

Significance Determination of Inspection Findings that Cause Initiating Event Occurrences

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Opening Remarks

- Complex technical and programmatic issue
- SDP Basis Document language is not written in a clear and concise manner
- Cannot rely on “reading the headlines”
- Helpful to understand several abbreviations and terms (e.g., Baseline CDF, Δ CDF, CCDP, CD sequence)
- Be sensitive to loosely defined terms that can be used out of context (e.g., there are several flavors of CCDP)

Problem Statement/Industry Concern

- The metric for the SDP is Δ CDF.
CCDP \neq Δ CDF - Cannot multiple CCDP by 1/yr to get Δ CDF
The use of CCDP as an SDP metric is programmatically incorrect.
- Several Performance Indicator (PI) thresholds were developed using the Δ CDF metric. In order for PIs and findings to be equivalent inputs in the Action Matrix they need to use the same metric.
- If an inspection finding was the proximate cause of an initiating event occurrence, the safety significance should not be modeled as if the initiating event happened, rather the initiating event frequency should be increased to a new higher value (i.e., Bayesian Update)

NRC Staff Perspectives

- $CCDP - CDP \approx \Delta CDF$ and $CCDP^* \approx \Delta CDF$
- As such, PIs and inspection findings effectively use the same metric and are therefore equivalent inputs in the Action Matrix.
- Bayesian updating the initiating event frequency is not appropriate for an inspection finding that was the proximate cause of an initiating event occurrence.

*Inspection finding that causes an IE occurrence

Outside the Scope

- Findings that cause an initiating event frequency to increase but do not cause the initiating event to occur.
- Discussions on “causality”. The SDP basis states the finding should most often be identified as the *proximate cause* of a degraded condition. This determination of cause does not need to be based on a rigorous root-cause evaluation, but rather on a reasonable assessment and judgment of the staff.

Inspection Program Basics

- Performance deficiency (PD)
- More than Minor screening criteria (MTM)
- Finding = PD that is MTM
- ALL findings are assessed and assigned a safety (or security) significance by the appropriate SDP

Inspection and Performance Indicator (PI) Program Overlap

- There is an overlap between the Performance Indicator (PI) and Inspection Programs.
- If there is an overlap, both programs assess their respective input.
- If both inputs are greater than green (e.g., White) AND stem from the same underlying cause, only 1 White input will go in to the Action Matrix (IMC 0308, Att 4, page 11)

Outline

- Recent activities
- Review SDP basis document language
- Review the technical details of CCDP and CDF
- Proposed resolution
- NRC response to PWROG White Paper (if needed)
- Bayesian Inference (if needed)

Recent Activities

- Several recent findings that caused IE occurrences
- NEI Letters
- Public Meetings – May, November (2013) - January, May (2014) – ROP WG meetings
- Interim Staff Guidance (ISG)
- Industry and NRC White Papers (2014)

SDP Technical Basis – IMC 0308, Att 3

- Guiding document IMC 0308, Att 3
- Specifically Section 8 “Use of Δ CDF (and Δ LERF) as the SDP Metric”
 - **Section A – Different Definitions of CCDP**
 - Section B – Overview
 - Section C – Basis in RG 1.174 and Mathematical Treatment of Δ CDF and CCDP

CCDP Definition – Take 1

- “Event” CCDP - represents the probability that a core would have gone to a damaged state given that (i.e., “conditioned on”) a specific initiating event occurred AND the *actual* plant equipment and operator responses are accounted for. This “event” use of CCDP represents the remaining probabilistic “margin” (related to defense-in-depth) to core damage at a precise moment in time, that of the event itself.

“Event” CCDP

- As described in the previous slide, the “event” CCDP depicts a risk analysis process that;
 - Accounts for SSCs unavailable due to test and maintenance
 - Accounts for actual (either successful or unsuccessful) operator actions
 - Does not measure an increase in risk above a baseline value

At a high-level describes a MD 8.3 or ASP type analysis; not a SDP evaluation

“Event” CCDP

- One key aspect of the “event” CCDP concept is that it looks at a:
 - precise moment in time
 - snapshot
 - instantaneous occurrence

CCDP Definition – Take 2

- “Condition” CCDP - refers to a degraded condition which may alter the plant’s risk over a period of time and is related to the plant’s ability to mitigate a number of different possible initiating events.
 - Focuses on a “period of time”
 - Focuses on a “degraded condition” (not defined)
 - Appears to only focus on “mitigating systems”

SDP Basis Document

- The risk-informed SDP tools are designed to estimate the increase in annualized CDF risk due to identified performance deficiencies that led to unavailability of equipment or safety functions or *to the increase in initiating event frequencies.*

Takeaway 1

- If a finding was the proximate cause of an IE occurrence, to evaluate the safety significance of the finding:
 - The nominal IE frequency should be increased to a new, higher number.

Condition CCDP

- From the SDP basis document *“The SDP actually estimates the CCDP given the degraded condition which resulted from the performance deficiency for the time this degradation existed.”*
- The NRC uses SAPHIRE (a risk modeling software tool) to support the SDP in developing detailed risk evaluations
- A SAPHIRE “condition assessment” calculates a CCDP (for the finding/degraded condition) and subtracts out a CDP (from the baseline model) for the time period of concern.

Condition CCDP

- Since we are concerned with the increase in risk above a baseline value over a certain duration (e.g., the course of a year), the Exponential cumulative distribution function provides an adequate mathematical model:

$$F(t) = 1 - e^{-\lambda t}$$

Equation Breakdown

$$F(t) = 1 - e^{-\lambda t}$$

λ is a rate and can be replaced with a CDF

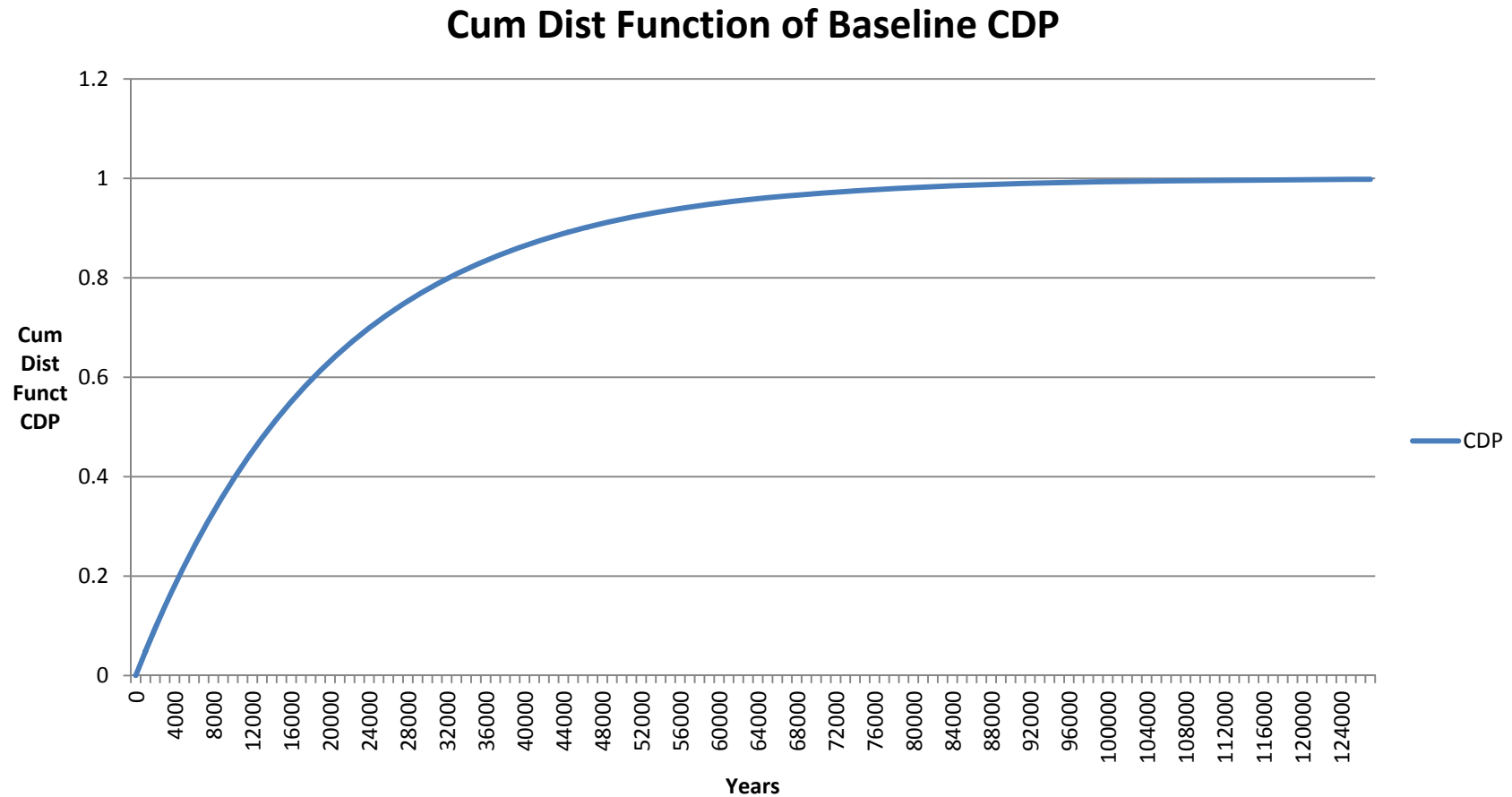
CDF is a rate and can be replaced with $(IE_N \times MS_N)$

Since there are multiple IEs and MSs...

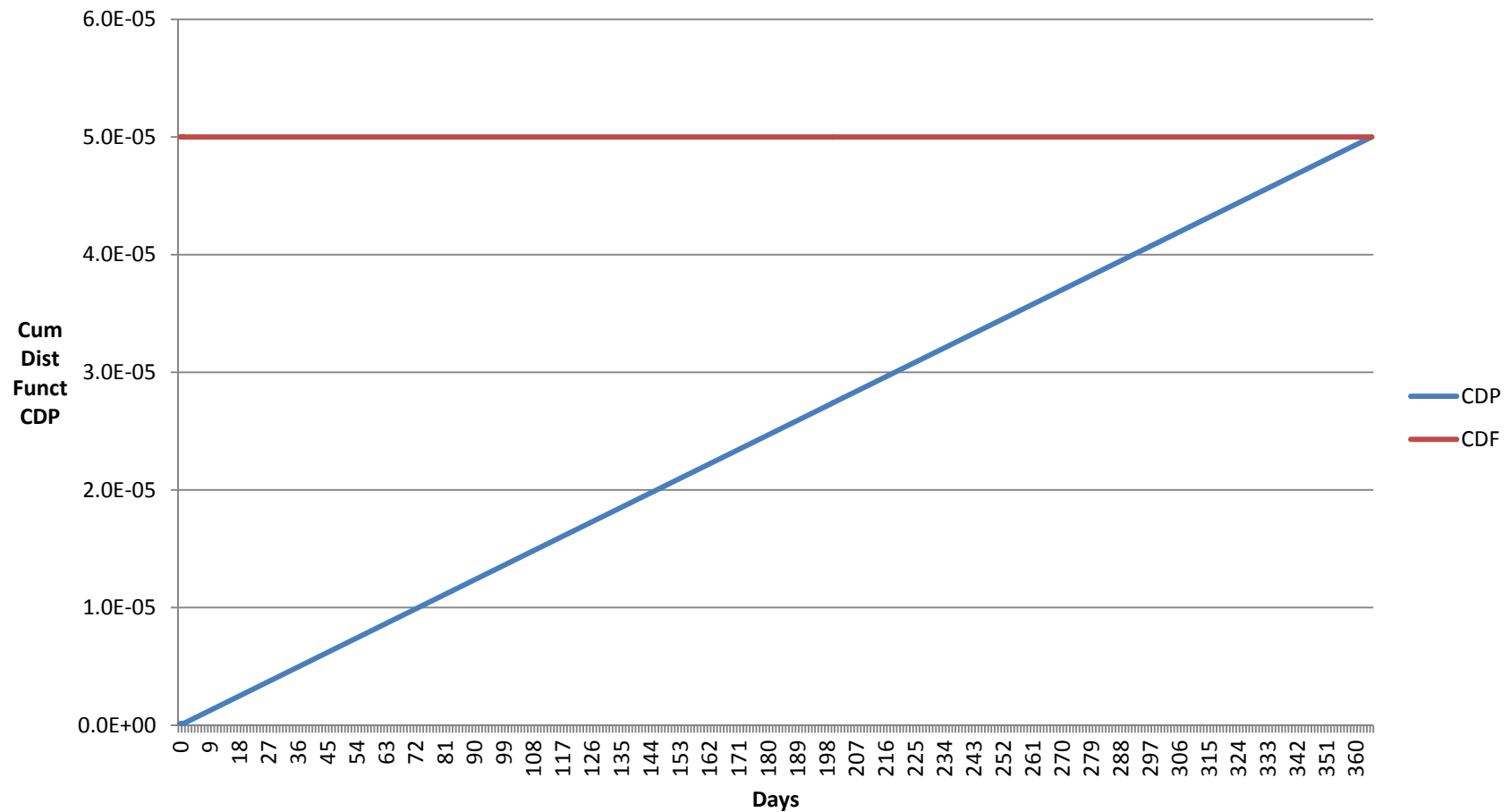
$$F(t) = 1 - e^{-(IE1*MS1 + IE2*MS2 + \dots + IEn*MSn) * t}$$

$$F(1) = 1 - e^{-\left[\left(5.5E - \frac{6}{yr} \right) (1 yr) \right]} = ???$$

Graph of Cumulative CDP of a plant with a Nominal $5E-5$ /yr CDF



Graph of Cumulative CDP of a plant with a Nominal $5E-5$ /yr CDF



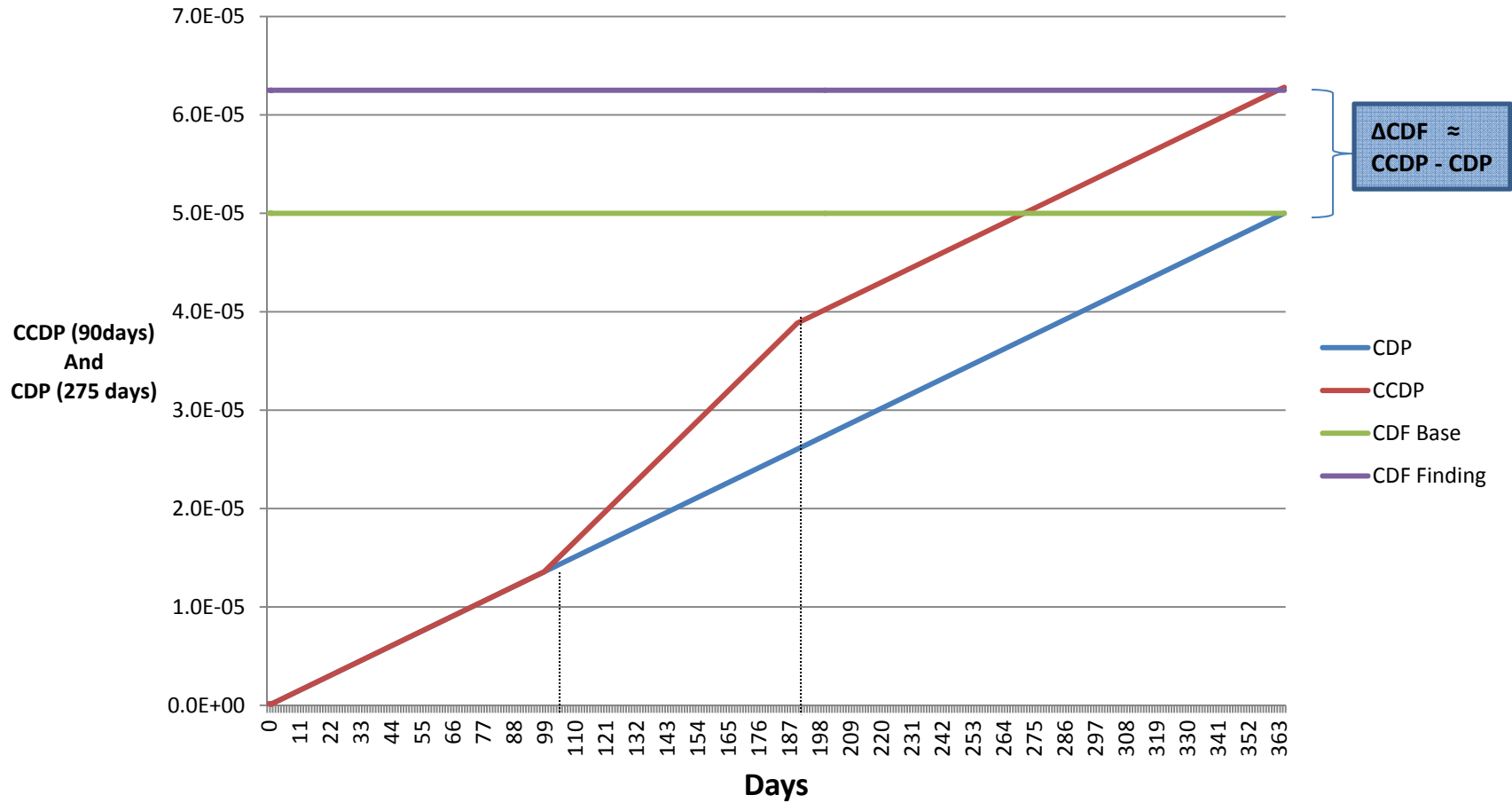
Model the Finding – “Condition” CCDP

- Example: A maintenance –related finding was the proximate cause of a safety-related pump being in a failed/non-functional state for 90 consecutive days.

$$F(t) = 1 - e^{-(IE1*MS1 + IE2*MS2 + \dots + IEn*MSn)*.25}$$

Failed pump is **MS2** and **.25** years = 90 days

Graph of Baseline CDP for .75 yr and Finding CCDP for .25 yr



Comparing Δ CDF and CCDP-CDP in a Spreadsheet



Delta CDF and CCDP-CDP Approximation

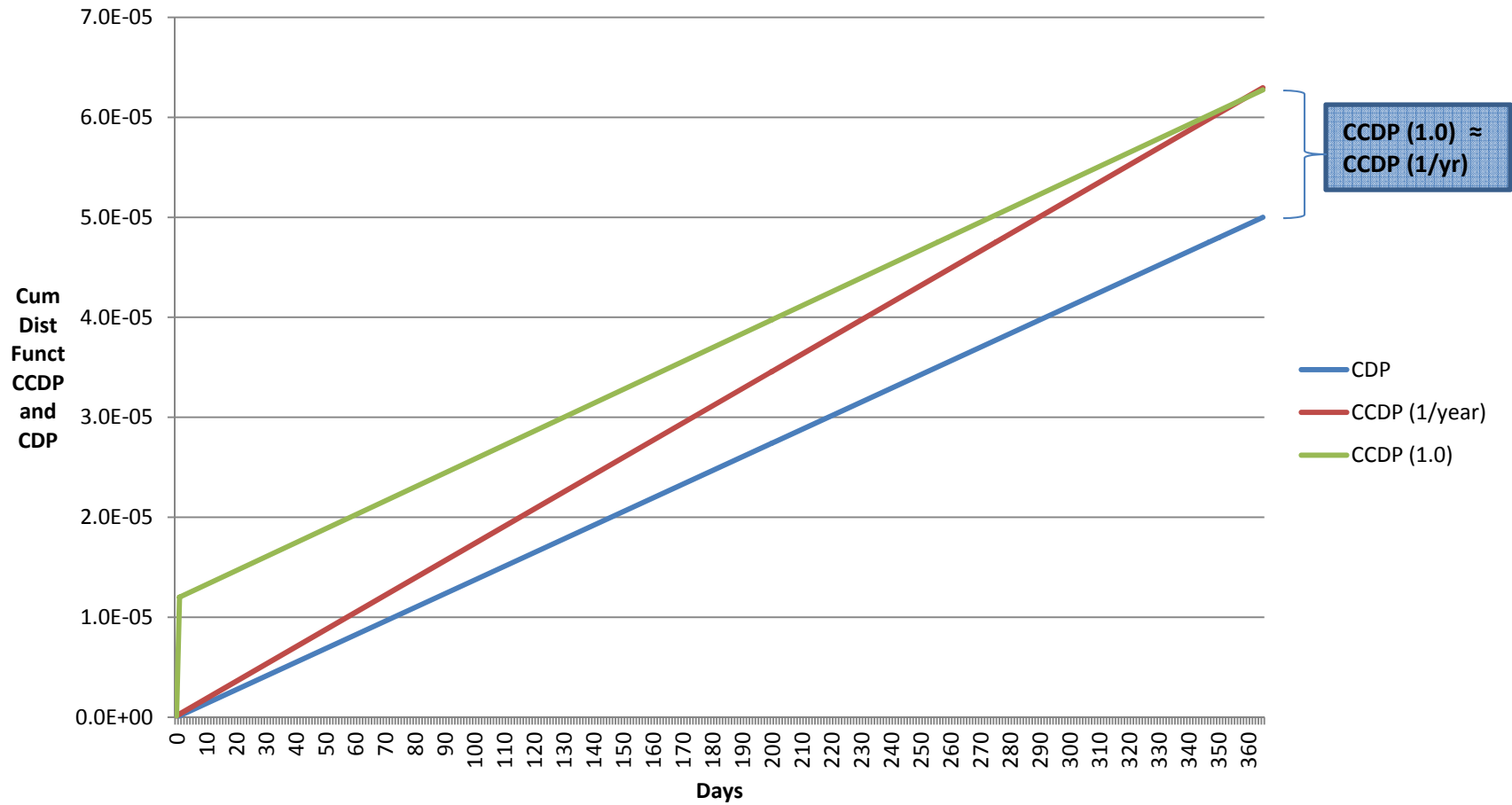
Is a MS 1.0 the same as an IE 1.0?

Initiating Events Modeling

- Two options:
 - 1) Increase the frequency to 1/year - same approach as the “condition” CCDP in that the result is a CCDP – CDP (No Bayesian Updating)
 - 2) Assume all other IEs did not occur (set to 0.0 probability) and assume the IE of interest did occur (set to 1.0 probability and subtract out the nominal IEF)

Both options follow the SDP rules. Every other aspect of the model not associated with the finding is in its nominal state. (e.g., average T&M, nominal failure probabilities)

Graph of CDP, CCDP (1/yr), and CCDP (1.0)



Proposed Resolution

- 1)** The SDP technical basis document language suggests that an “event” CCDP is one that includes the IE occurrence AND actual operator and equipment responses (i.e., akin to a MD 8.3 or ASP analysis)
- 2)** Mathematically a CCDP – CDP is very approximate to a Δ CDF.
- 3)** Likewise, setting the IE to a 1.0 (i.e., IE occurred) and subtracting out the nominal IEF is also very approximate to a Δ CDF. All other IEs are set to 0.0 (i.e., they did NOT occur)
- 4)** Bayesian updating to derive a new IEF given that an IE occurred is not an appropriate for the SDP (IE and MS cornerstones should be consistent).

Proposed Resolution

- RASP, Vol 1, Section 8 and IMC 0308, Attachment 3, Section be revised to clarify that:
 - 1) Findings that are the proximate cause of an IE occurrence are assessed by the SDP.
 - 2) The SDP assessment should model the safety significance using one of two methods (or both methods for comparison):
 - Set IEF to 1/year (perform a “condition” assessment)
 - Set IEF to 1.0 and subtract out the nominal IEF (perform an “initiating event” assessment)
- Note: Recovery credit and other detailed modeling assumptions will also be included in the analysis

Proposed Resolution

- The Draft revisions to IMC 0308, Attachment 3 and RASP Volume 1 will be reviewed internally by NRC staff and management and then shared publically with external stakeholders (e.g., ROP WG public meeting).
- Based on all stakeholders feedback revisions to IMC 0308, Attachment 3 and RASP, Volume 1 will be issued.

Back-up Slides

Back-up Slides

SDP Basis - Overview

- The risk-informed SDP tools are designed to estimate the increase in annualized CDF risk due to identified performance deficiencies that led to unavailability of equipment or safety functions or to the increase in initiating event frequencies.
- The increase is measured from the normal annualized (i.e., baseline) CDF that includes random failure probabilities and average test and maintenance (T&M) unavailabilities.

SDP Basis - Overview

- The SDP actually estimates the CCDP given the degraded condition which resulted from the performance deficiency for the time this degradation existed.
- The nominal CDP, which accounts for average T&M during this time, is subtracted from the CCDP to obtain the change in CDP due to the degraded condition alone (without consideration of any specific maintenance configuration that might have existed).
- This numerical result is then normalized by dividing it by 1 year to arrive at a delta CDF in units of “per year.”

SDP Basis - Overview

- The objective of using the SDP is to characterize the significance of inspection findings in a manner that is comparable to performance indicators (PIs) for use in the NRC Action Matrix.
- The reactor safety cornerstone performance indicator thresholds were developed based on the increase to annualized CDF.
- Thus, in comparing and “adding” the effects of PIs and inspection findings within the Action Matrix, it is necessary to use the same risk metric.

RG 1.174 and Mathematical Basis

- The basis documents for establishing the SDP risk guidelines were RG 1.174, which bring in the Regulatory Analysis Guidelines, and the Safety Goal Policy Statement.
- The NRC Accident Sequence Precursor (ASP) process typically includes any additional failures or unavailability in its assessment of risk significance. Therefore the question has arisen whether when applying the SDP, the failed or unavailable SSC that is not related to the finding per se should be treated as a failed or unavailable SSC.

RG 1.174 and Mathematical Basis

- If the finding relates to a specific reason that a particular SSC is, or has the potential to be, unavailable (e.g., failure to follow a particular procedure) then it should, for the purposes of the SDP, be irrelevant whether another SSC is unavailable because it has been taken out of service for routine or scheduled maintenance.
- The chance that the events could have occurred simultaneously is accounted for in the SDP by using unavailability values for the redundant or diverse trains or systems that reflect the probability that they are unavailable.

RG 1.174 and Mathematical Basis

- Including the plant configuration as part of the finding is equivalent to risk tracking, as captured by a safety monitor for example, and is a record of one sample of all the possible outcomes, or a snapshot of the condition of the plant.
- It is however, not directly related to the estimate of the risk impact in the sense required for calculating Δ CDF. It is more accurately characterized as a measure of the margin to core damage, which could be measured as a CCDF (for plant trip events).

RG 1.174 and Mathematical Basis

- If some of the failures that contribute to a high CCDP are truly random, then does it make sense to penalize the licensee because they occur?
- What makes much more sense is to track the residual CCDP with respect to the deliberate changes to plant configuration (i.e., those unavailabilities over which the licensee has direct control).

Technical Discussion

- How does the PRA produce a CDF?
- How is a “condition” CCDP calculation (i.e., a CCDP – CDP) extremely approximate to a Δ CDF?
- How can an “initiating event” CCDP calculation be extremely approximate to a “condition” CCDP calculation?

NOTE: The “initiating event” CCDP can also be a “delta” calculation

Theoretical Baseline CDF

- All the initiating events (IEs) that can occur at a plant are modeled as the first input in a specific Event Tree (e.g., SLOCA)
- All of the mitigating systems (MS) that are designed to operate and mitigate the onset of a particular IE are modeled as a series of Fault Trees (e.g., feed & bleed, high pressure injection, secondary cooling)

Theoretical Baseline CDF

- With all the IEs and MSs in their nominal state (i.e., IE with nominal frequencies and MS with nominal failure probabilities and average T&M unavailabilities), each event tree and associated fault trees are calculated to get CD sequences.
- The results for each CD sequence in a particular event tree is in units of “per year” or “1/year) because the IEF is in units of “per year” and the outputs from all the fault trees are probabilities (i.e., unitless number between 0 and 1)

Theoretical Δ CDF

- Let's assume a finding was the proximate cause of a pump being in a failed state for 1 year.
- For simplicity, we can assume that the failure probability for that pump is 1.0 for the entire year.
- The result would be a new CDF (for the degraded condition). If we subtract out the baseline CDF, the result is a Δ CDF.

How does SAPHIRE calculate a CCDP?

- Poisson distribution
 - Typical model for IEFs
 - Attempts to predict the frequency of a random event over a given period of time
 - Parameter of concern is λ (also t for time)
 - At a high-level the SDP metric is attempting to measure the frequency (which can be approximated/converted to a probability) of a CD event over the course of a year.

Poisson

- The Poisson density function is:

$$f(x) = \frac{(\lambda t)^x e^{-\lambda t}}{x!}$$

- So to observe 1 CD event in 1 year, the Poisson model reduces to:

$$f(1) = \lambda e^{-\lambda}$$

Exponential

- Commonly used model for a time duration (i.e., time to the first event (e.g., failure) and the time between successive events)
- Parameter of concern is λ (also t for time)
- At a high-level the exponential model is attempting to estimate the time to the next CD event.
- The exponential density function is:

$$f(t) = \lambda e^{-\lambda t}$$

And if the duration is 1 year the equation becomes:

$$f(1) = \lambda e^{-\lambda}$$

Poisson and Exponential

- In a Poisson process with event frequency λ , the time to the first event (and between events) follows an Exponential distribution (λ)
- So we are left with a common model density function of:

$$f(1) = \lambda e^{-\lambda}$$

Bayesian Inference

- PRAs typically use Bayesian Inference for parameter estimation (e.g., IEF, FTR probability).
- The Bayesian process takes Prior Information and blends in New Information to infer an “Updated” understanding or expectation.
 - Prior = 20 years of generic pump FTS data
 - New = 2 years of plant-specific FTS data
 - Update = A mathematical blend of the Prior and New data (called the Posterior)

Bayesian Update or Not?

Question: If a finding causes an IE to occur, should we (for the purposes of the SDP):

1. Use that single IE occurrence to update the IEF? (i.e., Bayesian update) or
2. Determine the safety significance of that single IE occurrence? (i.e., do not Bayesian update)

Bayesian Update or Not?

- **Example – Bayesian Update Approach:**
- Baseline Loss of Vital DC Bus
 - Prior info = 1 event in 1282 critical years
 - New info = 0 events in the past 44 critical years
 - Updated IEF – **7.5 E-4/yr**
- A finding causes a Loss of Vital DC Bus
 - Prior info = 1 event in 1282 critical years
 - New info = 1 event in the past 44 critical years
 - Updated IEF – **1.5 E-3/yr**

Bayesian Update or Not?

- **Example – Bayesian Update Approach**
- Using the Bayesian update process the IEF for a LODCB increased 7.5 E-4 .
- Using a typical PWR SPAR model, the frequency for a LODCB was increased 7.5E-4 (which calculates a CCDF – CDF and is extremely approximate to a ΔCDF)
- The result is a ΔCDF of **5.83 E-7** (Green or Very Low Safety Significance)

Bayesian Update or Not?

- **More Examples – Bayesian Update Approach**
- The same process using other initiating events produced the following results:

SLOCA	5.4 E-6	WHITE
MLOCA	5.6 E-6	WHITE

Bayesian Update or Not?

- What if Bayesian Updating was used in the Mitigating Systems (MS) Cornerstone?
 - Ex: An inadequate maintenance procedure resulted in improper lubrication of a trip throttle valve. After the ineffective maintenance was performed the pump started successfully 9 times and failed to start on the 10th monthly test. During the 30 day exposure period:
 - Is the new failure probability 0.1 (or 1/10)?
 - Or is the new failure probability 1.0 (or failed)?

Bayesian Update or Not?

- In the MS cornerstone we typically assume that the SSC was in a failed state for a defined exposure period (i.e., we do not Bayesian Update)
- So why would we do anything different in the IE cornerstone if an IE actually occurred as a result of an inspection finding?
- When the die is cast, the probabilistic distribution collapses (i.e., the uncertainty goes away)

PWROG White Paper

- Overall, the technical process that the PWROG developed basically results in the same outcome that the NRC staff is suggesting (i.e., different means, same basic end).
- PWROG proposed:
 - Define a fault exposure time (FET) for the finding
 - Derive a new IE frequency based on the FET
 - All other IEs are set to 0.00
 - Subtract out the baseline CDF

PWROG White Paper

Example:

- If the finding caused an IE occurrence and the FET for the finding was 3 months, then assume that the IEF is 4/year (i.e., 1/quarter for four quarters).
 - An IEF of 4/year that calculates a CDF (or CCDP) over a 3 months period essentially reduces to an IEF of 1/year.
 - Conceptually, a FET for a finding is not congruent with the MS paradigm.
 - In MS the exposure time is the duration of the degraded condition (i.e., pump unavailable); not the finding.
 - Reason for the confusion? An IE occurrence is considered instantaneous. To force fit the concept of an exposure time it had to be applied to the finding.

PWROG White Paper

- A main tenet of the PWROG proposal is based on a note from the ISG issued in late Dec 2013.
- The note states: “This guidance is appropriate only when the performance deficiency would always cause the initiator (i.e., there were no other performance deficiencies or atypical plant operational states that contributed to the initiation of the event).”
- The wording for this note is poor and unfortunately was used as part of the basis for PWROG method
- The “i.e.” part of the note does not correspond well with the first phrase

PWROG White Paper

- What the note is attempting to communicate is that the finding needs to be the “proximate cause” of the degraded condition or IE occurrence (i.e., the finding cannot just make a minor contribution (e.g., 15%) in causing the consequence and have the entire safety significance of the consequence be attributed to the finding).
- Overall, the NRC staff does not agree that the finding has to “always” cause an IE occurrence to be assessed by the inspection program and SDP.