the existing SDP thresholds. The results of applying relative risk are shown in Table 1 and are compared to the existing SDP for the same scenario. The results in Table 1 show that applying the relative risk approach will increase the significance, and therefore the regulatory response, of most findings compared to the existing approach. Applying the relative risk approach to the 19 cases from 2011, 13 of the findings moved up one color (i.e., green to white, white to yellow, or yellow to red). This is an increase in the significance of the finding and represents an increase in regulatory response accordingly. It should be noted that 3 of the 19 cases had a significance of red already based on the current SDP, so no increase was possible.

Baseline CDFs for new reactors will include internal and external events (e.g., seismic, flooding, and fires), and for new reactor designs with low internal event CDF values the PRA results will likely be dominated by external events, particularly seismic events. Staff expects that in most cases, once external events are quantified and factored into a plant's baseline CDF, it will likely result in an increase in the baseline CDF values for the new reactor designs. If a relative risk approach was applied that takes into account external events, the likely result would be a decrease in the significance of some findings. This is a consequence of the concept behind a relative risk approach that the higher the baseline CDF of a plant, the higher the ΔCDF value necessary for increased significance of a finding.

Other Options Considered

The staff considered other options than the proposed relative risk approach, such as a staircase thresholds approach and hybrid thresholds approach. Both of these alternative approaches are discussed below:

Staircase Thresholds Approach

At the public meeting on March 25, 2013, the staff presented a conceptual staircase thresholds approach (Figure 4). The staircase thresholds approach uses a step function with a plant's total baseline CDF (x-axis) and ΔCDF (y-axis) to determine the significance of an inspection finding using the staircase lines on the graph. A staircase function is a concept that simplifies the selection of thresholds by not having to use an algorithm, like the relative approach, to calculate the threshold as a function of baseline CDF.

The staircase thresholds approach has very acute cliff effects that have negative implications. It is possible that a licensee could calculate total baseline CDF just to the right of the cliff and lessen the chance of non-green findings by increasing the thresholds. Therefore, this approach does not offer an additional advantage over a relative risk approach.

Hybrid Thresholds Approach

At the public meeting on March 25, 2013, the staff also presented a conceptual hybrid thresholds approach (Figure 5). The hybrid thresholds approach uses a plant's total baseline CDF (x-axis) and ΔCDF (y-axis) to determine the significance of an inspection finding using the sloped and flat lines on the graph. This approach combines relative risk thresholds with the existing thresholds, with the transition happening at a baseline CDF of 10^{-6}/yr on the x-axis. The staff's idea behind this hybrid approach, and for selecting the transition point at 10^{-6}/yr, was that it would enable the application of a relative approach to the new reactors, and the operating reactors would continue to use the existing thresholds.

Industry representatives discussed with the staff pros and cons of the hybrid approach at a public meeting on April 15, 2013. In summary, many of the industry's "problems with establishing alternate risk metrics and/or thresholds" from the 2009 NEI white paper would not arise if total baseline CDF values were used and the transition point was established at or near 10^{-6}/yr. Industry expects the total baseline CDF values for new reactors, which include internal and external events, to exceed 10^{-6}/yr and therefore will retain the same color band thresholds as those of the existing fleet. Therefore, this approach would yield the same result as using the existing SDP thresholds.

Whether or not new reactor designs will have total baseline CDF values greater than or less than 10^{-6}/yr is debatable. However, if not now, eventually a design will likely have a CDF value below 10^{-6}/yr and the same concerns identified by NEI in 2009 will apply. Therefore, the staff views this approach as a short-term solution. If the new reactors' total baseline CDF values are greater than 10^{-6}/yr, there would be no benefit to implementing the hybrid thresholds approach, because it would yield the same results as the existing approach given that the thresholds would be identical. Accordingly, this approach does not offer an additional advantage over a relative risk approach.

Reexamination of the Pros and Cons

The staff developed a white paper (ADAMS Accession No. ML090160004) in 2009 that identified the issues posed by the lower risk estimates for new reactor designs in risk-informed applications and potential options for implementation. The staff specifically addressed the pros and cons of converting to a relative risk approach for the ROP thresholds and RG 1.174. The Nuclear Energy Institute (NEI) developed an additional white paper in 2009 (ADAMS Accession No. ML090900674) to discuss these issues and recommended no change to the current risk metrics.

The staff reexamined the pros and cons from both the staff and NEI white papers. An additional advantage, or pro, of the relative risk approach that was evaluated and discussed during the public meetings is that it could be developed and applied in a manner that is consistent with the Commission's stated expectation to maintain the enhanced safety margins for new reactors, while providing greater operational flexibility than for current reactors. This was the main benefit described in the ACRS letter dated April 26, 2012 (ADAMS Accession No. ML12107A199). The example that was used by the ACRS, based on the conceptual thresholds (Figure 2), was that a plant with a baseline CDF of 10^{-4}/yr would trigger a White finding with a CDF increase of 1 percent (i.e., a CDF increase of 10^{-6}/yr). However, a plant with a baseline CDF of 10^{-8}/yr would trigger a White finding with a CDF increase of a factor of 10 (i.e., a CDF increase of 10^{-7}/yr). The staff understands the ACRS's recommendation, and an approach involving relative risk was previously considered, but was not pursued because the staff did not view it as consistent with the Commission decision to not approve the development of lower numerical thresholds for new reactors (in SRM-SECY-10-0121).

Some of the more significant impediments, or cons, to a relative risk approach for new reactors that were evaluated and discussed during the public meetings included:

- potential to inadvertently focus licensee and staff attention on less significant safety issues;
- concerns with public perception issues in communicating the safety significance of findings; and
- concerns with creating less incentive for licensees to enhance safety margin.

Participants at the public meeting discussed the potential for the relative risk approach to inadvertently focus licensee and NRC staff attention on less significant safety issues for two reasons. For example, using the conceptual relative risk thresholds in Figure 3, a plant with a baseline CDF of 10^{-7}/yr would receive a White finding for a finding with a ΔCDF value of 2×10^{-7}/yr, while a plant with a baseline CDF of 10^{-4}/yr would receive a Green finding for a finding with a ΔCDF value of 9×10^{-7}/yr. Under the current ROP, more attention, by both licensees and NRC staff, would be spent on a White finding that has a lower safety significance than a Green finding that has a higher safety significance (e.g., 2×10^{-7}/yr (White finding) compared to 9×10^{-7}/yr (Green finding)). Likewise, using the conceptual relative risk thresholds, a plant with a baseline CDF of 10^{-6}/yr would receive a White finding if they had a finding with a ΔCDF value greater than approximately 3×10^{-7}/yr. However, the current SDP threshold is at 10^{-6}/yr for a White finding. More attention, by both licensees and NRC staff, would be spent on a White finding that was greater than approximately 3×10^{-7}/yr using the relative risk approach, compared to a Green finding that was greater than 10^{-6}/yr using the current SDP.

A relative risk approach creates potential public perception issues in communicating the safety significance of a finding for two reasons. First, the current SDP thresholds are used to communicate both performance deficiencies and the safety significance of a finding. Changing to a relative risk approach would no longer communicate a consistent safety significance of findings. The thresholds for Green, White, Yellow, and Red would no longer be directly comparable to the ROP-defined safety significance (i.e., very low safety significance, low to moderate safety significance, substantial safety significance, and high safety significance) of a finding for a new reactor ROP that used relative risk thresholds. Second, applying a relative risk approach to new reactors but not operating reactors would create public perception issues as pointed out in NEI's 2009 white paper. When using two sets of SDP thresholds, the possibility exists for two findings with the same quantitative value to be different colors. This communicates to the public that the findings have a different safety significance, when in fact they have the same safety significance based on the quantitative PRA assessment.

The current SDP creates an incentive for licensees to enhance safety margin through plant improvements. Under the current SDP approach, if a licensee made an improvement that decreased their baseline CDF value, that would increase the ΔCDF value that would be necessary to receive a greater than GREEN finding. However, under a relative risk approach, if a licensee made an improvement that decreased their baseline CDF value, that would decrease the ΔCDF value that would be necessary to receive a greater than GREEN finding. The enhancement in safety margin would effectively result in a stricter SDP threshold when applying a relative risk approach.

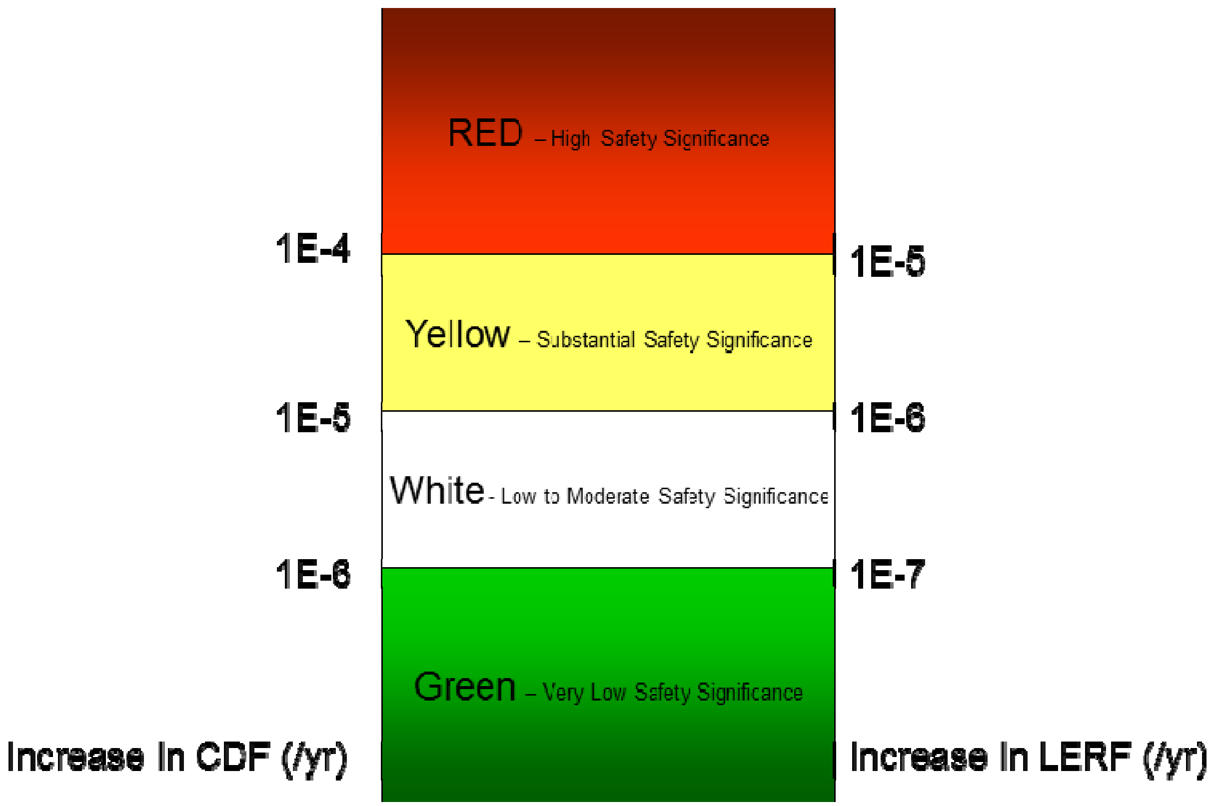

Figure 1 Quantitative thresholds for the significance of findings for the current SDP

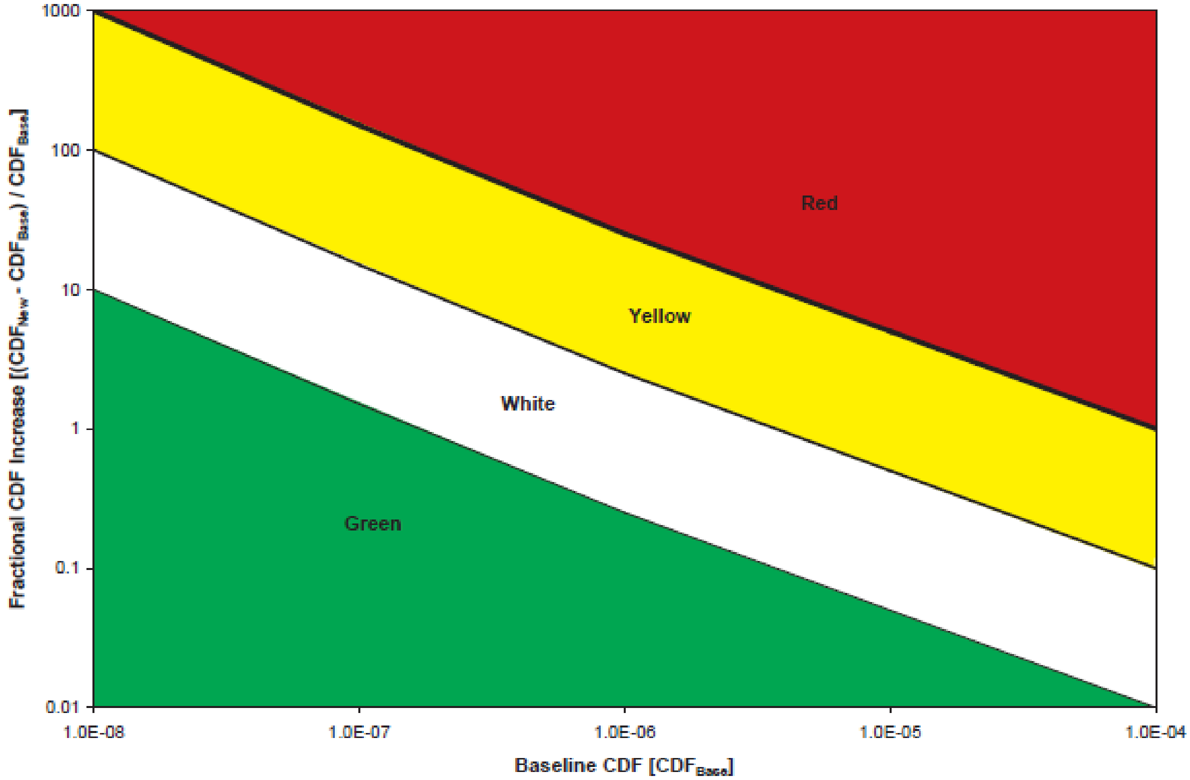

Figure 2 Relative risk approach—ACRS

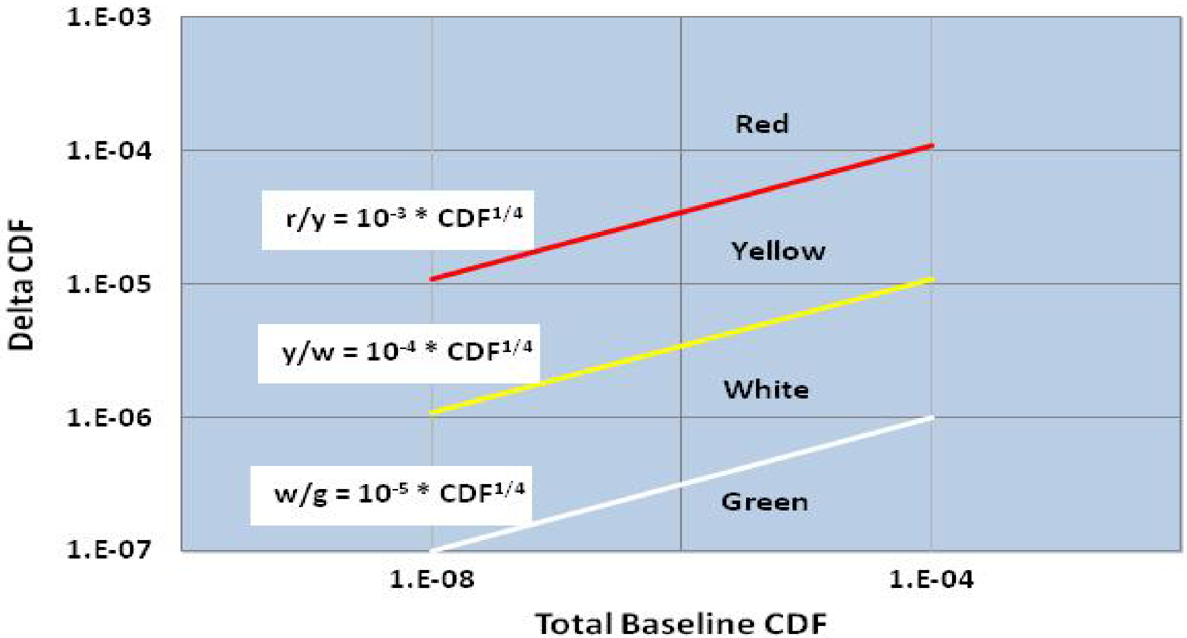

Figure 3 Relative risk approach—staff

Table 1 Application of Relative Risk to the 2011 Tabletop Cases

Design	Example	Exposure Period	ΔCDF (/yr)	Model	2011 Tabletop Outcome	Applying Relative Risk Approach
Advanced Boiling Water Reactor (ABWR)	HPCF pump fails	23 days	1.4E-8	SPAR		
		1 year	2.2E-7			
	Both HPCF pumps fail with common cause	23 days	4.8E-8	SPAR		
		1 year	7.7E-7			
United States Advanced Pressurized Water Reactor (US-APWR)	One TDEFW pump fails	1 year	2.2E-5	SPAR		
		1 year	3.4E-6	PRA importances (internal events)		
		1 year	3.4E-6	MHI PRA (internal fire and flooding)		
	Both TDEFW pumps fail with common cause	1 year	4.4E-4	SPAR		
		1 year	3.4E-5	PRA importances (internal events)		
		1 year	8.8E-6	MHI PRA (internal fire and flooding)		
ABWR	RCIC pump unavailable	1 year	4.1E-7	SPAR		
	RCIC pump and both HPCF pumps unavailable	1 year	1.6E-6	SPAR		
US-APWR	One MDEFW pump and one TDEFW pump unavailable because of lost suction source	1 year	1.3E-4	SPAR		
		1 year	7.7E-5	MHI PRA (internal fire and flooding)		
United States EPR Design (U.S. EPR)	One train of EFW unavailable because of lost suction source	1 year	7.7E-7	Areva PRA		
AP1000	PXS-V121A fails to remain open because of disk-stem separation	295 days	9E-5	SPAR		
		1 year	1.1E-4	SPAR		
US-APWR	RV head corrosion (increases medium and large LOCA frequencies)	1 year	1.4E-7	SPAR		
AP1000		1 year	1.2E-6	SPAR		

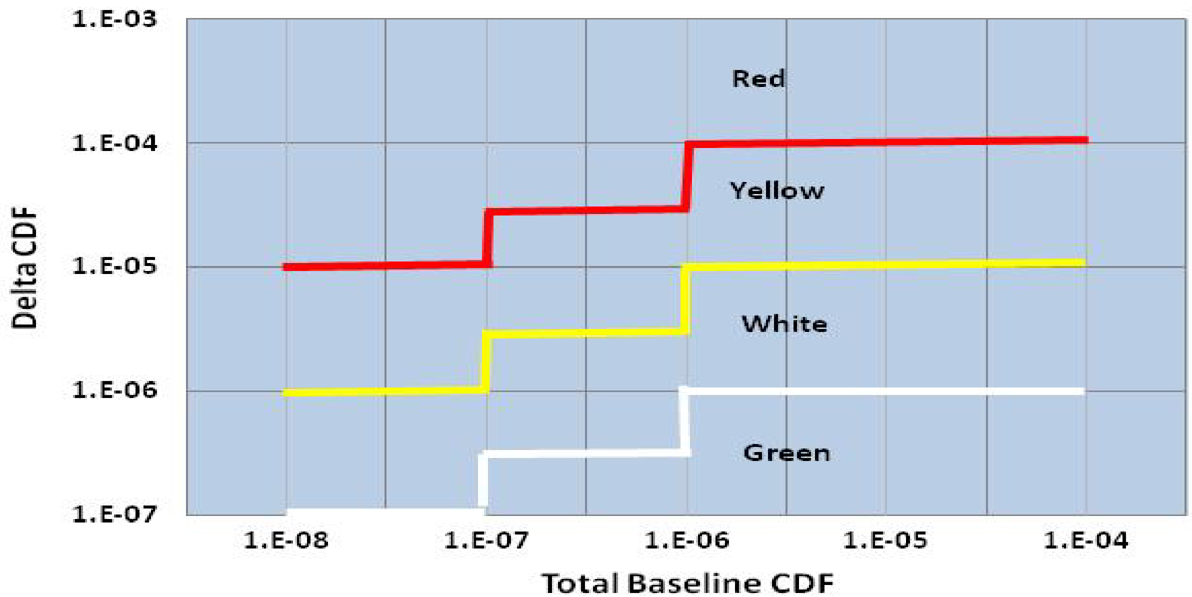

Figure 4 Staircase thresholds approach

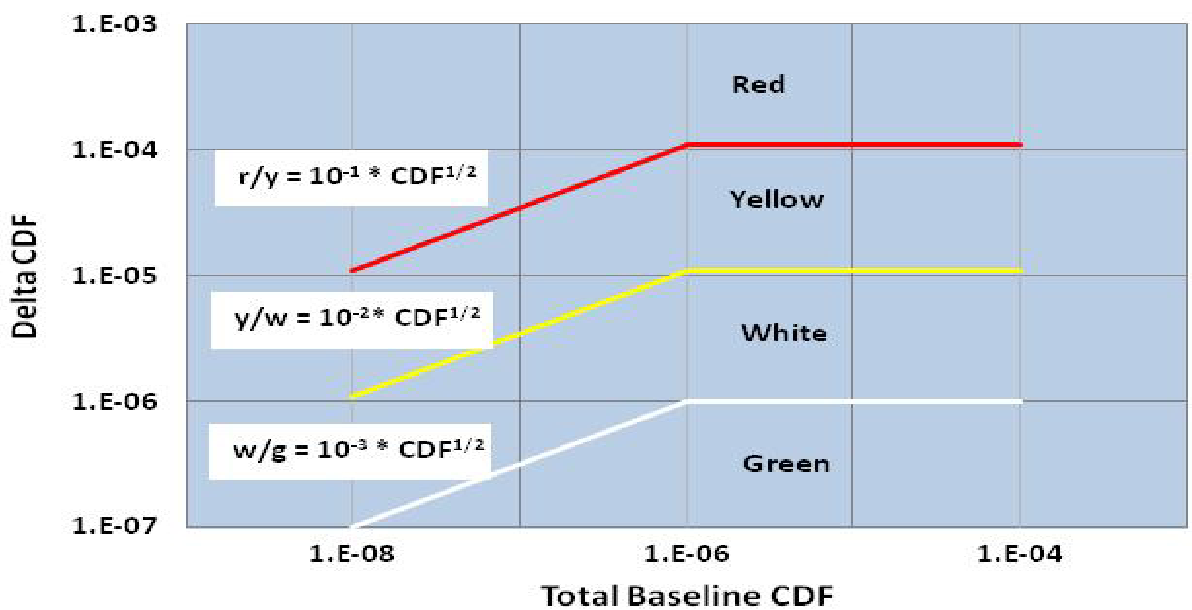

Figure 5 Hybrid thresholds approach